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Research Project MR 13 01 99 Subtask 1 Report No. 7

Final Report

AUDITORY AND NON-AUDITORY EFFECTS OF HIGH INTENSITY NOISE

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JOINT PROJECT

Final Report

AUDITORY AND NON-AUDITORY EFFECTS OF HIGH INTENSITY NOISE

Central Institute for the Deaf, St. Louis, Missouri
Under Contract Nonr-1151 (02) Project Designation No. NR(146-092)

and

Bureau of Medicine and Surgery
Research Project NM 13 01 99 Subtask 1
Report No. 7

Approved by

Captain Ashton Graybiel, MC USN
Director of Research

Released by

Captain Langdon C. Newman, MC USN
Commanding Officer

2 June 1958

CONTRACT NUMBER Nonr-1151 (02)
(NR 146-092)

Project ANEHIN
(Auditory and Non-auditory Effects of High-Intensity Noise)

FINAL REPORT

Conducted in Collaboration with the
U. S. Naval School of Aviation Medicine, Pensacola, Fla.

Submitted by:

Central Institute for the Deaf
818 South Kingshighway
St. Louis 10, Missouri

Submitted to:

Chief of Naval Research (454)
Department of the Navy
Washington 25, D. C.

Prepared for the Contractor by:

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SUMMARY

Conclusions:

The following over-all conclusions from the ANEHIN study are clear:

(1) As of March, 1957, there is no reasonable cause for immediate alarm concerning cumulative after effects of jet-engine noise exposures of naval personnel.

(2) It is unsafe to extrapolate from present noise exposures to the more severe exposures that must be anticipated in the future. The extent of the present margin of safety is not known, and continued vigilance is required.

(3) In the opinion of the ANEHIN group, at least two other undesired effects of high-intensity noise are, as of 1957, more serious threats to military operations than are its cumulative aftereffects. They are: (a) interference with communication and (b) decrement in performance of personnel during actual exposure to high-intensity noise.

Procedure:

Carrier flight deck personnel on board the USS FORRESTAL and the USS TICONDEROGA and shore-based jet aircraft personnel at NAS Cecil Field were tested by pure tone audiometry, psychological and psychomotor performance tests, group paper-and-pencil tests, psychiatric interviews, and analysis of sick-bay calls. The results were related to the estimated relative noise exposures of the various exposed and control groups tested.

The audiometry was conducted in a specially designed and constructed trailer laboratory by means of a group audiometer that was developed as part of the project. This semiautomatic instrument is suitable for monitoring audiometry elsewhere.

A method for the measurement of the total noise exposure of individuals during actual military operations or maintenance tasks was developed. This method relies upon a special device, the "noise comulator," which was designed, constructed, and a prototype tested on board a carrier. The complete device was not, however, available until after the three field studies. This instrument is suitable for monitoring the noise exposures to be expected from future aircraft.

The battery of psychological and psychomotor tests was composed of simple, well-tried tests of known significance that sampled a wide variety of sensory, motor, intellectual, and emotional functions.

Observations:

No clear, positive effects, either auditory or non-auditory, of exposure to noise were shown by any of our tests. Certain small positive effects were found in the audiometric and by the psychiatric studies, but these are attributed to causes other than jet engine noise. A suggestive trend toward a slight general decrement in performance did appear in the psychological and psychomotor tests of jet plane maintenance personnel.

Recommendations:

(1) Further field studies of this sort are not necessary until there is a considerable increase in operational noise exposures. Meanwhile monitoring of noise exposures with the equipment developed by ANEHIN should be instituted to detect such increases.

(2) Monitoring audiometry and also monitoring by selected psychological and psychomotor tests should be instituted for the protection of personnel who suffer the most severe noise exposures.

(3) Valid criteria of hazardous noise exposures should be established by carefully controlled experiment with human volunteers, using careful measurements of noise exposure and the tests of the AHEHIN battery. In such an experiment the decrement of performance during actual exposure to noise should also be measured.

OTHER PUBLISHED ANEHIN MATERIAL

NAVAL SCHOOL OF AVIATION MEDICINE REPORTS

1. Cox, J. R., Benson, R. W., and Niemoeller, A. F., A mobile laboratory for group hearing tests. Joint Project NM 13 01 99 Subtask 1, Report No. 3, Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1956.

2. Doehring, D. G., Changes in psychophysiological responses produced by delayed speech feedback. Joint Project NM 13 01 99 Subtask 1, Report No. 1, Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1956.

3. Doehring, D. G., The relation between manifest anxiety and rate of eyeblink in a stress situation. Joint Project NM 13 01 99 Subtask 1. Report No. 6, Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1957.

4. Doehring, D. G., and Harbold, G. J., The relation between speech distrubance and psychophysiological changes resulting from delayed speech feedback. Joint Project NM 13 01 99 Subtask 1, Report No. 5, Pensacola, Florida: Central Institute for the Deaf, and Naval School of Aviation Medicine, 1957.

5. Doehring, D. G., Ward, W. D., and Hixson, W. C., The development and standardization of a group test for critical flicker frequency. Joint Project NM 13 01 99 Subtask 1, Report No. 4, Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1957.

6. Harbold, G. J., and Doehring, D. G., A rating scale measure of speech disturbances resulting from delayed speech feedback. BuMed 18 02 99 Subtask 1, Report No. 71, Pensacola, Florida: Ohio State University Research Foundation, 1957.

7. Ward, W. D., The method of "single descent" in group audiometry. Joint Project Nm 13 01 99 Subtask 1, Report No. 2, Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1956.

PUBLICATIONS IN JOURNALS

1. Cox, J. R., Benson, R. W., and Niemoeller, A. E., A mobile laboratory for group hearing aid tests. Noise Control, 3: 44-48, 92, 1957.

2. Ward, W. D., The method of "single descent" in group audiometry. J. Acoust. Soc. Amer., 29: 371-376, 1957.

3. Ward, W. D., The single descent group audiometer. Noise Control, 3: 15-18, May, 1957.

4. Ward, W. D., The hearing of naval aircraft maintenance personnel. J. Acoust. Soc. Amer., 29: 1289-1301, 1957.

CHAPTER 1

HISTORICAL SURVEY

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THE CONTRACT

Contract life

The Auditory and Non-Auditory Effects of High-Intensity Noise Project (ANEHIN) was undertaken in April, 1954, as a joint effort of the Central Institute for the Deaf, St. Louis, Missouri, and the Naval School of Aviation Medicine at Pensacola, Florida. The contract, initiated by the Navy Bureau of Medicine and Surgery through the Office of Naval Research, was twice extended, once in October, 1955, and again a year later. It is not anticipated that additional funds will be requested beyond those already appropriated for the year ending 31 October 1957.

In accordance with the terms of the contract, the Central Institute for the Deaf planned and organized a long term researach program and developed the appropriate equipment for the study of the auditory and non-auditory effects of high-intensity noise. The research work itself was done in cooperation with the Naval School of Aviation Medicine at the Naval Air Station, Pensacola, Florida.

Need for the contract

Noise has always been a natural by-product of war and the constant training that is entailed in keeping the military services in a state of proper readiness. This is so much the case that noise in the Armed Services has, in general, been taken for granted as part and parcel of the kind of work done, just as one expects noise in a boiler factory. Except in certain situations where noise interfered with important functions, as in voice communications in aircraft, the control of noise and the study of its effects on people were not major problems in the Armed Services during the last war.

World War II, however, accelerated the technological advances necessary for the development of jet-powered aircraft. With the large scale introduction of such noise makers in the fleet shortly after the war, some concern developed as to the possible effects of such high intensity noise upon the human organism. Anecdotal evidence from Service personnel showed that the effects could be felt in a variety of ways. A survey made early in 1952 aboard the USS CORAL SEA[1.1] showed that the use of jet aircraft aboard carriers would produce acute noise problems in the immediate future. Later reports stated that the noise produced by jet aircraft might have serious adverse effects on both the hearing and the physiological reactions of men. The Benox Report[1.2] in 1953 suggested that noise might cause undue fatigue and special physiological stresses in operating personnel. Another report[1.3] in early 1954 concluded that safe operation of jet aircraft aboard a carrier might be very difficult in the presence of noise above 150 db sound pressure level, and that operations might be impossible in the presence of 160 db noises, or above. Inasmuch as the jet engines then in the process of development or which were being readied for the fleet were thought to be in the 150-160 db class (and possibly above), and since

the prospects for more powerful fighter aircraft meant that the engines must undoubtedly become even noisier, genuine concern was felt in the Navy as to the necessity for analyzing the over-all effects of high-intensity noise on the physical and psychological well-being of man.

PLANNING THE PROGRAM

Guides to research

Some general clues to the direction that the research into this subject should take had already been provided by the analysis of the previously mentioned reports (see footnotes (1.1, 1.2 and 1.3). All had been 'survey' type reports, and each had clearly stated that the problems presented by high intensity noise could not be solved by the survey method.

The 'Coral Sea Report'(1.3) (p. 1: and enclosure 2, pp. 22, 26) noted that personnel would have to be experimentally exposed over a long period of time in order to determine if injurious effects would result from exposure to high-level noise. More permanent hearing loss was found in the carrier's flight deck personnel than in a control group tested at the Naval Air Test Center, Patuxent River, Maryland, but there was not sufficient evidence to state categorically that these losses were due to exposure to jet-engine noises. In addition, a reasonable environment for audiometric examinations was not available aboard ship, and the accuracy of such examinations was much limited by masking noises from various sources (e.g., ventilator fans and the ship's engines).

The Benox Report (p. 65-67, 106) noted that personnel spoke of dizziness, nausea, and vomiting, of not being able to remain in the noise field, and of difficulties in locomotion while in the noise field. Various visual, physical, and psychological disturbances (apparently all related to vestibular functions) were also reported by the Benox investigators, who had used themselves as subjects.

Early in 1954 the whole problem area was reviewed in CHABA Report No. 1,(1.4) and the direct and indirect hazards were discussed. The report emphasized that the available indications of physical and psychological difficulties caused by exposure to high-intensity noise made it imperative to know definitively whether or not these indirect and possibly cumulative hazards do or do not exist. To settle this question the report recommended a detailed, full scale, long term research program on the biological effects

(1.1) Goldman, D.E., Preliminary Report on a Noise Level Survey of Flight Operations Aboard the USS Coral Sea (CVB-43). Research Report, Project NM 004 005.03.06, 30 June 1952. Passim

(1.2) Benox Report. (An Exploratory Study of the Biological Effects of Noise.) ONR Project NR 144079. The University of Chicago, 1 December 1953. P. 65-67.

(1.3) Bio-Acoustic Aspects of High Intensity Aircraft Engine Noise, NATC USS Coral Sea, Report No. 1, Final Report, Project TED No. PTR-SI-442, 29 Jan. 1954. P. 1.

(1.4) CHABA Report No. 1. High Intensity Noise and Military Operations: An Evaluation. Armed Forces-National Research Council Committee on Hearing and Bio-Acoustics. (1954). Technical Report No. 1 to the office of Naval Research from the Central Institute for the Deaf. Contract No. Nonr-1151 (01), NR 140-069. Passim.

of high-intensity noise. To be most effective, this research should be done in the field, using laboratory methods and equipment to test people who, as part of their regular duty assignments, were exposed to high-intensity noise.

Questions to be answered

Analysis of the Benox, Coral Sea, and CHABA reports showed three major questions which required answers at the earliest possible moment. These were:

1. Is there really a risk of cumulative auditory or non-auditory ill effects on personnel exposed to high-intensity noise?
2. How may these possible effects be detected in their early stages, both now and in the future?
3. If cumulative ill effects do exist, at what levels and with what durations of exposure do they become a significant risk to personnel and military operations?

The importance of these questions gave a very real sense of urgency to the undertaking of the ANEHIN project.

Planning the study program

Certain of the recommendations found in CHABA Report No. 1 were used by the Central Institute as the starting point for planning the research program. These were:

1. Perform routine, pure-tone audiometry on those naval personnel aboard carriers who are regularly exposed to very-high-intensity noise.
2. Perform routine measurement of the noise fields to which naval personnel are exposed, using trained technicians and appropriate techniques.
3. Measure psychomotor performance, central nervous system functions, physiologic changes, and neuro-psychiatric alterations to determine possible extra-auditory effects of high-intensity noises on human behavior.

The achievement of the above recommendations was initiated in six overlapping phases:

1. The design and construction of a sound-treated mobile trailer laboratory suitable for use aboard an aircraft carrier.
2. Selection of the form of audiometric testing and determination of how the data obtained should be handled.
3. The design and construction of a group audiometer for installation in the mobile laboratory.
4. The design of electronic equipment for measuring noise exposures aboard aircraft carriers.
5. The selection and evaluation of a battery of tests of non-auditory functions.
6. The selection of statistical techniques, and planning for the

handling, processing, and analyzing of the data obtained. Whereever practicable, work on the six phases proceeded simultaneously.

EXECUTING THE PROGRAM

Cooperation by the Naval School of Aviation Medicine

An important contribution to the success of the project has been the collaboration given by the Naval School of Aviation Medicine. Advice was given in the selection of the non-auditory tests, 'control' groups were provided, and facilities were made available for the reduction of statistical data. A permanent 'fixed' laboratory, containing the same equipment as the mobile laboratory, is now being completed at the School of Aviation Medicine.

Development of the research program

Work on the mobile trailer laboratory was begun at once in April 1954. The plans, drawn by the Central Institute for the Deaf, were completed early in 1955. Contract N600 s-m-38444 for the construction of the trailer was concluded on 1 April 1955, between the Herman Body Company of St. Louis and the Naval School of Aviation Medicine at Pensacola. Using a 40 by 8 foot, twenty-ton trailer chassis supplied by the Navy, the Herman Body Company completed its contract in June 1955. The Navy accepted the trailer in July, 1955, at Pensacola, Florida. (See Chapter 2 for a detailed discussion of the trailer design and development.) The Central Institute staff has advised the Navy regarding the equipment to be procured for the fixed laboratory which the Navy is establishing at the School of Aviation Medicine. As of October, 1957, the space for the laboratory has been assigned, has been modified for its new purpose, and the procurement of the equipment has been completed.

The problem of the measurement of the noise exposure of personnel was met by the design and construction by the Central Institute for the Deaf of a measurement system whose core is a new piece of electronic equipment, the Noise Cumulator. The machine is designed to answer the question of how much noise exposure a man has experienced who has been working in a variety of different noise fields. In actual use, the noise is recorded on magnetic tapes with the help of an FM transmitter which is worn by the subject. Later, under laboratory conditions, the tapes are analyzed by the noise cumulator to show the number of seconds in which the noise level rose above certain preselected levels and in various frequency bands. (See Chapter 3.)

Selection among the auditory tests was made in the Fall of 1954, so that the Central Institute could proceed with the design and construction of a group audiometer. By June of 1955 the group audiometer was completed and ready for trials. The audiometer, installed in the mobile trailer, will test ten men at a time in fifteen minutes and yield a pure-tone threshold audiogram for each man by the method of 'single descent.' After the field

trials of 1956, an Automatic Aduiometer Data System (AADS) was developed and constructed at the Central Institute for the Deaf. This system operates an electric typewrit[illegible], thus making the thresholds of ten subjects immediately available. The Automatic Audiometer Data System was delivered to the School of Aviation Medicine in August, 1957. (See Chapters 2 and 4 for further discussion.)

The non-auditory tests were selected after several conferences and pre-trials. Dr. Ward Halstead, and also Dr. Morris Bender of Mount Sinai Hospital in New York City, were consulted extensively during the period April through Oct., 1954. During 1955 the original test selections were improved and in 1956 the final test runs were made. A complete discussion of this subject will be found in Chapter 5.

In March, 1955, at a five-day conference at the School of Aviation Medicine, it was agreed that the medical examinations and the neuropsychiatric studies required by the ANEHIN program should be conducted by a naval medical officer. William I. Stryker, M. D., a Psychiatrist, was commissioned by the Navy in July of 1955 and assigned to the Naval School of Aviation Medicine. Lt. Stryker either developed or selected the necessary materials for the testing program. He participated in three of the testing programs in 1956 on the USS FORRESTAL (March 1956), and on the USS TICONDEROGA (Sept. 1955, and June, 1956). (See Chapt. 6 for a detailed description of this part of the program.)

Summary list of field trials

1. Patuxent River, Maryland, June, 1955. Tests of noise measurement equipment. (Joint field trial with the Acoustics Research Group of Ohio State University, the Electronics Group from the School of Aviation Medicine, and the Service Test Division from NAS Patuxent River, Maryland).
2. The Naval School of Aviation Medicine, Pensacola, Florida, March, 1955. Group audiometry and non-auditory tests on 33 enlisted men.
3. Sea trials aboard the USS TICONDEROGA, 10 September - 2 October 1955. First sea trial of the mobile trailer, including group audiometry and many of the non-auditory tests. First psychiatric interviews.
4. Sea trial aboard the USS FORRESTAL, January - April 1956. Group audiometry tests, psychological and psychophysical testing, and medical-psychiatric interviews of flight deck personnel. Trial run of noise-exposure measuring equipment including a prototype of the noise cumulator.
5. Sea studies aboard the USS TICONDEROGA, May - June, 1956. Certain non-auditory tests, and psychiatric interviews.
6. NAS Cecil Field, Jacksonville, Florida, July - August, 1956. Group audiometric testing of 1209 enlisted men, using the mobile trailer. Non-auditory tests of 173 enlisted men.
7. NAS Cecil Field, Jacksonville, Florida, March 1957. Audiometric

retest of 720 of the enlisted men tested during July - August 1956. Non-auditory retest of 95 of the enlisted men tested during July - August 1956. Additional non-auditory tests given to 49 enlisted men. Analysis of sick-call records of 183 enlisted men.

PERSONNEL

Central Institute personnel

Members of the Institute staff who were stationed at Pensacola for the three years involved in the contract were:

W. DIXON WARD, Ph. D., Principal Investigator (full time)
(Experimental Psychologist) (April 1954 - June 1957)
DONALD G. DOEHRING, Ph. D., Principal Investigator (full time)
(Experimental Psychologist) (September 1954 - July 1957)
JEAN DOEHRING, B. S. Research Assistant (part time)
(March 1956 - March 1957)

Central Institute personnel at St. Louis, all on a part time basis, were:

HALLOWELL DAVIS, M. D., Project Director
(April 1954 - October 1957)
ROBERT W. BENSON, Ph. D. Principal Investigator
(April 1954 - October 1954)
JEROME R. COX, Jr., ScD., Principal Investigator
(September 1955 - October 1957)
ARTHUR NIEMOELLER, M. S., Research Assistant
(April 1954 - October 1957)
QUINETTE HALE, Secretary
(November 1954 - October 1957)
ETHEL Z. LEWINTER, Secretary
(April 1955 - October 1957)
MARCELLA REICHMAN, Secretary
(April 1954 - March 1955)

Central Institute personnel at St. Louis who served without compensation were:

DONALD H. ELDREDGE, M. D., Physiologist and Physician
(- October 1957)
IRA J. HIRSH, Ph. D., Experimental Psychologist
(April 1954 - October 1957)
S. RICHARD SILVERMAN, Ph. D., Audiologist
(April 1954 - October 1957)
J. RICHARDSON USHER, Ph. D., Technical Writer
(October 1955 - October 1957)

Navy Personnel

Two naval officers were assigned to the ANEHIN project to conduct the medical and psychiatric phases of the study:

PHILIP B. PHILLIPS, M. D., Capt. (MC) USN. U. S. Naval School of Aviation Medicine. (Psychiatrist)
(Consultant, October 1954 - October 1957)
WILLIAM I. STRYKER, M. D., Lt. (MC) USN. U. S. Naval School of Aviation Medicine. (Psychiatrist)
(Assigned to the project from July 1955 to July 1956; available for consultation, July 1956 - July 1957)

Four enlisted men were assigned to the ANEHIN Project to assist in the audiometric and psychophysical test programs.

HM-1 BONDURANT, Technical Assistant
(July 1956 - September 1956)
HM-2 CALOF, Technical Assistant
(September 1955 - November 1955)
HM-2 CRUDEN, Technical Assistant
(February 1956 - April 1957)
HM-3 Kaspar, Technical Assistant
(December 1955 - May 1956)

Other civilian personnel:

Consulting services during all phases of the ANEHIN project were provided from time to time by the persons listed below.

HARLOW ADES, Ph. D., Neurophysiologist
(November 1955 - October 1957)
MORRIS B. BENDER, M. D., Neurophysiologist
(April 1954 - October 1954)
JEROME R. COX, Jr., Sc. D., Physicist and Electro-Acoustic Engineer. (October 1954 - September 1955)
WARD C. HALSTEAD, Ph. D., Medical Psychologist
(October 1954 - October 1957)
GEORGE M. HARBOLD, Ph. D., Speech Science
(December 1956 - June 1957)
NELLO PACE, Ph. D., Physiologist
(November 1955 - October 1957)
GEORGE SASLOW, M. D., Psychiatrist
(October 1954 - October 1957)
WILSE B. WEBB, Ph. D., Psychologist
(October 1954 - October 1957)

CHAPTER 2

THE MOBILE LABORATORY; THE AUDIOMETRIC METHOD

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INTRODUCTION

A major requirement in the research to be done under the ANEHIN program was the provision of an acoustically quiet area for the testing of hearing and the giving of certain psychophysical tests. Since the test program was to be conducted aboard aircraft carriers and at other field installations, necessity dictated the construction of laboratory space which could be taken to the scene of operations. The mobile trailer laboratory constructed on a semi-trailer bed was the obvious solution to the problem.(2.1)

A second important requirement was a method for rapid testing of hearing. A method for group testing using a pulsed tone whose intensity gradually decreases was chosen. In addition to speed, this method, the "method of single descent,"(2.2) has the advantage of great simplicity.

THE MOBILE LABORATORY

Design Considerations

The laboratory floor space was allocated to provide rooms for both audiometric and psychophysical testing. In addition, space was provided for a 5-ton air-conditioning unit, and for a control room containing various pieces of measuring and testing equipment (Fig. 2.1).

The trailer was designed to produce a noise reduction of 40-50 db in the 300-600 cps octave band. This amount of noise reduction should prevent masking of the listener's thresholds at the lowest aduiometric test frequency (500 cps) even for comparatively intense outside levels. A double

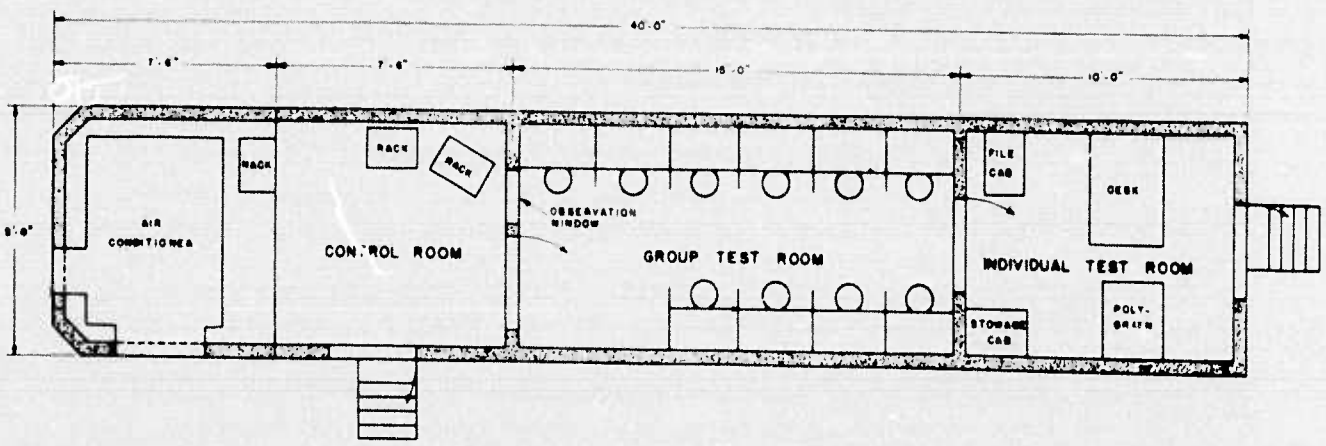


FIGURE 2.1 - Floor plan of mobile laboratory for auditory and non-auditory testing of naval personnel exposed to high-intensity noise.

2.1 For greater detail see Cox, J.R., R.W. Benson and A.F. Niemoeller, A Mobile Laboratory for Group Hearing Tests. Joint Project NM 13 01 99 Subtask 1 Report No.3 Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1956.

2.2 For greater detail see Ward, W. Dixon, The Method of 'Single Descent' in Group Audiometry. Joint Project NM 13 01 99 Subtask 1 Report No. 2 Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1956.

wall and ceiling design was selected for its effectiveness in sound reduction but a necessary compromise was the use of a single, rather than a double, floor.

Construction Details

The laboratory was designed by the Central Institute for the Deaf and constructed by the Herman Body Company, of St. Louis, Missouri.

The group test room (see Figure 2.1) is divided into ten small enclosed booths, each with a built-in desk and stool. A pair of earphones, two voting buttons and an indicator light are in each booth for purposes of group audiometry. In addition, there is a telegraph key and a neon light, permitting group measurement of reaction time, speed of tapping, and testing of critical flicker frequency. Paper-and-pencil tests associated with the non-auditory test phases of the program may also be given in these booths.

At the rear of the trailer is the individual test room, which contains a desk, equipment for the psychomotor tests, storage space, and a file cabinet. The control room is at the front of the trailer and contains the air-conditioner and various pieces of electronic equipment.

The walls and the roof of the laboratory are of double plywood construction, with the outside wall sheathed in aluminum. The studs for the inner and outer walls are not interconnected except at the floor. The joints between the plywood panels on both the inner and outer double-layered walls are staggered so that no joints are aligned. Sandwiched in the middle of the wall and ceiling construction is a 2-inch layer of absorptive material for thermal insulation and for reducing standing waves. The floor was covered first with sponge rubber and then a carpet.

Heavy, gasketed refrigerator-type doors and door catches were installed both within the trailer, at either end of the group test room, and outside the trailer, in the two entrance openings.

The air-conditioning system is equipped with acoustically treated ducts, and with an inlet and an outlet in each of the three rooms. No diffuser outlet is installed in the group test room so as to minimize the noise caused by moving air.

Acoustic Performance

Measurements have been made to determine the acoustical characteristics of the mobile laboratory.[2 3] Some were made at the Herman Body Company, and others were made aboard an aircraft carrier on the hangar deck.

The results of these measurements show that the mobile laboratory has a noise reduction characteristic that is slightly better than would have been predicted for a single-walled structure of equal surface density. Exactly 40 db of noise reduction is achieved in the 300-600 cps octave band.

2.3 See Appendix 2.1 for a detailed description of the measurements.

THE AUDIOMETRIC METHOD

The Method of "Single Descent"

In developing the method to be used in group audiometry, two main considerations were involved. First, the testing time should be as short as possible for minimal interference with operations. Second, the method should be able to measure hearing losses over as wide a range as possible. Any testing scheme represents a compromise between these two opposing factors; however, it was clear that improvement was possible over extant systems in which the method of constant stimuli has been customarily used.

Accordingly, two general methods were compared, using as subjects enlisted men typical of those working near aircraft. In the first, the subjects adjusted an attenuator, either directly (by means of Selsyn motors), or indirectly (by remote control of a reversible motor geared to the attenuator). In the second method, the subject simply signalled the disappearance of an interrupted tone as the intensity decreased at a fixed rate.

The comparison of methods indicated that the two methods were about equally rapid and reliable; the chief disadvantage to the method of adjustment is that in a group situation, the total testing time would be determined by the slowest man in the group. Therefore, despite the fact that most men preferred direct adjustment, we decided to use the method of "single descent," the second method described above.

A test comparing performance with different rates of intensity-descent was run next. Slowing the rate of descent from 3 to 1.5 db/sec (thereby doubling the testing time) did not improve the reliability; the standard deviation of repeated judgments in both cases was about 1.7 db.

Other experiments established the following points:

(1) When the intensity descent is begun at about 60 db SPL, thresholds determined by this method are indistinguishable from those determined by the standard clinical method of limits. This means that the method is "valid"; the fear that a considerable constant error ("overshoot") might be found proved unjustified.

(2) If a higher starting level is used, there is some indication that thresholds will be slightly higher. However, this effect is not pronounced; changing the starting level from 40 to 80 db SPL changed the indicated thresholds by only 2.5 db.

(3) The problem of practice effects is no more serious with this method than with any other. Although thresholds at lower frequencies gradually improve with time by 2-3 db, those at higher frequencies do not. This phenomenon has been reported in other methods.

In the field surveys described in later chapters the method proved fully as satisfactory as the preliminary studies had indicated. A threshold determination takes about 30 seconds, so that in a 10-minute testing session, thresholds can be determined for seven frequencies in both ears, and several frequencies can be repeated in order to detect malingering. As in the laboratory studies above, the standard deviation of repeated judgments

at a given session is 1.7 db. However, the variability associated with a longer test-retest interval is somewhat larger than this. Quite apart from real changes in threshold that may have occurred over the period concerned, the following factors contribute toward raising variability: (1) differences in earphone placement; (2) slight differences among headsets at different listening positions (headband tension, cushion hardness, earphone response); and (3) differences in ambient noise levels at various positions.

Variability due to earphone placement can be minimized though not eliminated by careful supervision, and probably represents the limiting variability in threshold testing. Using the newest MX-41/AR ear cushions available, the mean shift disregarding sign when phones are removed and are replaced is about 2 db for frequencies from 1 to 3 kc; at higher frequencies it increases gradually, becoming 4 db at 8 kc.

Test-retest variability due to positional differences (factors 2 and 3 above) can be eliminated by making sure that each listener sits at the same position for both tests. However, this will generally be impossible; but the error is not extreme in any event, since the earphones were all matched within $\pm$ 2 db from .5 to 6 kc. The ambient noise from the ventilating system posed a slight problem for frequencies below 1.5 kc since at the positions immediately under the intake and exhaust, thresholds better than normal could not be measured because of the masking noise. However, these frequencies are not as important as the higher frequencies in the study of acoustic trauma.

The development of the group audiometer has been fully described in several other publications.[2.2, 2.4, 2.5] A discussion of the equipment installed in the control room of the mobile laboratory is found in Appendix 2.2.

Automatic Audiometric Data System

The Automatic Audiometric Data System (AADS)[2.6] was developed to fill the ANEHIN program requirements of a quick, reliable method of recording the hearing thresholds obtained by the method of single descent. As many as ten men at a time can be tested in the booths of the group testing room, and the AADS automatically types out the hearing thresholds of each man tested. This makes the audiometric data available for immediate inspection or for later analysis. If necessary, at a later time the information can be entered on punched cards for rapid statistical analysis.

A simplified block diagram of the AADS is shown in Figure 2.2 and a photograph of a typical automatically-typed record is shown in Figure 2.3.

2.4 Ward, W.D., Method of 'single descent' in group audiometry, J. Acoust. Soc. Amer., 29: 371-376, 1957.

2.5 Ward, W.D., The single-descent group audiometer, Noise Control, 3: 15-18, May 1957.

2.6 See Appendix 2.3 for a detailed discussion of the operation of this system.

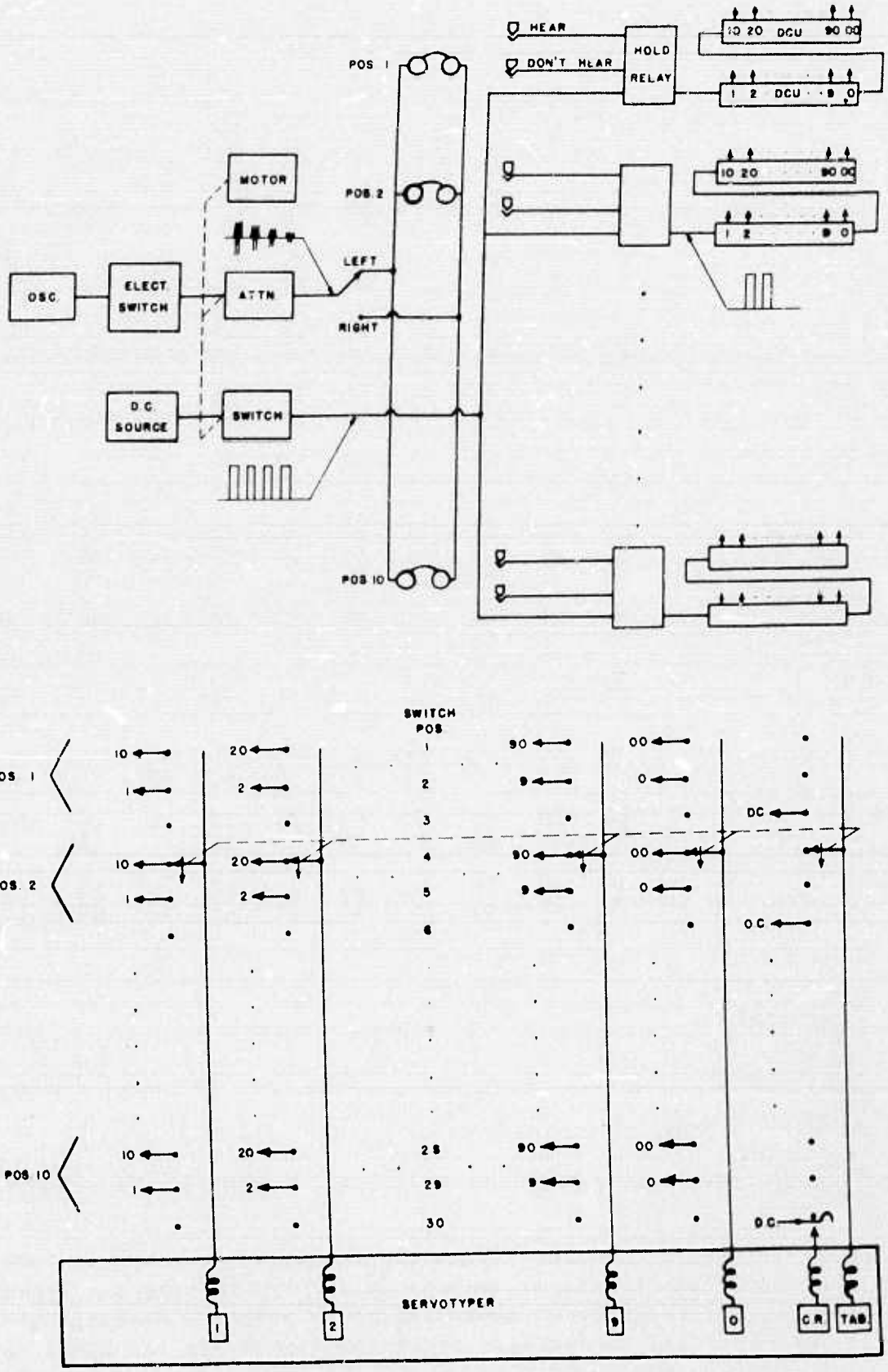


FIGURE 2.2 - Schematic diagram of group audiometer and automatic data system showing (a) the audiometer itself and the counting mechanism that converts the threshold level to digital form, and (b) the printing mechanism that connects the outputs of the various counters to the automatic typewriter (Servotyper).

November 23, 1957 Class 46 57A Tester: J.W.G.

	1	2	3	4	5	6	7	8	9	10
250 R	30	00	42	42	30	42	36	00	36	46
	30	00	40	46	32	38	30	00	34	40
250 L	32	00	34	44	28	40	44	00	32	30
	32	00	36	42	28	38	40	00	34	36
500 R	48	00	56	54	44	54	62	00	46	56
	48	00	58	54	46	54	64	00	50	56
500 L	50	00	46	68	46	56	58	00	42	56
	48	00	48	66	40	54	56	00	50	56
1000 R	54	00	62	74	50	60	64	00	56	64
	54	00	70	76	44	62	68	00	58	66
1000 L	52	00	64	64	50	60	68	00	60	64
	52	00	66	78	42	60	68	00	56	62
2000 R	58	00	58	90	52	64	76	00	66	66
	58	00	58	72	56	58	70	00	62	64
	60	00	60	70	54	64	72	00	58	62
2000 L	60	00	64	76	56	50	70	00	60	62
	52	00	58	68	46	52	70	00	54	54
4000 R	40	00	62	78	44	54	70	00	58	60
	42	00	60	80	40	58	72	00	62	60
4000 L	36	00	58	68	42	54	58	00	66	56
	38	00	58	70	46	50	64	00	70	56
8000 R	00	00	26	54	00	50	42	00	46	48
	00	00	20	52	00	48	44	00	46	52
8000 L	16	00	18	52	14	44	48	00	48	50
	08	00	14	46	10	42	46	00	48	48

1 FMB
2 Unoccupied
3 DLW
4 JIC
5 JDH
6 LMR
7 WG
8 Unoccupied
9 WM
10 RWF

FIGURE 2.3 - Sample data sheet from the Automatic Audiometric Data System (AADS). The two-digit numbers in the ten columns are typed automatically. The operator makes all other entries. Readings are thresholds expressed in decibels of attenuation below the starting level of the test tone. Re-runs at each frequency demonstrate the repeatability of the procedure. Note that the occupant of Position 4 failed to push his "Don't Hear" button on the first trial of 2 kc in the right ear. The operator chose to repeat the test a third time at this frequency to verify the readings obtained on the second trial.

CONCLUSIONS

The mobile laboratory has proved to be a useful facility for making hearing measurements in the field. It is relatively easy to move about and has proved itself seaworthy on the hangar deck of two aircraft carriers.

The allocation of space in the laboratory itself has, on the whole, proved satisfactory. The arrangement of the rooms still seems quite logical, and the space distribution is probably the best possible with the total floor area that is available.

The audiometer has performed well the task set for it. It is simple, fast, and not particularly costly. The audiograms obtained are reliable and valid. We believe that the average time spent by the operator in obtaining an audiogram is close to the practical minimum.

APPENDIX 2.1

NOISE REDUCTION MEASUREMENTS

NOISE REDUCTION MEASUREMENTS

Measurements made in the manufacturer's plant just before completion of the laboratory gave an indication of the noise reduction provided by the walls. Since the laboratory was too large for conventional testing procedures, improvised measurements were performed in a large Quonset Hut where the construction was taking place.

Several chipping hammers were operated near the laboratory. The repeated impact sound resulting from the blow of the chisel of the chipping hammer on a large piece of steel produced a wide-band noise. The output of microphones located both inside and outside the laboratory were recorded on tape. The outside microphone was carried around the perimeter of the trailer. After each circuit around the trailer, the inside microphone was moved to a new station. In all, recordings were made at 13 stations inside the laboratory.

The difference between the average level at the outside microphone during a complete circuit around the laboratory and the average level at each of these 13 measurement locations is shown in Table (2.1). The first 10 measurement positions were in the listening booths in the group test room. The measurement position numbers correspond to the booth numbers. Position 11 was in the individual testing room, and Position 12 was in the control room. Low readings obtained at Position 12 are a result of an opening in the wall that had not, at the time of the measurements, been

TABLE 2.1

Noise Reduction (db)
Octave Bands (cps)

POSITION	37.5-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600
1	16.6	16.9	30.0	41.7	44.2	53.0	59.9	63.5
1 (RERUN)	15.1	18.4	30.2	42.1	44.5	53.8	59.8	64.5
2	15.5	20.4	29.6	40.2	45.2	53.5	60.6	63.8
3	17.1	21.7	30.7	41.3	44.8	53.5	61.4	64.3
4	21.3	21.9	30.7	41.3	45.2	53.5	60.2	64.7
5	21.5	20.7	28.5	40.4	43.8	52.7	60.5	63.5
6	18.8	20.4	28.6	41.2	44.5	54.3	60.8	64.3
7	19.5	18.1	29.1	40.1	45.1	53.5	60.7	64.0
8	22.4	20.9	28.4	38.7	43.8	53.0	60.1	63.5
9	18.6	13.3	33.0	36.4	45.2	53.0	59.8	64.8
10	22.1	17.6	27.7	39.7	45.1	53.1	59.0	63.4
11	21.0	23.0	25.6	32.3	35.2	41.3	49.4	51.7
12	15.5	15.1	19.8	17.3	15.9	19.0	20.6	17.9

closed off. An average noise reduction was obtained from the measurements at the 10 test booths and is shown in Figure 2.4. Positions 11 and 12 are not included in this average since the two end rooms are not so well isolated from outside noise.

The noise reduction characteristic measured (Figure 2.4) is slightly better than one would have calculated for a single wall of equal weight. It was evident, however, that most of the noise was entering through the floor. Steps should be taken that will minimize transmission by this path, but a completely independent interior structure would be needed if a significant increase in noise reduction is to be obtained.

Noise measurements (Figure 2.5) were made both inside and outside the laboratory while it was aboard the hangar deck of an aircraft carrier. These measurements were made with the aid of an electronic switch and a graphic level recorder. The input to the recorder was switched alternately to a microphone outside the laboratory and to one in the group test room. The inside microphone channel had 30 db more amplification than the outside. The measurements shown are for the 300-600 cps band only. As pointed out above, this band is by far the most important in determining masking of the threshold of hearing.

Examination of the graphic level record in Figure 2.5 shows that the ventilating system usually controls the background noise. When the ventilating system is off, the background level falls to about 42 db SPL in the 300-600 cps band. This is almost quiet enough to obtain normal audiograms at 500 cps. However, some masking of the threshold should be anticipated with the ventilation turned on since the 300-600 cps band SPL is about 6 db higher. The operation of an FJ-3 jet airplane in the same hangar bay and the period of operation of a portable generator just outside the control room door are shown clearly in both the records of inside and outside SPL.

At present the ventilating system is the major background noise problem. However, even when this noise source is quieted, steps must be taken to decrease transmission through the floor. The present background noise levels do not affect thresholds at higher frequencies, but do cause an apparent hearing loss in normal listeners at 500 cps.

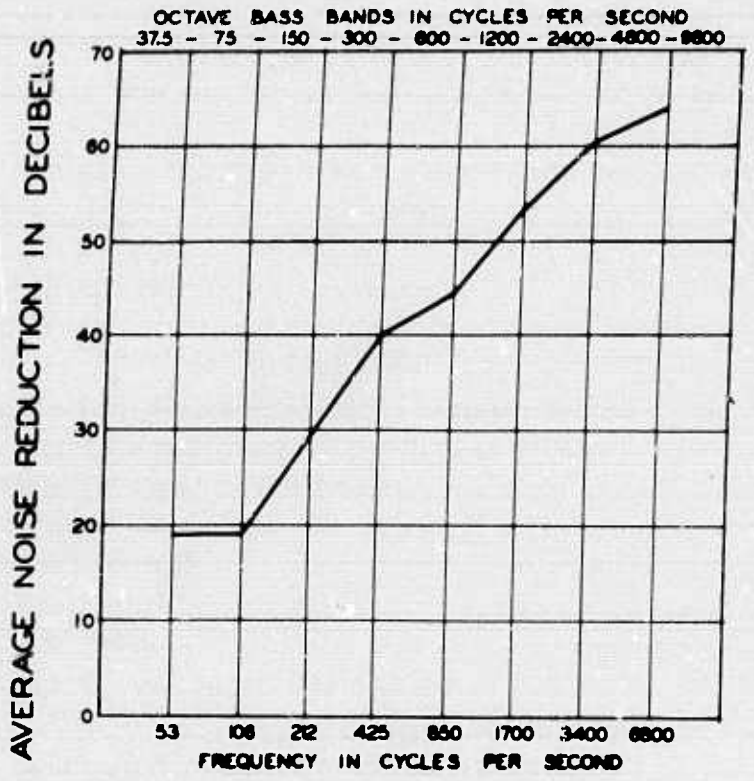


FIGURE 2.4 - Noise reduction of the laboratory walls: The difference between the level inside the group test room and the level outside measured just before completion of the mobile laboratory.

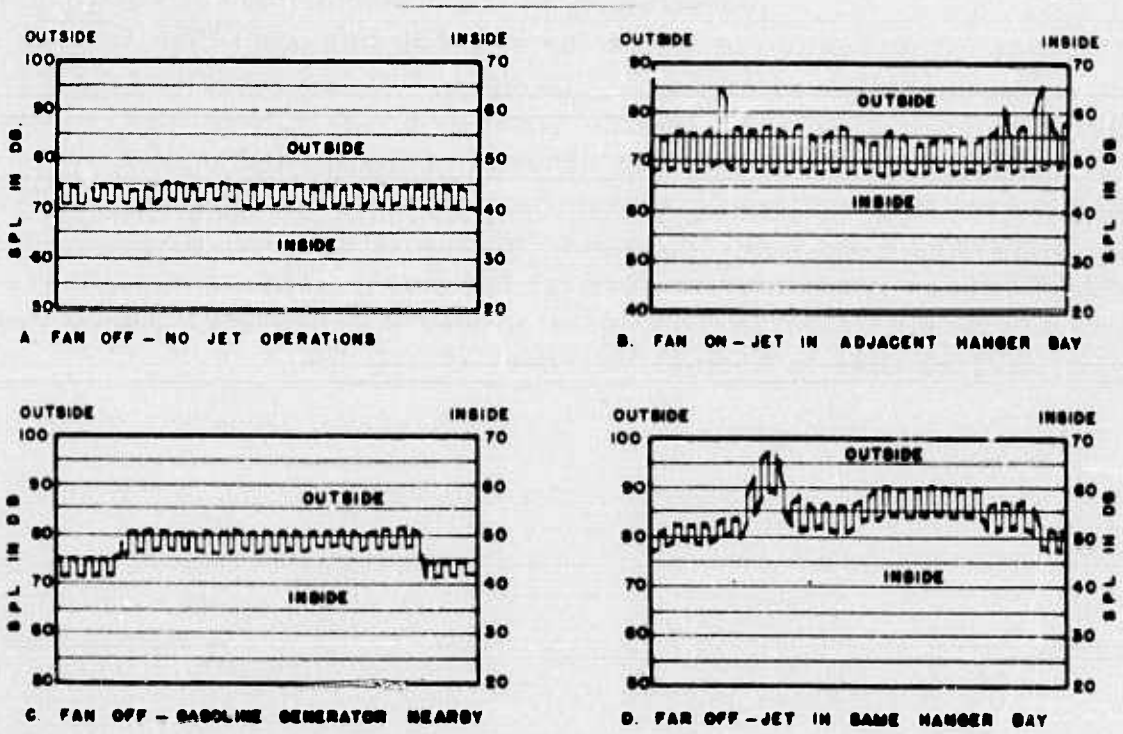


FIGURE 2.5 - Measurements of sound pressure level inside and outside the mobile laboratory during routine operations on the hangar deck of an aircraft carrier. All measurements shown were made in the 300-600 cps octave band. These records were made with the aid of an electronic switch that alternated between the output of the outside microphone and the inside microphone.

APPENDIX 2.2

LABORATORY EQUIPMENT

LABORATORY EQUIPMENT

The block diagram of the audiometric facilities in the mobile acoustics laboratory during the studies to be reported in Chapter IV is shown in Figure 2.6. By simply setting the 5-gang switch S_1, four different testing arrangements are possible:

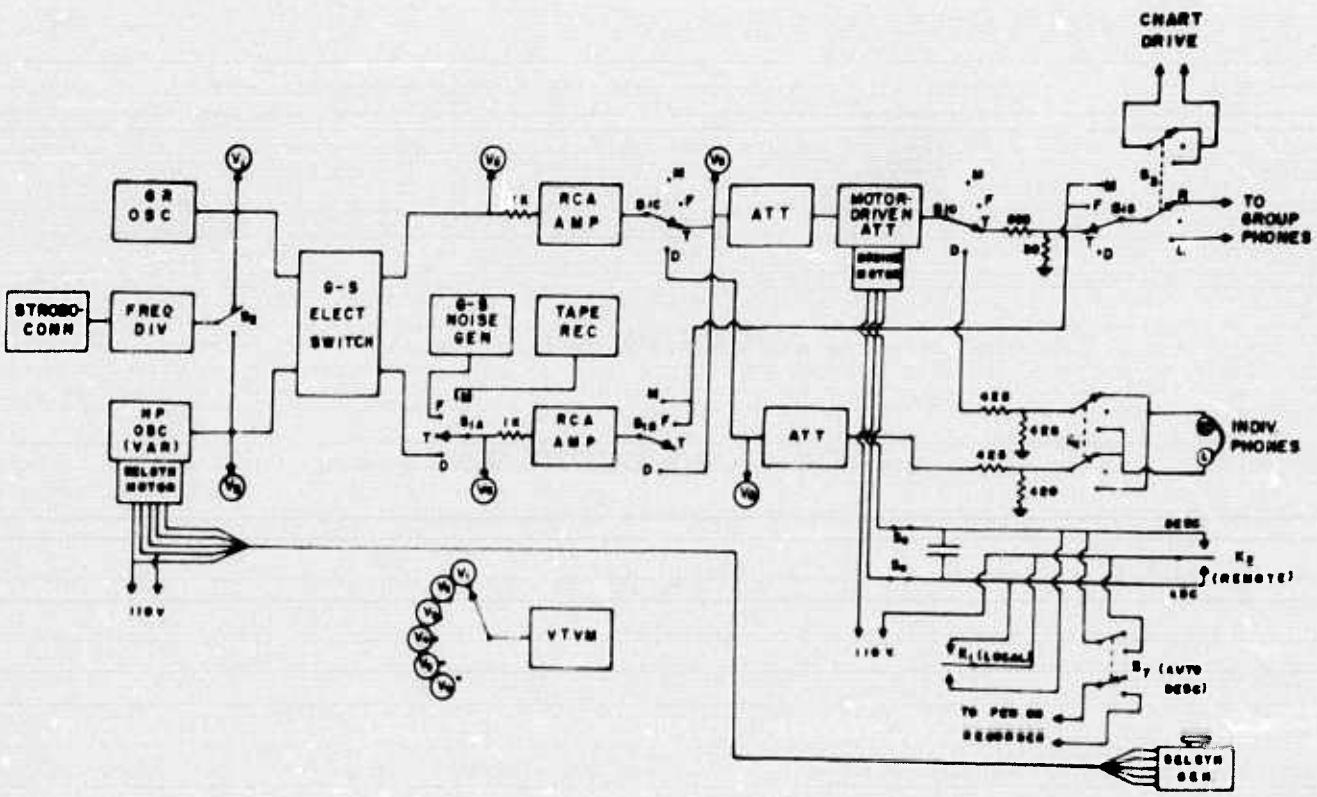


FIGURE 2.6 - Block diagram of the equipment for conducting audiometric tests by the method of "single descent." Many other audiological tests may also be conducted with this equipment.

(m) When S_1 is in position M, the output of the tape recorder is fed directly to the group phones through an amplifier. This setup would be used for tests of intelligibility, auditory pattern discrimination, auditory critical fusion, etc.

(F) With S_1 in position F, the output of a Grason-Stadler noise generator is fed through the amplifier to the phones. This was used for producing temporary threshold shift in testing for susceptibility to acoustic trauma.

(T) In position T, S_1 permits threshold testing by the method of single descent. The General Radio (GR) oscillator is fed through the electronic

switch to the amplifier. From here the signal passes through two attenuators. The first attenuator is normally set at zero for threshold testing; the second is a 90-db attenuator driven by a slow-speed motor. The signal is then matched by means of a resistive pad to the impedance of the ten 300-ohm earphones in parallel.

Switch S_3 connects the signal to the phones, and at the same time starts the chart drive of the Esterline-Angus recorder. As soon as all subjects signal that they are hearing the tones, switch S_7 is thrown, energizing the Bodine motor and beginning the intensity descent. The beginning of this descent is automatically noted on the chart by means of the other half of S_7.

(D) The most complicated setup is obtained in position D of S_1. Tests of diplacusis and recruitment can then be conducted using a special pair of earphones in one of the listening positions. The tone from the GR oscillator now passes through a fixed attenuator; this half of the circuit is controlled by the experimenter. The Hewlett-Packard oscillator, on the other hand, supplies the signal to be adjusted by the subject. He can control the intensity by means of K_2 and the frequency by means of a selsyn system. Switch S_4 permits reversing the fixed and variable stimuli in the ears without removing the earphones.

S_5 and S_6 are protective microswitches that automatically stop the Bodine motor when the attenuator nears maximum or minimum attenuation.

Frequency is monitored and measured by means of a Stroboconn and a 4:1 frequency divider that permits use of the Stroboconn up to 16 kc. Voltage at various points is measured by a vacuum-tube voltmeter.

Figure 2.7 illustrates the wiring of the voting system. When the listener presses the "hear" button (normally open), the relay is energized, thereby turning on his signal light, closing a pen circuit to the recorder and turning off the position-1 panel light in the control room. The relay is made self-locking by connecting pins 2 and 8, so that the above conditions hold until he presses the normally-closed "don't hear" button.

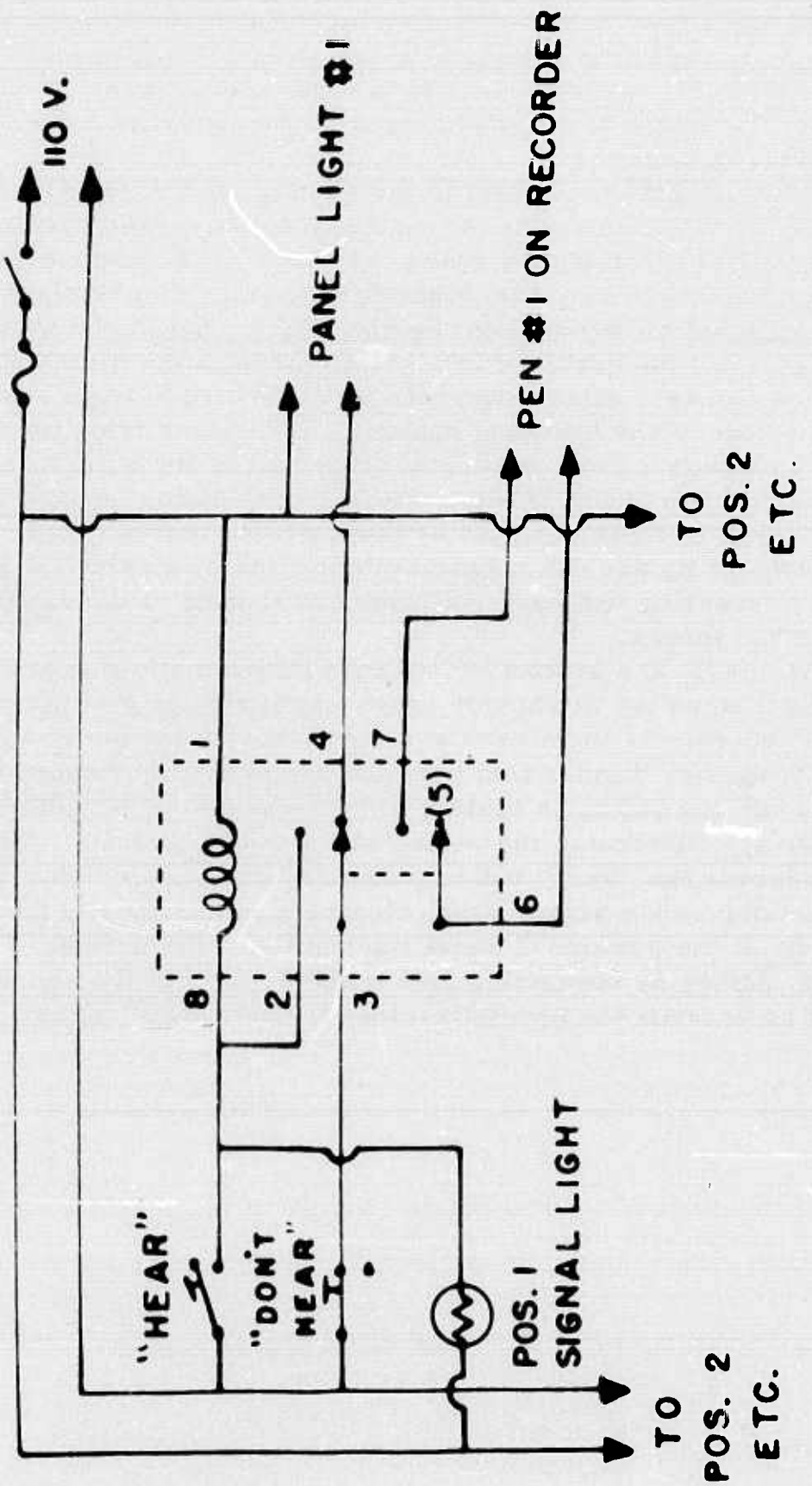


FIGURE 2.7 - Schematic diagram of the wiring of the voting system installed in each of the testing booths.

APPENDIX 2.3

OPERATION OF THE AADS

OPERATION OF THE AADS

The Sequence of Operations

Figure 2.8 shows the complete schematic of the AADS. The sequence of operations is as follows:

The operator starts the test by throwing the motor switch from "run" to "ready." Since the cam-operated microswitch on the motor shaft is at this time in the depressed position, voltage is applied to the motor causing it to rotate until the cam-operated switch is released. This occurs when the main attenuator has advanced to the first step (0 db attenuation). The operator may now present the tone to the left or right ear of the listeners by means of the three position, left-off-right switch. Each listener upon hearing the tone depresses his "Hear" button. Momentary contact of this switch will close and hold relays l_1 through l_0. Closure of additional sets of contacts on these relays illuminate signal lights, informing the operator that all listeners are hearing the tone. A signal light on each listener's desk is also lit to reassure him that he pressed the "Hear" button properly. Finally, 10 normally open contacts in series with coils u_{1c} - u_{0c} are closed.

The test is now ready to start. The operator throws the "ready-run" switch to the "run" position, establishing continuity through the cam-operated microswitch. The motor turns the main attenuator and a toothed wheel. The teeth on this wheel close a second microswitch once for each 2 db step on the main attenuator. The trigger signal thus generated operates the pulser which supplies the coils of ten stepping relays that count units, u_{1c} - u_{0c}. This pulser delivers an approximately rectangular pulse at an average voltage of about 130 volts, and a maximum current of 2 amperes with a duration of 30 milliseconds. A detailed description of its operation follows this section.

The stepping relays advance by one step for each 2 db change in the main attenuator. The wiring on these relays, however, is arranged so that one step is equivalent to an increment of 2 units. A 500-milliampers selenium rectifier is connected in the reverse direction across the stepping relays to provide a path for the current through the coils at the moment of the interruption of the supply current.

When the stepping relays u_{1c} - u_{0c} have stepped 5 times, corresponding to 10 decibles of attenuation, contacts u_{15} - u_{05} close. At the termination of the pulse supplying the coils u_{1c} - u_{0c}, a trigger signal is generated and applied to the second portion of the pulser circuit. Here a low-resistance short to ground of about 30 milliseconds duration occurs. This action grounds the stepping relays that count the decades d_{1c} - d_{0c}. Since the main attenuator has introduced 10 db of attenuation, u_{15} - u_{05} will be closed connecting d_{1c} - d_{0c} to the 150-volt DC supply. Thus the stepping relays that count the decades advance one step.

As soon as this action is completed, relay coil b is energized connecting the release windings u_{1r} - u_{0r} to the low side of a 300-microfarad capacitor. The high side of this capacitor is connected to the release coils

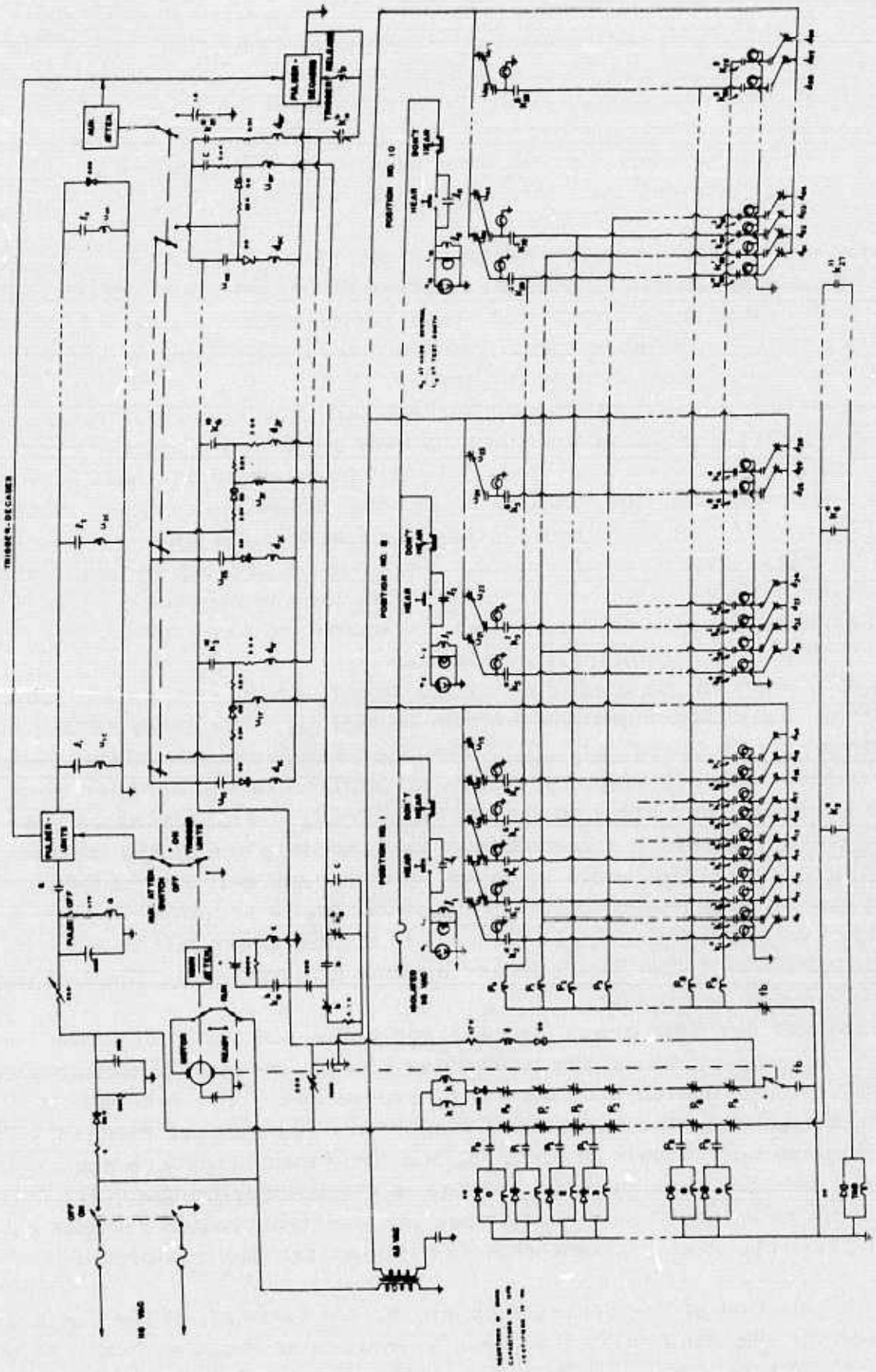


FIGURE 2.8 - Complete schematic diagram of the AADS.

through switch contacts u_{15} - u_{05}. The 300-microfarad capacitor has been charged through a 4.1 k resistor to a voltage of 150 volts. Thus the release coils will have ample voltage for their operation independent of the decay in the 150-volt supply caused by the operation of d_{1c} - d_{0c}. Two 60-milliampere selenium rectifiers are placed in series with the coils d_{1c} - d_{0c} and u_{1r} - u_{0r} to prevent current from flowing backward through any of the non-operating coils and thus forming an undesired path to ground for one of the coils.

The release coils u_{1r} - u_{0r} when energized reset to zero the stepping relays that count the units. Continued rotation of the main attenuator will cause additional counting of units, but since switch contacts u_{15} - u_{05} open upon application of the release signal, another decade will not be counted until the attenuation has increased by another 10 db.

It is important to note that the operations take place one at a time: (1) The stepping relays that count the units receive a pulse; (2) after (1) has been completed five times and a count corresponding to 10 decibels of attenuation has been reached, the stepping relays that count the decades receive a pulse; (3) after (2) has been completed the release coils are energized on the stepping relays that count the units. There is no overlap in time among these three operations. This is necessary because the magnetic coupling between the various coils may cause erratic operation when any two of the above three steps are attempted simultaneously.

When a listener (n) no longer hears the tones, he depresses his "Don't Hear" button. This interrupts the current to coil l_n. The relay returns to the unoperated position and coil u_{nc} is disconnected from the pulser. Therefore, the count on the nth stepping relays for both units and decades remains at the last value attained prior to the operation of l_n. The wiring on the contact bank of the stepping relays allows one and only one of the in-line read-out lights designating units to be lit, and one and only one of these lights designating decades to be lit. This switching is accomplished through contacts u_{n1} - u_{n5} and d_{n1} - d_{n0}. When all of the listeners fail to hear the tone, the remainder of the "Don't Hear" buttons are pressed. None of the stepping relays can then count.

The operator may then press the carriage return on the Underwood Servotyper. The operation of the typewriter closes one pair of contacts on a "feedback" switch located underneath the typewriter. The feedback switch grounds the coils, k, of the two rotary steppers. The ratchet mechanisms on these steppers cock a pair of springs, but the wiper arms are not advanced to the next position until the voltage is removed from the coils, k. Thus the steppers actually move only when the feedback switch returns to the normal position. This occurs when the typewriter has completed its operation.

The first position of the rotary stepper, k, connects all of the contacts, d_{11} - d_{10}, on the stepping relay that counts decades at Position No. 1 to the appropriate relays p_0 - p_9. At the same instant the normally closed half of the feedback switch in the typewriter closes and one of the coils p_0 - p_9 will be energized corresponding to the count that is stored on the stepping relay

for decades at Position No. 1. If all the other relays p_0 - p_9 are in their unoperated position, 150 volts DC will be applied to the appropriate solenoid on the Servotyper. As soon as the typewriter begins to operate, the feedback switch is actuated so that none of the relays p_0 - p_9 is grounded. Voltage is immediately removed, therefore, from the typewriter solenoid, allowing the key to return to its normal position. Inductive surges are controlled by means of small selenium rectifiers across the typewriter solenoids.

When the typewriter completes its operation, the feedback switch operates and rotary switch k advances one step further. The contact bank and lights associated with the units at Position No. 1 are then connected to relays p_0 - p_9. In the manner described above a second character is printed that will correspond to the unit that is stored on the stepping relay for Position No. 1.

It is necessary to interrupt the 6.3 volt supply to the indicator lights and the contact banks on the stepping relays during the time that the coils on switch k are energized. This is accomplished by relay f. If this were not done, unwanted return paths would be provided through the unoperated relay coils p_0 - p_9 and a small voltage would appear across the coil that has just been energized. In some cases this voltage is sufficient to keep the relay contacts from opening promptly. When this happesn, two characters may be struck simultaneously when the feedback switch returns to its normal position or switch k may not advance.

After the character representing the decade and the unit for Position No. 1 have been printed, switch k advances to Position No. 3, closing contacts k_3^{11}. This connects the tab key to 150 volts DC and advances the carriage to the next column. Switch contacts k_3^{10} are also closed connecting 150 volts DC to the release coils u_{1r} - d_{1r}. When the tab operation is completed, the feedback switch returns to its normal position and the two digit count stored on the stepping relays for Position No. 2 is printed in a manner similar to that described for Position No. 1. At the conclusion of this operation, the tab key is again operated and coils u_{2r} and d_{2r} are actuated to reset the second pair of stepping relays. The stepping relays are reset in pairs at the conclusion of the printing phase for each position to circumvent the multiple switching problems that would be encountered if simultaneous resetting of all relays were attempted. This difficulty is a result of the fact that is is not possible to connect all the various release coils to one point.

When the count stored on the 10th position is printed, switch k returns to the 0th position but the tab key is not actuated as it was for positions 3, 6, 9 . . . 27. Therefore, there is no signal applied to the typewriter and the feedback switch remains in its normal position. Switch k is advanced no further until the next printing cycle is begun. In order to avoid continuous application of the reset voltage to the coils u_{0r} and d_{0r}, relay c is energized momentarily when switch k first reaches the 0th position. Only when relay c is energized are the low sides of coils u_{0r} and d_{0r} connected to the supply.

By the time that the printing cycle is complete, the main attenuator will have reached the maximum attenuation position. The cam-operated microswitch will be depressed interrupting the voltage supply to the motor. The motor will not run again until the "ready-run" switch is thrown to the "ready" position. At this point the cycle begins again.

The Operation of the Pulser

Figure 2.9 is the schematic diagram of the unit that supplies pulses to the stepping relays in the AADS. These pulses should have an average voltage of approximately 130 volts and an average duration of 30 milliseconds. Since as many as ten relays may step at one time, a total current requirement of 2 amperes must be put on the unit. A reliable and fast-acting relay to control 2 amperes at 130 volts was not immediately available. Therefore, vacuum tube control was used. The power-handling capacity of the two halves of a 6AS7 tube was sufficiently great to do the job. When the grids are connected to the plates by means of relay contacts and 2 amperes are drawn from the tube, the drop across the tube is sufficiently small to allow an average voltage of about 130 volts to be supplied to the stepping relays from a 150-volt DC supply.

A monostable multivibrator is triggered by the microswitch actuated by the toothed wheel on the attenuator shaft. A peak reading circuit, followed by a differentiating circuit, assures a sharp single trigger to the grid of the multivibrator. The coil of relay K_3 is in the plate circuit of the normally conducted half of the multivibrator. The positive trigger at the grid of the other half of the multivibrator tube momentarily interrupts the plate current through the relay coil. The time constant of the mulitvibrator is adjusted so that the relay will operate again after approximately 30 milliseconds. A pair of normally closed contacts on this relay are connected between the grids and the plates of a 6AS7 tube. The interruption of the current through the coil K_3 turns the 6AS7 on and allows the current to be drawn by the stepping relays connected to the cathodes of the tube. The grids are premanently connected to a -150 volt (negative) supply through a 100k resistor. Therefore, as soon as the relay operates at the end of the 30-millisecond period, disconnecting the grids from the plates, they are cut off by the -150 volt bias. This step is necessary to insure that no current flows through the stepping relays between steps. Even very small amounts of current can prevent the stepping relays from moving to the "ready" position prior to the next pulse. When the 6AS7 controlling the stepping relays for the units is cut off, a normally open pair of contacts connect a 2 mfd capacitor to relay coil K4. This 2 mfd capacitor has previously been charged through a 1k resistor and a pair of normally closed contacts on relay K_3. The operation of relay K4 connects the grids to the plates of a second 6AS7. After 30 milliseconds this connection is also removed and the grids returned to a -150 volt bias. The cathodes of this second 6AS7 are connected to ground and the plates are connected to the low side of the stepping relay coil for the decades. Thus, when relay K_4

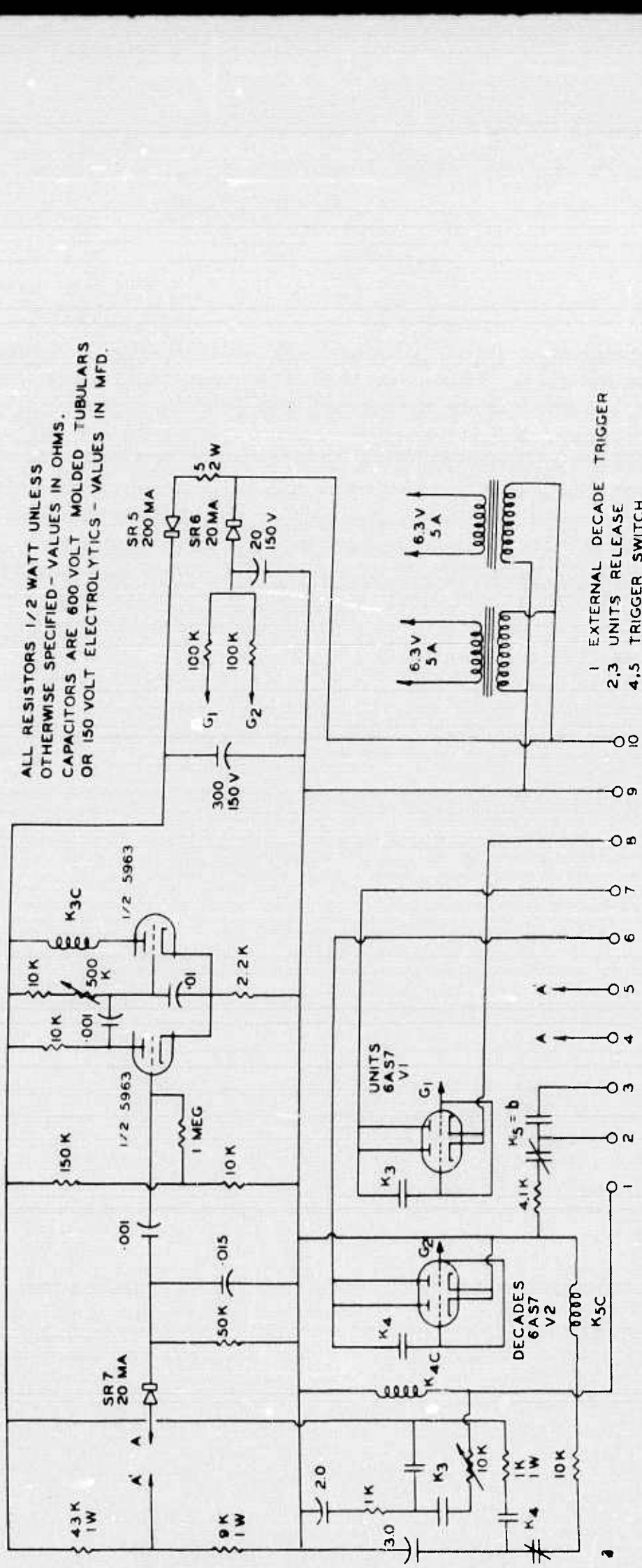


FIGURE 2.9 - Detailed schematic diagram of the pulser for the AADS.

is actuated, a low-resistance path to ground is provided for the stepping relays that count the decades. This operation takes place only after the stepping relays that count the units have completed their operation.

Finally, a third relay, K_5, is energized by the charge on a 3 mfd capacitor through normally closed contacts on relay K4. The method for operating relay K_5 is identical to that for operating K_4. Operation of K_5 connects the low side of the release coils on the stepping relays that count units to the bottom of a 300-microfarad capacitor located in the main power supply. Since this capacitor is not connected until after the decade count has been registered, a full 150 volts is available to operate the release coils. Relay K_5 remains closed for approximately 60 milliseconds in order that the complete reset operation take place reliably.

It is important that the operation of relays K_3, K_4, and K_5 are not simultaneous. They close in sequence and only when the previous one in the chain has completed its operation. Each sequence of three relay closings is triggered by the microswitch connected between points A' and A.

Figures 2.10 and 2.11 show additional details of the wiring of the AADS.

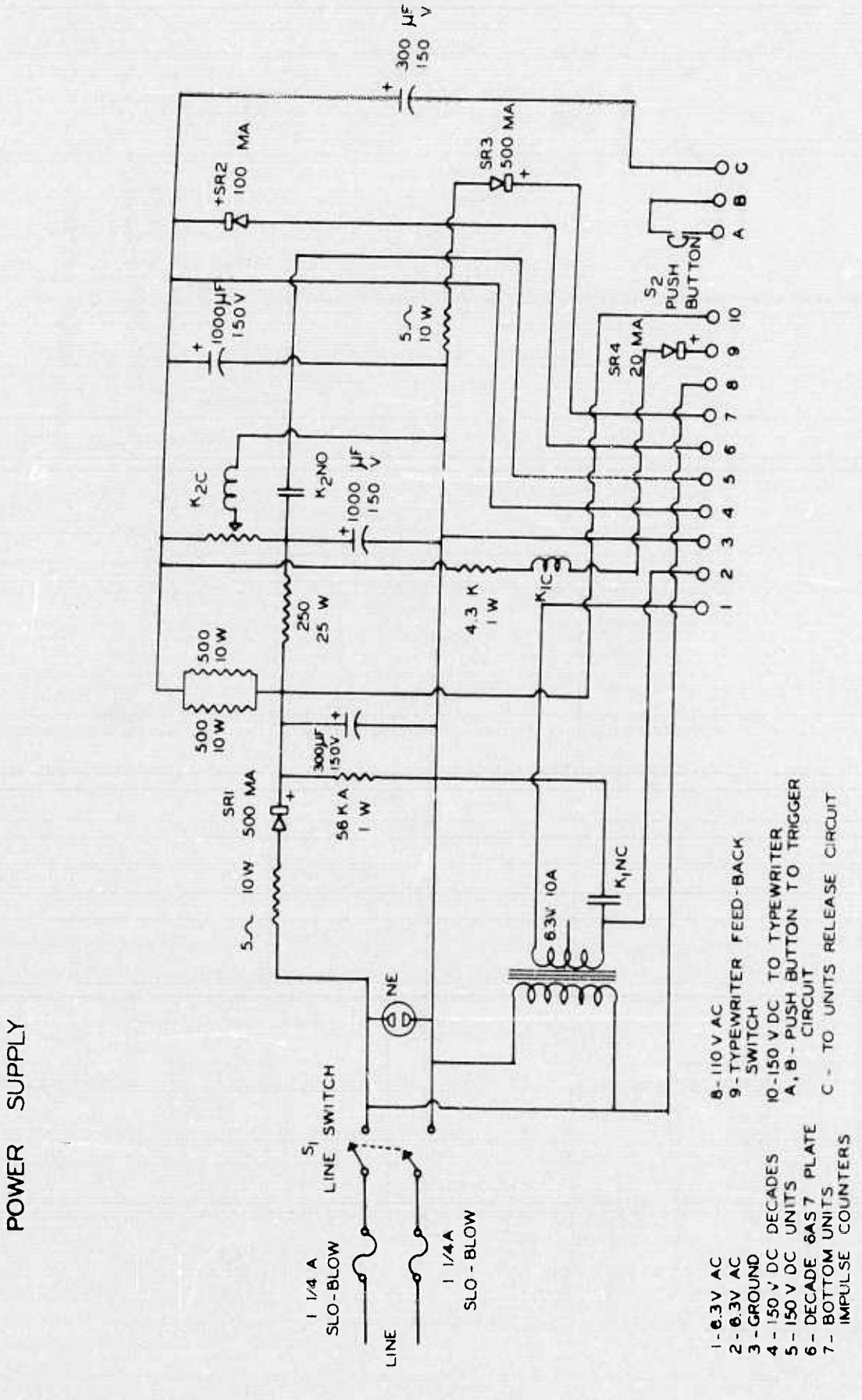


FIGURE 2.10 - Detailed schematic of the power supply for the AADS.

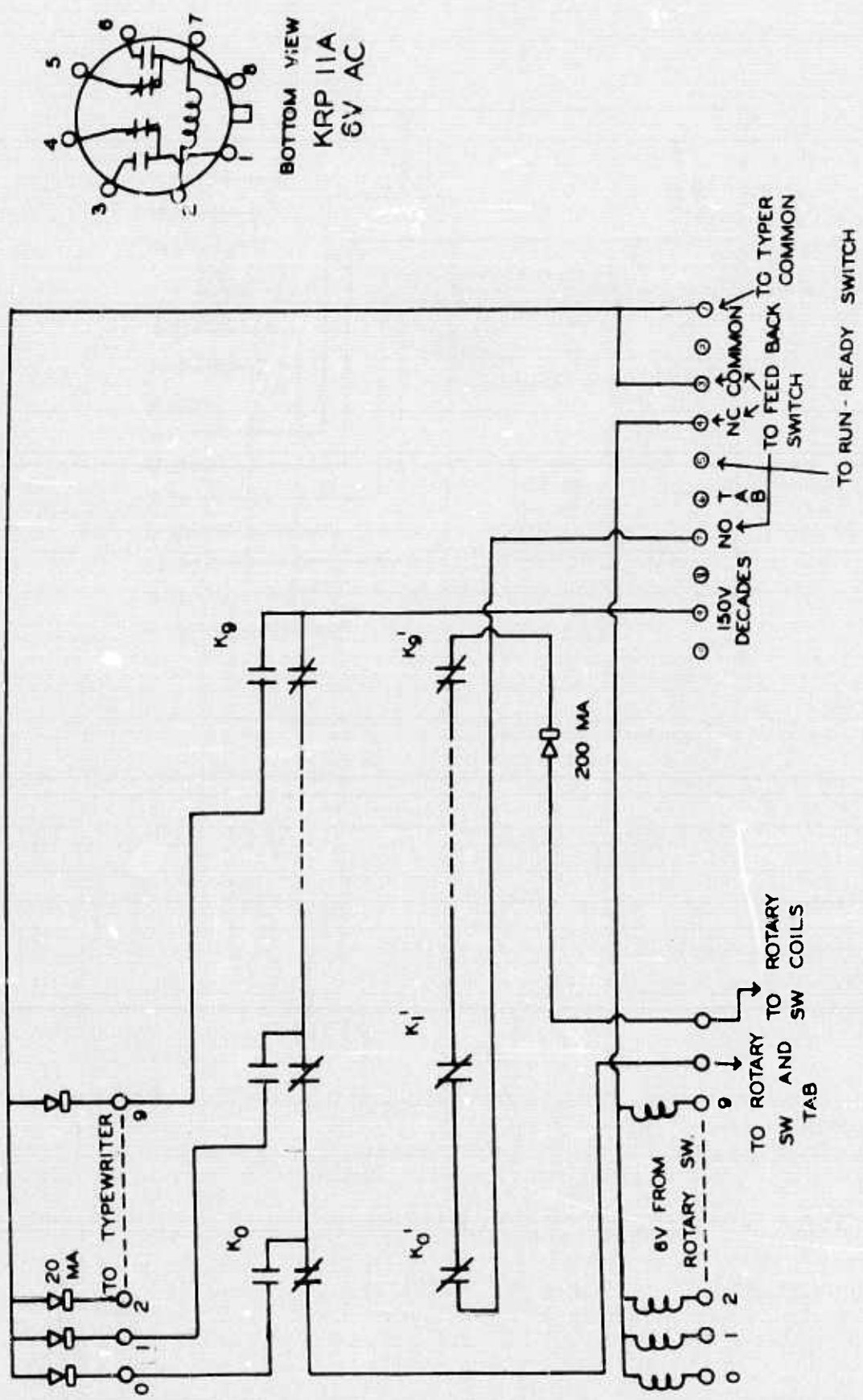


FIGURE 2.11 - Detailed schematic of the relay connections that operate the Servotyper of the AADS.

CHAPTER 3

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INTRODUCTION

As a result of the operation of jet aircraft, flight deck and aircraft maintenance personnel are exposed to an intense, fluctuating sound pressure. This is a noise exposure that requires special equipment to be properly quantified. A system has been designed that overcomes many of the special difficulties met in the measurement of such a noise exposure. Considerations underlying the design, construction, and evaluation of the components and results of a field trial of this system are described below.

THE MEASUREMENT PROBLEM

A system for measuring noise exposure should be capable of producing data that can be correlated with the hearing losses of the men exposed. A tape recording of the output of a microphone placed at a man's ear would give a complete record of the sound pressure level versus time that is his noise exposure. However, the task of relating the information stored on a tape to the hearing losses incurred by the men would be impractical even for studies involving only a few kinds of noise exposure. It is clear, therefore, that some method of identifying and extracting the significant information from the complete record of the noise exposure is necessary.

The problem can be greatly simplified by assuming that the total amount of time during which a man is exposed to noise of a given sound pressure level determines the seriousness of the exposure rather than the exact order or scheduling of quiet and noisy periods. On this basis, a noise exposure that occurs during one hour of an 8-hour day is as hazardous as an exposure to the same noise for one minute out of every eight during an 8-hour day. By treating all exposures to a given sound pressure level alike, no matter when they occur during the day, tremendous simplification in reporting the data may be achieved.

Additional simplifications may be obtained by the familiar scheme of grouping adjacent data points together. For example, the noise may be quantized by the use of octave bands or similar methods of frequency analysis. Within the frequency bands chosen, adjacent sound pressure levels may be grouped together. The grouping may cover a 5 db range or 1 db range, depending upon the characteristics of the data. The data may also be segmented in time. During any one of the segments of time, it is only necessary to report a single measure of the intensity of the noise. Grouping the data in each of these three dimensions (frequency, level and time) makes possible a statistically manageable presentation.

In some industrial situations, a single set of measurements with an octave band analyzer may be sufficient to forecast the noise exposure that a man may incur for many years. Unfortunately, the noise exposure of the men working in the vicinity of jet aircraft is not so simple. The spectrum of the noise and the over-all level radiated by an aircraft depend upon the power setting and the direction as well as the distance from the aircraft.

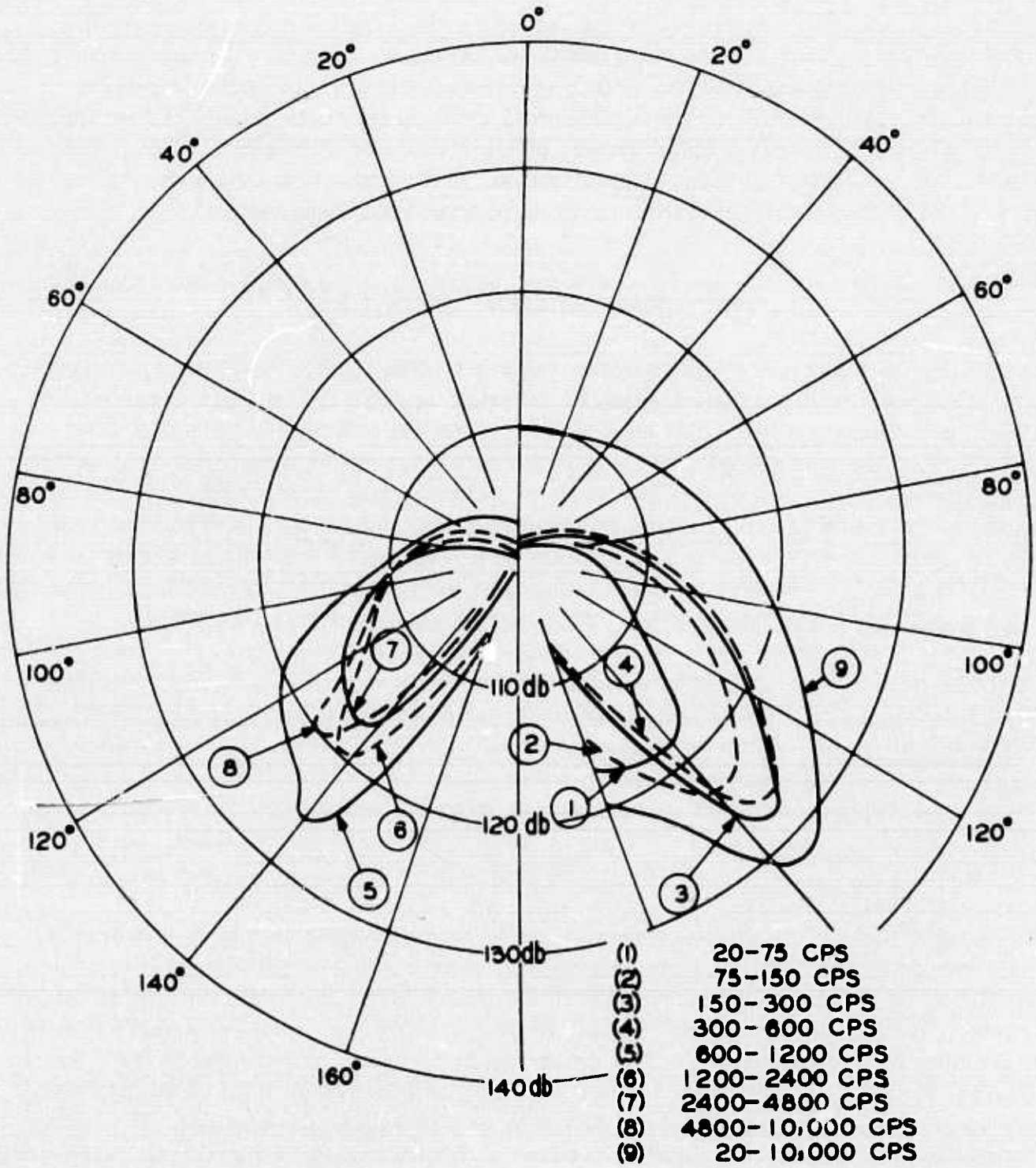


FIGURE 3.1 - Noise radiation characteristics of jet aircraft.

(a) Directivity patterns for several frequency bands at 100 feet from exhaust of F7U3 airplane with both engines at military power.

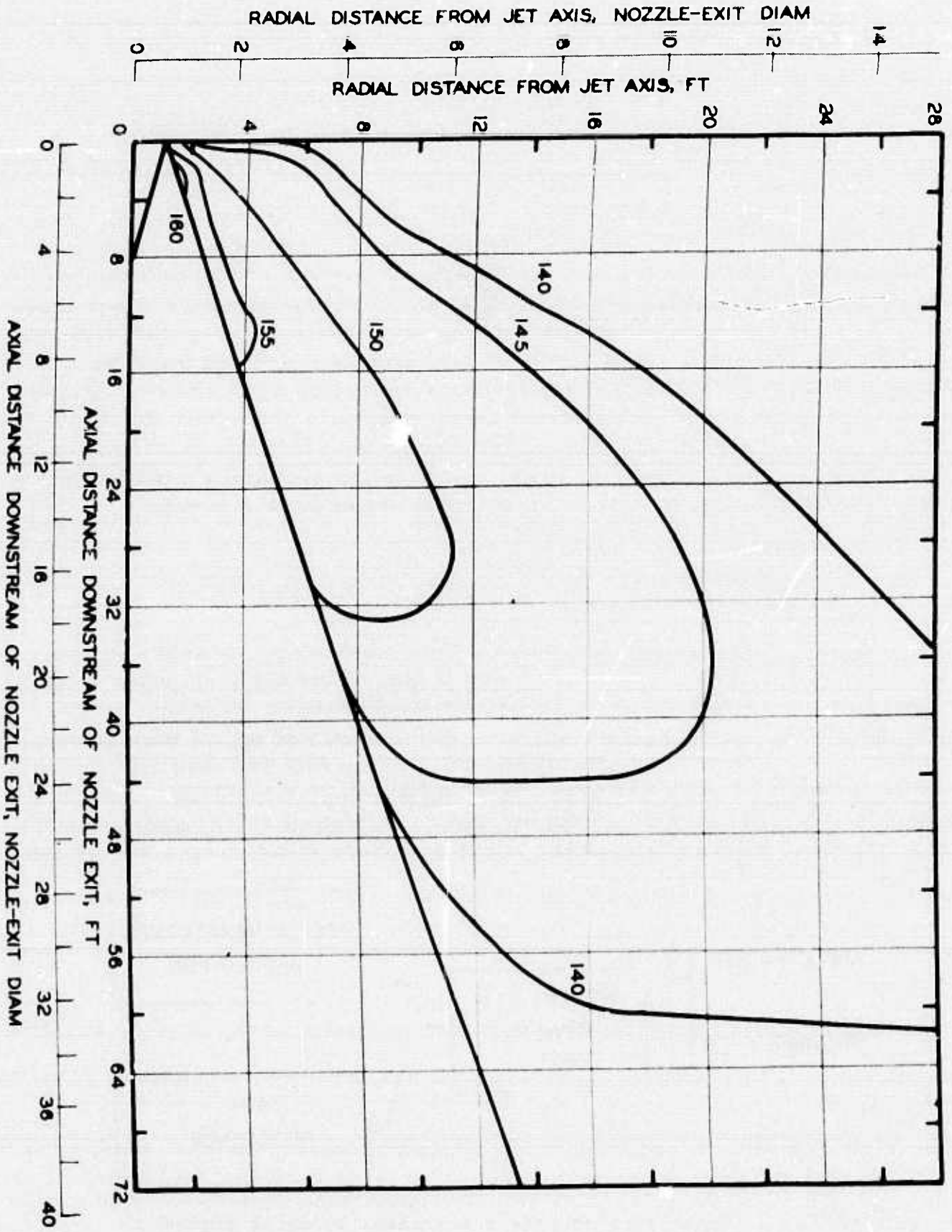


FIGURE 3.1 - Noise radiation characteristics of jet aircraft.

(b) Near field contours for equal over-all sound pressure level for a J-57 jet engine (from reference 3.1).

Figure 3. 1a shows directivity patterns in octave bands for an F7U-3 measured on a 100-foot circle with both engines operating at military power. Figure 3. 1b shows the complexity of the contours of equal sound pressure level in the vicinity of a J-57 engine operating at military power (from reference 3. 1). Very small changes in position may cause large changes in the sound pressure level to which personnel who work near the aircraft are exposed.

Because of insufficient knowledge of the movements of personnel, it is at present impossible to predict the noise exposure of maintenance personnel who work near jet aircraft, even though complete noise measurements have been made around the aircraft. The problem becomes even more difficult when one attempts to estimate the noise exposure of men on the flight deck of aircraft carriers. In this case both the plane and the men are moving, the power setting of the aircraft is changing, and an accurate prediction of noise exposure from known characteristics of sources is completely impractical. As an alternative, therefore, one can sample the exposure that actually occurs. In order to do this, a method is required for measuring the noise exposure in the vicinity of the subject's ear.

A SYSTEM FOR NOISE EXPOSURE MEASUREMENT

The basic scheme used to measure "noise exposure" is shown in the block diagram, Figure 3. 2a. The "noise exposure" of the man under study is converted to an electrical signal by means of the high-intensity microphone shown at the left of tne diagram. This electrical signal may be reinforced by a preamplifier located at the microphone and then transmitted over wires to the remainder of the measurement system. This "wired" system will be particularly useful on land in studies of noise exposure where the presence of microphone cables is not a serious disadvantage and where

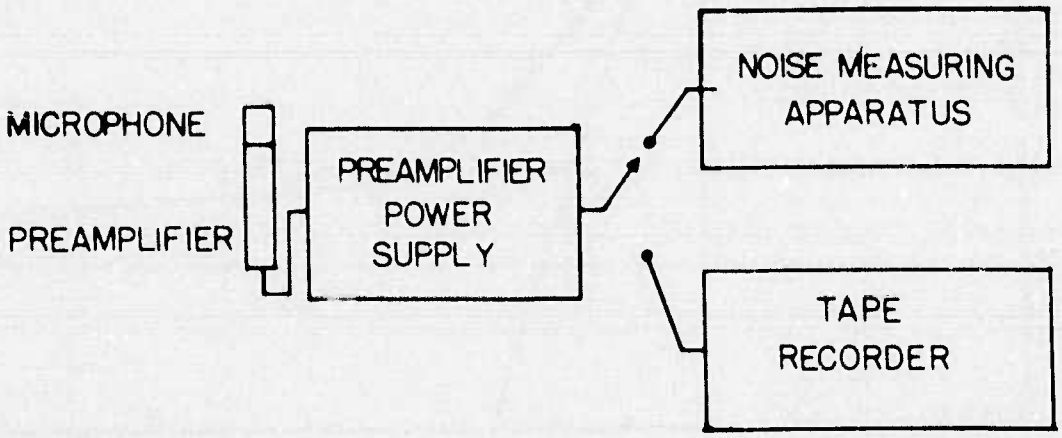


FIGURE 3.2 - Two systems for the measurement of noise exposure.

(a) Measurement system using a conventional or "wired" microphone.

3. 1 Howes, W. L., and Null, H. R., Near noise field of a jet-engine exhaust, I - sound pressures. NACA Tech Note 3763, October, 1956.

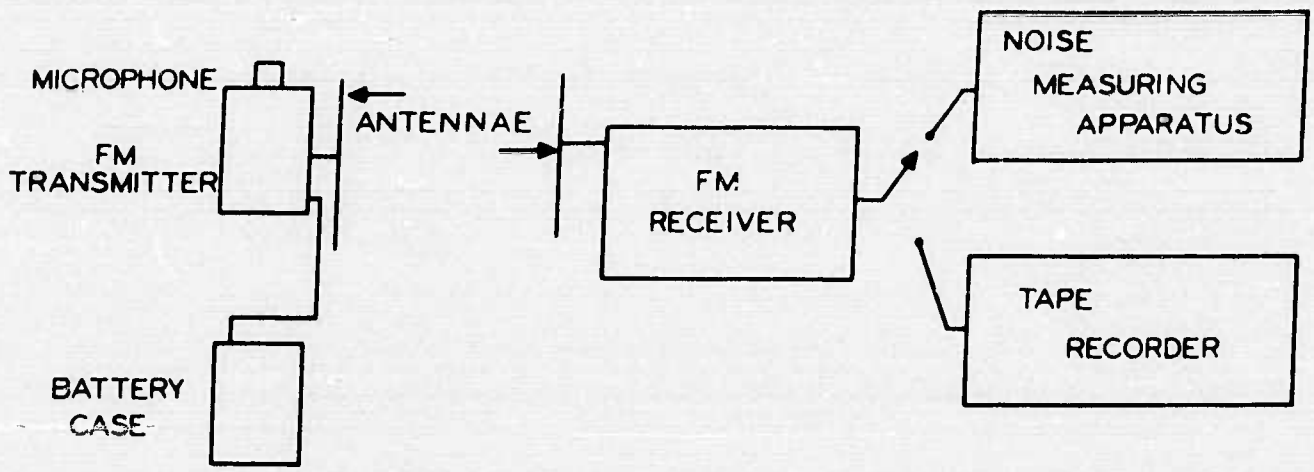


FIGURE 3.2 - Two systems for the measurement of noise exposure.
(b) Measurement system using an FM link or "wireless" microphone.

minimum of equipment is desirable.

An alternate scheme is shown in Figure 3.2b, in which a radio transmitter broadcasts the electrical signal produced by the microphone. This radio signal is monitored by a conventional radio receiver at a convenient location some distance from the transmitter. Frequency modulation is particularly well suited to this task since the amplitude calibration of the system is not affected by changes in the placement of the transmitter. In addition, the condenser microphone can be used as a simple modulating device for an FM transmitter. This "wireless" system is most useful on the flight deck of aircraft carriers and in other operational situations where the presence of cables is undesirable. In any situation where the personnel move from place to place with rapidity or urgency, it is likely that the wireless system will be preferable.

The output of either the wired or the wireless microphone system can be fed directly to the remainder of the noise measuring apparatus. Alternatively, the output can be fed to a broadcast quality tape recorder (see Figure 3.2). At a later time the tape can be played back into the remainder of the system. Recording the data on tape has the advantage that any portion of the data can be reexamined by re-playing the tape. In addition, the tape recorder is considerably more portable than the data analyzing equipment. In situations in which portability is unimportant, the storage of the data on the tape recorder may be eliminated. In other cases, the tape recorder and data analyzing equipment may be used simultaneously to advantage.

The spectrum of the noise is an important factor in the determination of noise exposure. Both physiological and psychophysical experiments indicate that the amplitude of motion of the parts of the inner ear are dependent upon frequency. One region of the cochlea reacts strongly to high-frequency sounds. Another is relatively inactive during these sounds, but reacts strongly in the presence of low-frequency sounds. In addition, the

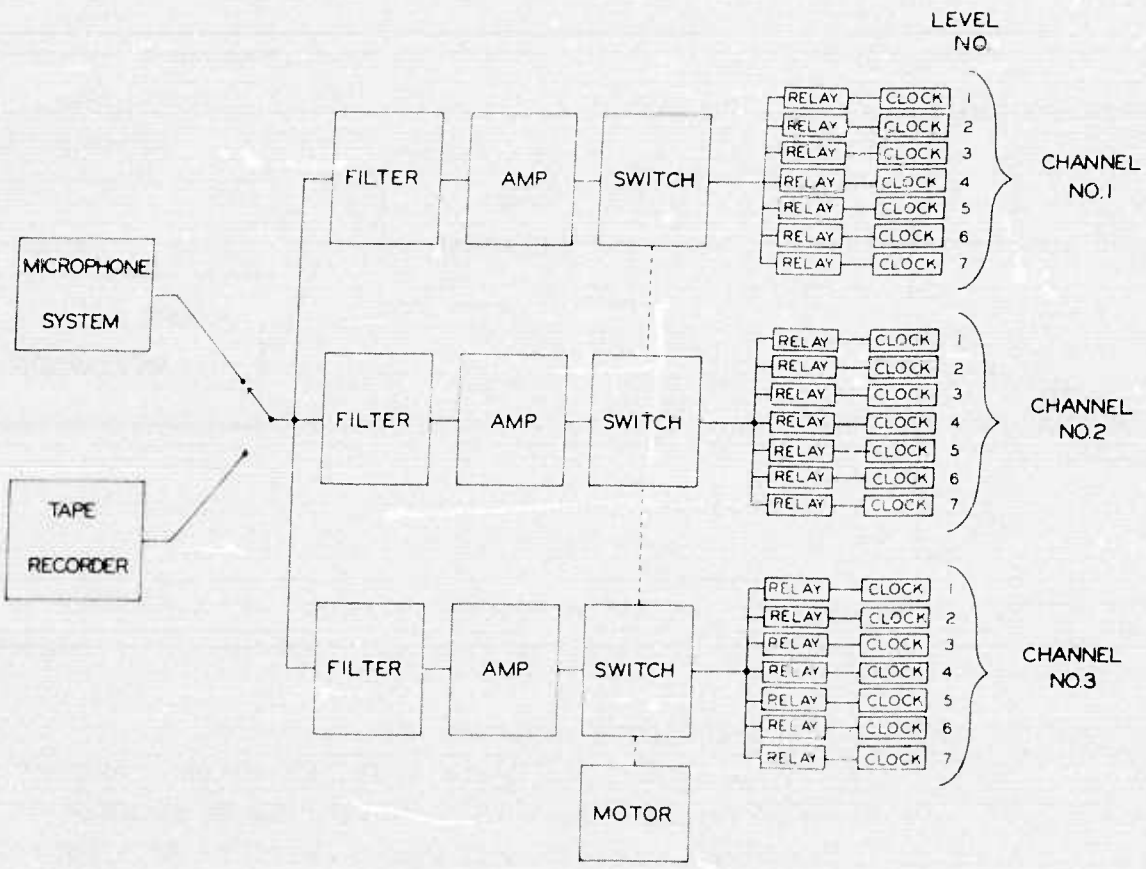
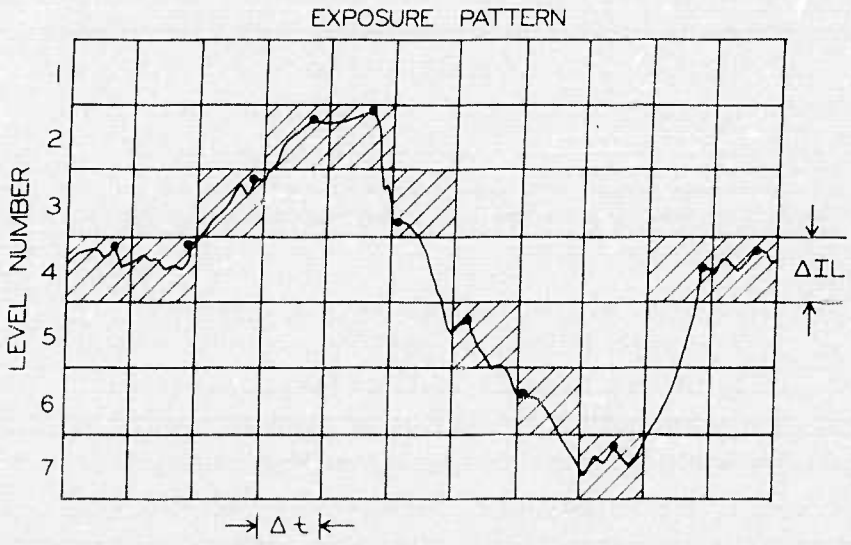


FIGURE 3.3 - Block diagram of the Cumulator, an automatic system for the analysis of noise exposure in which the noise exposure data is analyzed as a function of frequency, intensity and time.

variability of the nosie spectrum (Figure 3.1a), requires that frequency analysis of the noise be performed continuously. Electrical band pass filters are used for this purpose and they are shown in Figure 3.3. The bandwidth of these filters is adjustable, and the optimum width can be chosen empirically. The bandwidth of these fliters should be sufficiently wide so that rapid changes in the envelope of the noise can be passed without significant distortion. On the other hand, the filters should not be so wide that significant details of the frequency spectrum are lost. The octave is a popular compormise bandwidth and there is no clear evidence that any other bandwidth is preferable. Experience may show in the future that a narrower bandwidth is advisable.

As can be seen by the block diagram, three electrical filters are in the circuit simultaneously. Each of these filters can be adjusted to any center frequency or bandwidth desired. A typical set-up is as follows: Filter No. 1, 300-600 cps; Filter No. 2, 1200-2400 cps; Filter No. 3, wide-band 20 cps to 10 kc. Such an arrangement would provide information on the octave bands that may appear to be critically related to hearing loss plus information on the over-all sound pressure level. The output of the electrical filter is still much too complicated for visual analysis. Grouping the data in two more dimensions (intensity and time) will, however, greatly reduce its



STATISTICAL FREQUENCY DISTRIBUTION OF EXPOSURE LEVELS	CUMULATIVE DISTRIBUTION OF EXPOSURE LEVELS
(NUMBER OF SECONDS PER LEVEL)	
0	0
2	2
2	4
4	8
1	9
1	10
1	11

FIGURE 3.4 - Typical pattern of noise exposure after filtering indicating the manner in which the Cumulator groups the data in intensity and time.

complexity.

Figure 3.4 gives a sketch of the output of one of the filters. The rectangular grid indicates the manner in which the data are grouped in the two dimensions of intensity and time. For example, some measure of the signal's intensity can be used to select one of the cells in each vertical column. The example shown here selects the cell according to the maximum intensity during the interval of time corresponding to the width of the cell. This measure of a signal selects one cell in each column.

If the dimensions of the cell are small enough so that no significant details of the envelope of the signal are lost, a complete specification of the signal can be obtained from a series of cell numbers containing the maximum amplitude of a signal. For the purposes of correlation with hearing loss measurements, the dimensions of a cell can probably be fairly large. The accuracy of the sound pressure level measurements are likely to be no better than ± 2 db as a result of differences between the sound pressure arriving at the eardrum and that arriving at the microphone. Significant changes in the envelope of the noise are unlikely to occur in an interval of less than a few tenths of a second. Therefore, a cell size of about 5 db in intensity by about 1 second in time is not likely to eliminate the essential features of the data.

Now, if we make the assumption that the particular "pattern" of the noise is unimportant, we may ignore the order in which the signal passes through the cells. The noise exposure may then be characterized by the sum total of the entries in each horizontal row. This total for the cell width of 1 second gives the total number of seconds in which the peak of the noise signal fell in a given horizontal row. Each horizontal row represents a specific range of intensities and therefore the totals at the right of Figure 3.4 give the distribution of noise exposures as a function of intensity. This distribution of the intensity of noise exposure provides data that can be easily entered on IBM cards or treated by other statistical methods.

The physical realization of the methods of data analysis described by Figure 3.4 is shown at the right-hand side of Figure 3.3. A motor-driven switch obtains a measure of the intensity of the signal during each one-second interval. The output of this switch actuates one or more of seven relays, depending upon the intensity of the signal. All relays below and including that corresponding to the intensity during the previous 1 second interval are actuated. The relays always remain closed for at least 1 second so that the clocks attached to their outputs show an increment of 1 second for each second during which the signal is equal to or greater than the indicated intensity level. The resultant display is a cumulative distribution rather than the statistical frequency distribution (Figure 3.4). The frequency distribution can be obtained from the cumulative distribution by subtracting the readings of adjacent clocks.

Because the data analysis system presents cumulative distributions of the intensity of the noise to which a man is exposed, it has been given the name "Cumulator." As shown in Figure 3.3, the Cumulator has three channels, one for each of the electrical filters. Each channel is analyzed in one-second intervals and the resultant intensity is grouped in one of seven different levels or cells, each of which is displayed by means of a clock assembly. Since each of the three channels has seven different intensity levels, there are a total of 21 clock assemblies. The resultant display (Figure 3.5) makes it possible to obtain a significant amount of data on the noise exposure of an individual in a relatively short time. It is unnecessary to spend more time on data reduction than was originally spent in the collection of the data itself.

In summary, the advantages of this method of data reduction are:

(1) The reduction of a complex signal to an amount of data that can be handled by practical means; (2) The method of presentation of the data lends itself to statistical analysis; (3) The time required to analyze the data is no greater than the time required to obtain it; (4) Most of the essential features of the original exposure are retained, if one assumes that the time pattern of the noise exposure is unimportant; (5) The width of the frequency bands and the intensity bands may be adjusted.

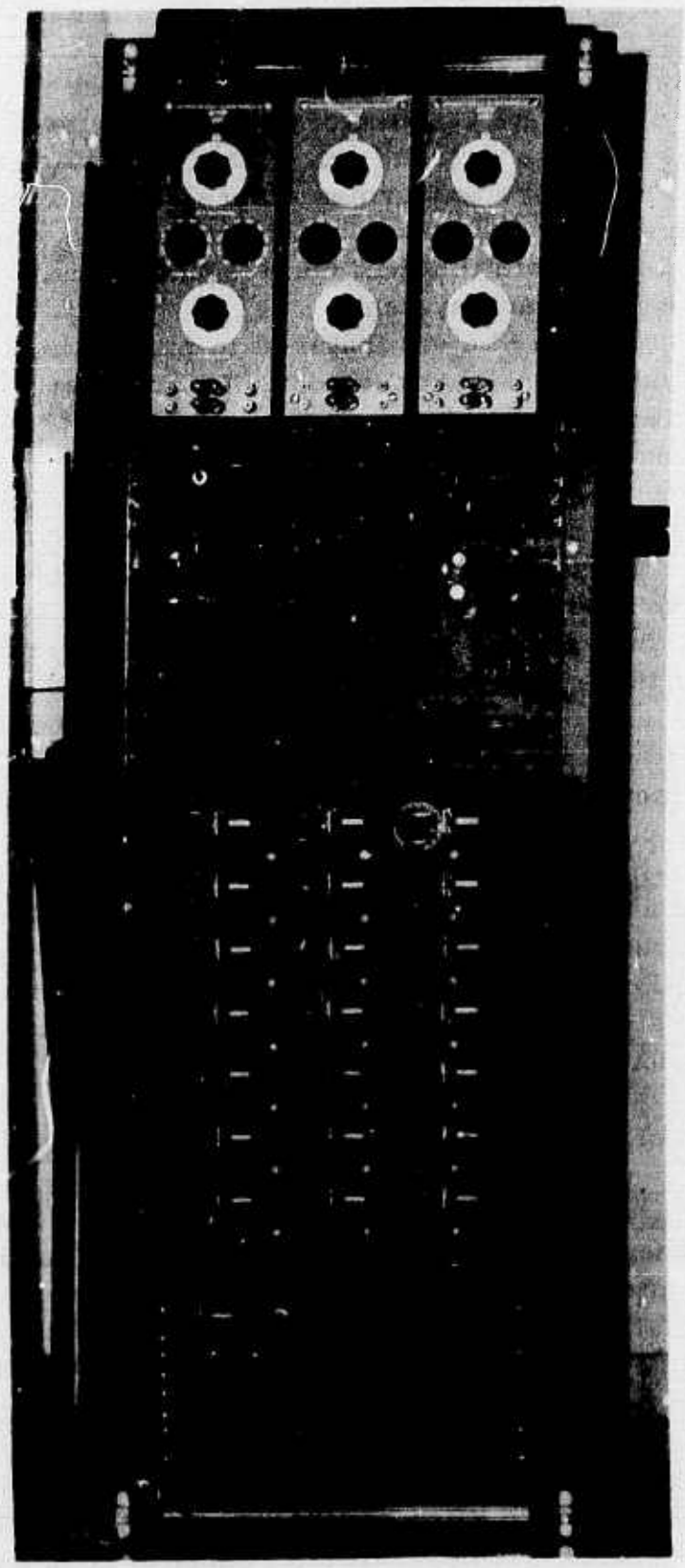


FIGURE 3.5 - Photograph of the Cumulator panel. Each column of clocks represents one channel or one frequency band, and each clock within a channel displays the cumulative time during which the noise exposure exceeds a predetermined level.

CONSTRUCTION AND EVALUATION OF THE MEASUREMENT SYSTEMS

The mocrophone systems used to measure the noise exposure of personnel must be able to operate satisfactorily in very intense sound fields. Microphone systems that are currently available do not appear to be universally dependable. Tests were performed, therefore, to determine the most satisfactory system among those presently available. It was anticipated that these tests would indicate the maximum sound intensity that could be measured accurately with each system.

The difficulties that may be encountered in making high-intensity measurements can be discussed conveniently by consideration of the standard sound level meter, which is a particular kind of microphone system. First, the microphone itself may not respond linearly to high-intensity sound. In most sound level meters, this effect becomes important above about 155 db. Second, the electronic components associated with the microphone may generate extraneous signals as a result of air-borne or structure-borne sound. These signals may become important in a typical sound level meter at about 130 db, and in a typical octave band analyzer at about 120 db. Third, vibration of the microphone may generate signals comparable to those generated by the sound. Fourth, vibration of the connecting cables may cause intermittant connections or the generation of extraneous signals. In the sound level meter, this difficulty is generally overshadowed by the other three mentioned above.

Except for non-linearities exhibited by the microphone itself, the difficulties enumerated above cannot be detected in a microphone system except by means of measurements made with the entire system exposed to the intense sound field. For this reason, comparison measurements on several microphone systems were made under field conditions and in the immediate vicinity of several jet engines.

1. "Wired" Microphone Systems

Two manufacturers supply condenser microphones specially designed for high-intensity measurements. The Kellogg Switchboard and Supply Company supplied microphones that had been modified for high intensity use by increasing the distance between the diaphragm and back plate. The Altec-Lansing Company supplied four different types of high-intensity microphones belonging to the 21BR series. Data furnished by the manufacturers and verifications in the Central Institute's laboratories indicated that the microphones and the associated preamplifiers, cables and power supplies were linear well above 150 db when only the diaphragms of the microphones were subjected to the high intensity sound. These high intensities were produced in our laboratory in a closed system called a standing-wave tube.

The standing-wave tube, having a length of six inches, was driven by a Western Electric 722-A Receiver and was terminated by the condenser microphone. The combination of the 722-A driver and the standing-wave tube limited the frequency range and frequencies that could be used. The

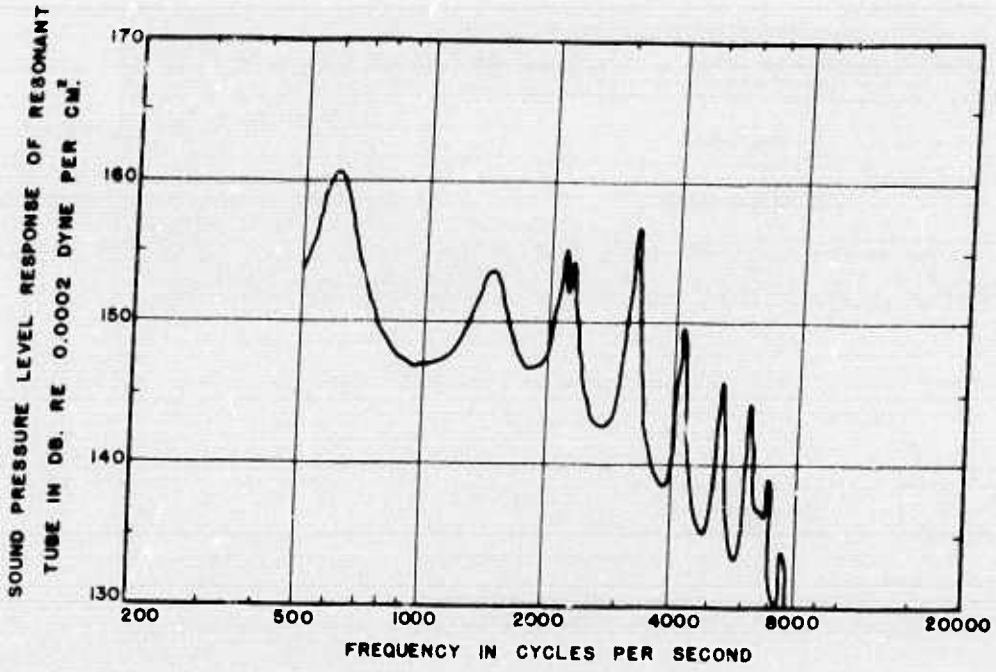


FIGURE 3.6 - Frequency response of the resonant tube and driver used to make linearity measurements on high-intensity microphone systems.

first quarter-wave-length resonance of the standing-wave tube, 590 cps, determined the lowest frequency, and measurements were made at succeeding tube reasonances. Distortion in the driver at the 4050 cps resonance fixed the upper frequency limit.

The maximum sound pressure that could be obtained at a given resonant frequency was determined by the relative height of the resonant peaks in the response of the standing-wave tube. The response of the driver-resonant tube combination is shown in Figure 3.6. Measurements such as those in the standing-wave tube are not sufficient, however, to ensure reliable operation of the entire microphone system in the field. Consequently, several field trips were made to installations operated by the McDonnell Aircraft Corporation in St. Louis, Missouri, to make comparison calibrations in the vicinity of operating jet engines.

The output of an Altec 21BR-180 modified with the acoustic shield of Figure 3.7, was compared at McDonnell with the other microphone systems as received from the manufacturers. The modified Altec system was designated as the "standard" or reliable system because: (1) it was designed specifically for the measurement of high intensity noise; and (2) the acoustic shield protected all of the microphone and preamplifier, except the microphone diaphragm, from the high-intensity noise.

Some of the data from these field trips are shown in Figures 3.8 and

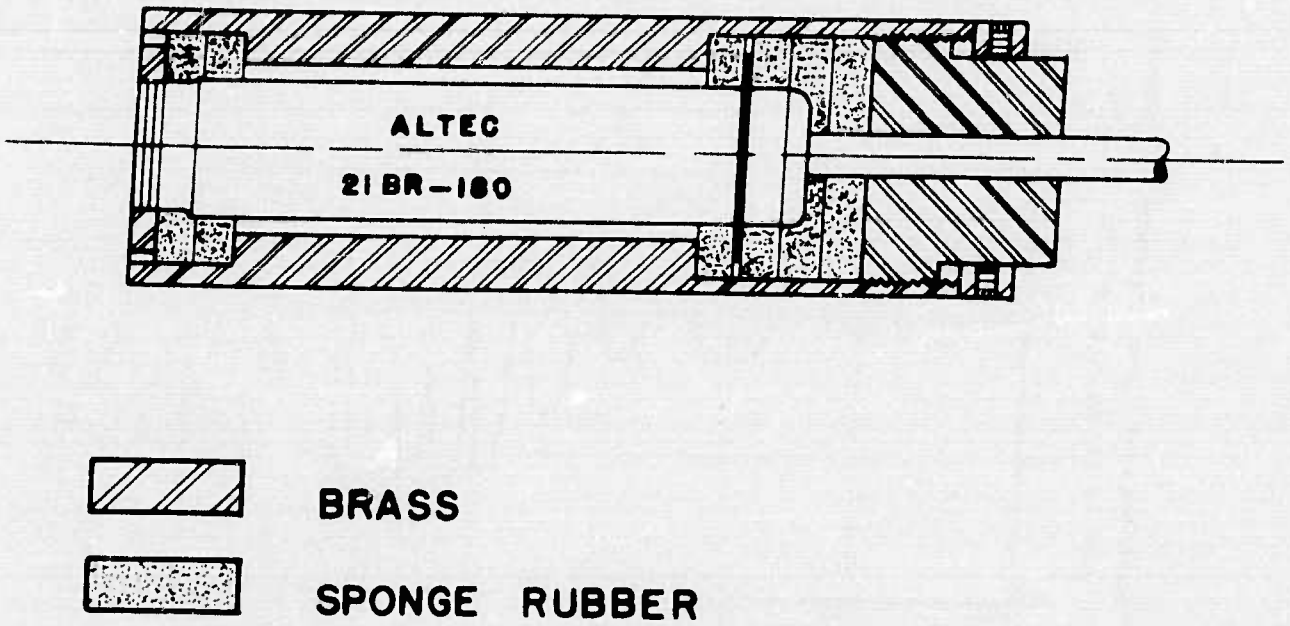


FIGURE 3.7 - Acoustic shield for Altec 21BR microphone and 165-A base.

3.9. Figure 3.8 shows the microphonic output of the Atlec 165-A base equipped with a dummy microphone. The microphonics in the 75-150, 150-300, and 300-600 cps bands were also investigated, but the output in these bands did not exceed the background noise of the measurement system and hence are not included in the graph.

Measurement problems caused a small uncertainty in the absolute sound pressure level of the data reported in Figure 3.9. Therefore, the difference between the standard and comparison microphones are only on a relative basis. The differences were set equal to zero at the lowest common average sound pressure level.

When the high-intensity microphones were used properly, they were reliable, and their outputs had no greater deviation than the measurement errors one would find in almost all acoustical surveys of this type. However, only average sound pressure levels up to 147 decibels were encountered and only six octave bands were analyzed.

The slight deviations discovered may have been a result of non-linear distortion in the comparison microphone (No. 8759) since instantaneous peak levels exceeded 160 db. If the trends of these errors (and they were not the same for all octave bands) were to continue in the same manner at higher levels, they would soon render microphone No. 8759 useless for high-intensity acoustic measurements.

Other possible explanations of the deviations observed are variation of the parameters of the preamplifier tube, fluctuations in the bias on the grid of the preamplifier, and vibration transmitted to the microphone from the preamplifier case. Speculation about the cause of these deviations is hampered, however, by the absence of large differences. Similar measurements made at higher levels would be required to localize the difficulty.

An unusual effect was observed during field trials of one of the micro-

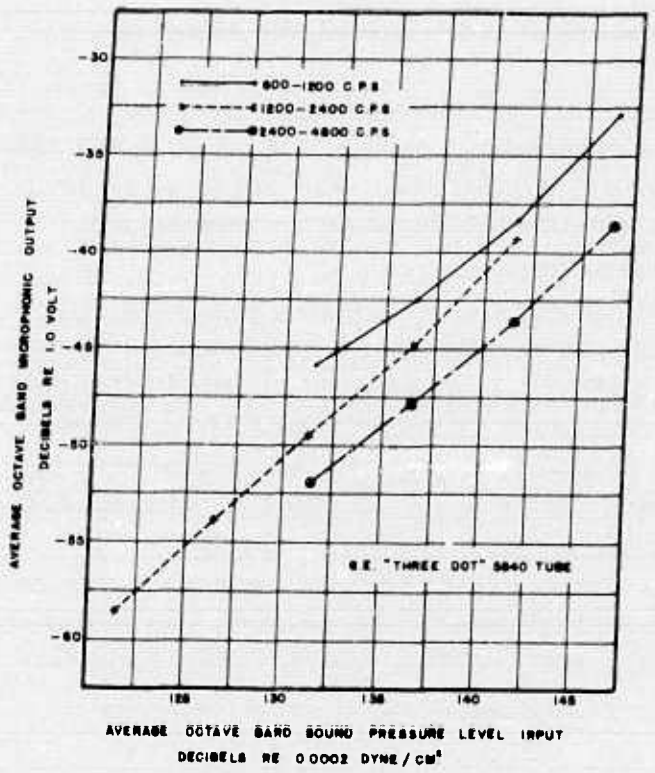


FIGURE 3.8 - Microphonic output of Altec 165-A base subject to acoustical shock.

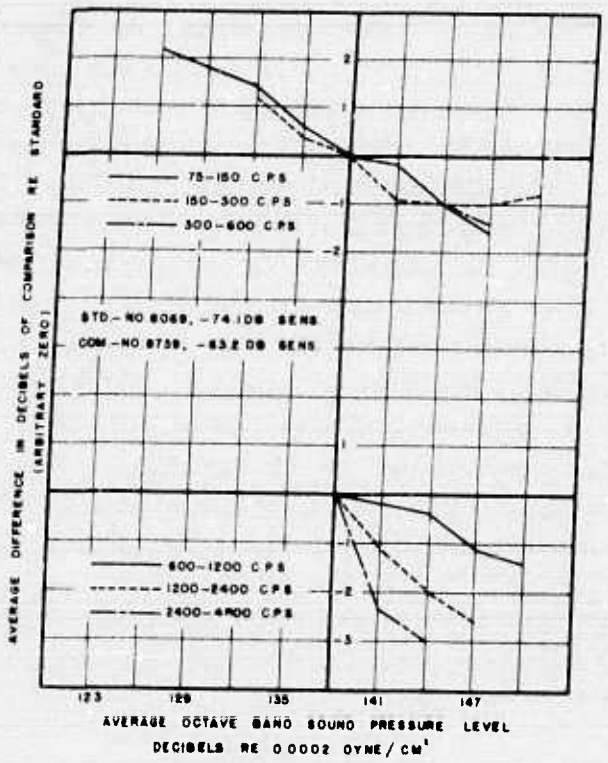


FIGURE 3.9 - Comparison of the output of two Altec 21BR microphones, when subjected to high intensity sound.

phone systems. After an exposure to intense noise, the sensitivity of two new specially made Kellogg microphones improved by up to 5 db. This effect was apparently similar to the change in sensitivity that occurs during the initial aging period of the microphone. The microphones involved had not been in service long enough to have had their calibrations stabilized. The exposure to high-intensity noise apparently hastened the initial aging process since no further change in sensitivity has been observed in spite of additional noise exposure.

2. "Wireless" Microphone System

Laboratory measurements were made to determine the dynamic range of a Jansky and Bailey frequency modulation (FM) receiver and transmitter system. * The results help to evaluate the feasibility of using this system for the measurement of the noise exposure of personnel exposed to jet engine noise.

The linearity of the FM system was first determined by producing a pure tone of known sound pressure at the diaphragm of the microphone on the FM transmitter, and then measuring the distortion in the output of the FM receiver. Hence, any extraneous signals due to microphonic output

* The transmitter is a type RT 54-N subminiature transmitter manufactured by Jansky and Bailey Inc 1339 Wisconsin Avenue, N.W., Washington 7, D.C. The FM receiver is a Jansky and Bailey type RR 55-X

from the case, vacuum tubes, or electronic components of the transmitter were not included in this particular test.

The standing wave tube was again used as a sound source in measuring the ratio of the second harmonic to the fundamental in the output of the FM link. The second harmonic proved to be (1) larger than the other harmonic outputs, and therefore easier to measure, and (2) as good as any other harmonic as an indicator of the total distortion.

The second part of the measurement procedure was to substitute an Altec M-14 system for the FM link, and, using the same condenser microphone and the same receiver inputs as before, to measure again the fundamental and second harmonic outputs. Assuming no distortion in the electrical part of the M-14 system, it was possible to separate the distortion in the receiver and microphone from that introduced by the FM link by comparing the results of the first and second parts of the procedure.

Block diagrams of the instruments and their arrangements in parts one and two of the measurement procedure are shown in Figures 3.10a and 3.10b. The condenser microphone used in both parts was an Altec 21BR-180, No. 8069.

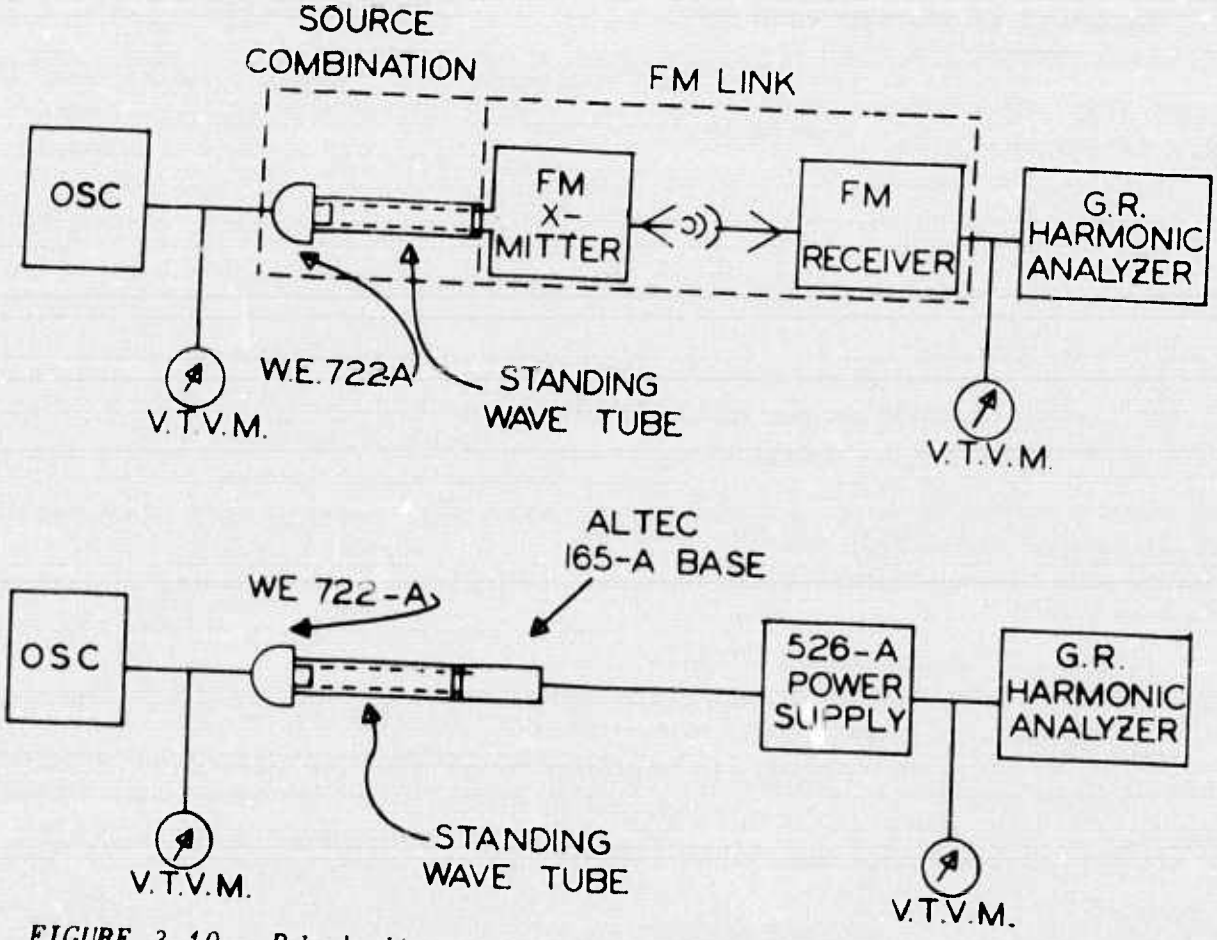


FIGURE 3.10 - Block diagram of the systems used to make linearity measurements on the FM link.

(a) System for determining distortion in the source combination, microphone, and FM link.

(b) System for determining distortion in the source combination and microphone.

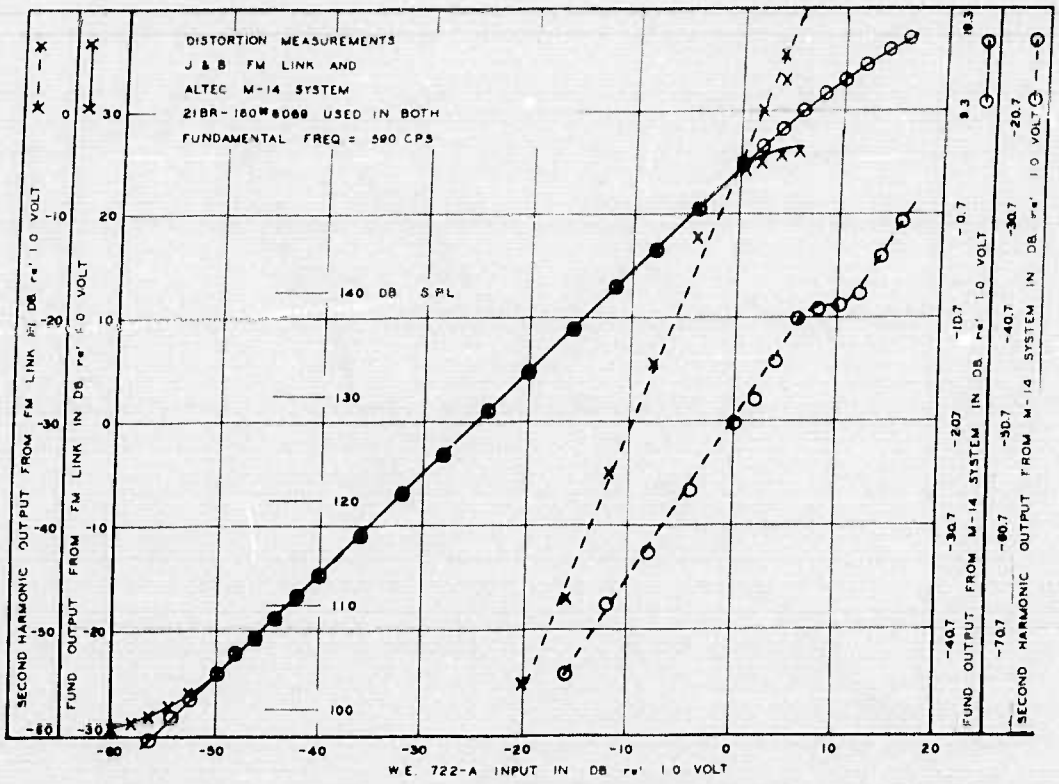


FIGURE 3.11 - Fundamental (590 cps) and second harmonic output of FM link and Altec M-14 system plotted as a function of the driver input.

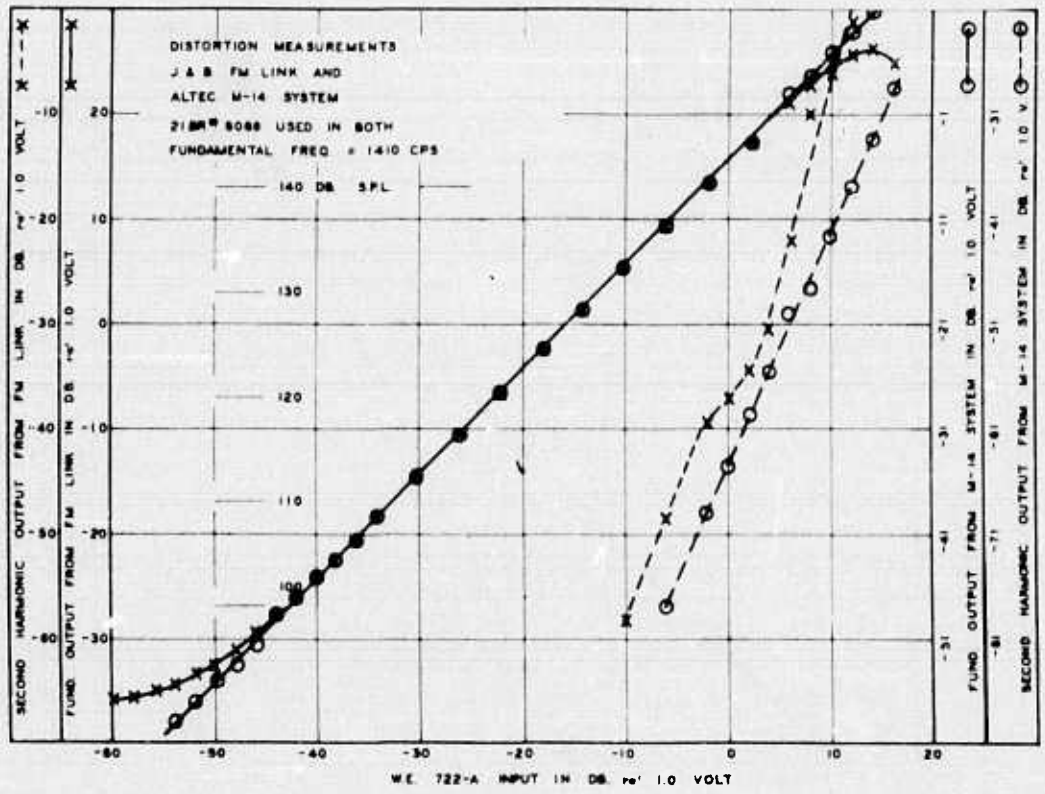


FIGURE 3.12 - Fundamental (1410 cps) and second harmonic output of FM link and Altec M-14 system plotted as a function of the driver input.

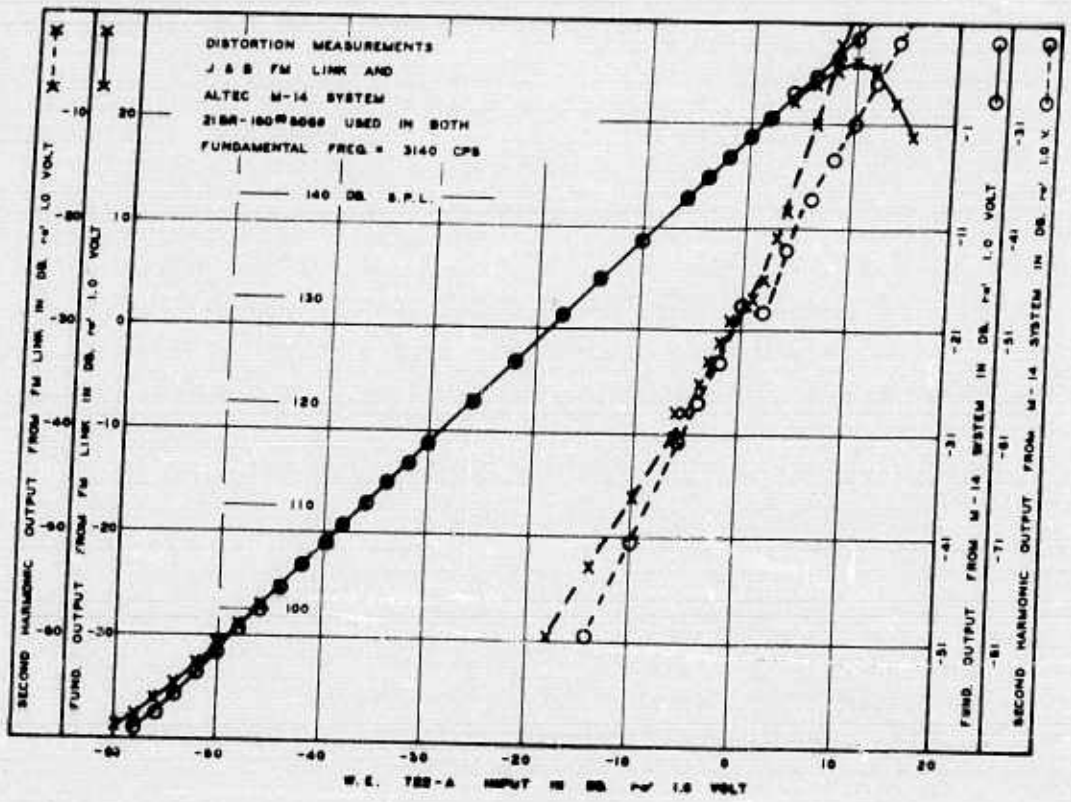


FIGURE 3.13 - Fundamental (1340 cps) and second harmonic output of FM link and Altec M-14 system plotted as a function of the driver input.

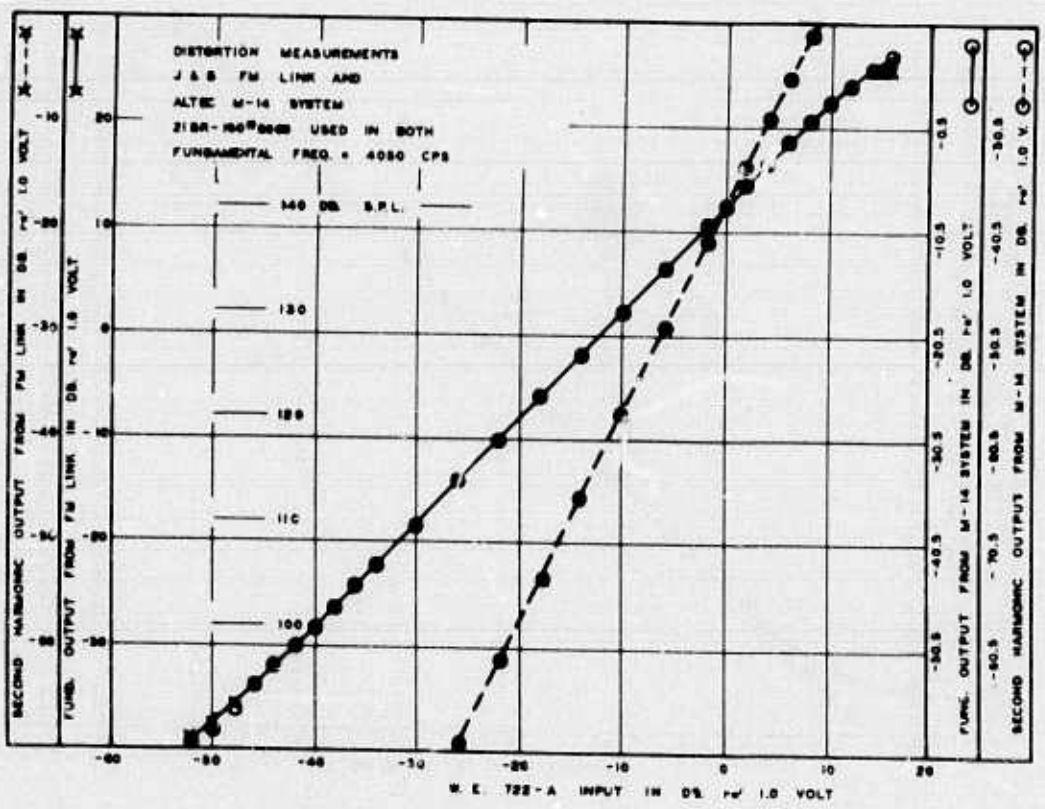


FIGURE 3.14 - Fundamental (4050 cps) and second harmonic output of FM link and Altec M-14 system plotted as a function of the driver input.

The results of the linearity measurements are shown for 590, 1410, 3140, and 4050 cps, respectively, in Figures 3.11, 3.12, 3.13 and 3.14. Notice in Figures 3.11, 3.12 and 3.13 that the distortion in the source combination of driver, resonant tube, and microphone was less than that of the source combination plus the FM link. However, with increased frequency, the difference between the two decreased, except at 4050 cps, where the distortion in each was equal. Hence, at 4050 cps, there was less distortion in the FM link than the source combination.

Figures 3.11, 3.12, 3.13 and 3.14 indicate that the FM link performed linearly over a 50 db range at 590, 1410, 3140, and 4050 cps. This range was independent of the frequencies used, and its limits were approximately 100 db to 150 db sound pressure level input when using a microphone whose sensitivity in the frequency range of interest was -74.1 db re 1 volt/dyne/cm^2.

The upper limit of 154 db sound pressure level is shown in Appendix 3.1 to be determined by the 150 kc intermediate frequency bandwidth of the FM receiver. An analysis of non-linearities resulting from the basic physical laws governing a condenser microphone was applied to the microphones and it was determined that the effects of such non-linearities were very small for the microphones and sound pressures under consideration.(3.2)

In order to be sure that the sensitivity of the FM link was the same at frequencies other than those used to measure the linear dynamic range, the frequency response shown in Figure 3.15 was measured. The acoustic source was an Altec 12185 Acoustic Calibrator.

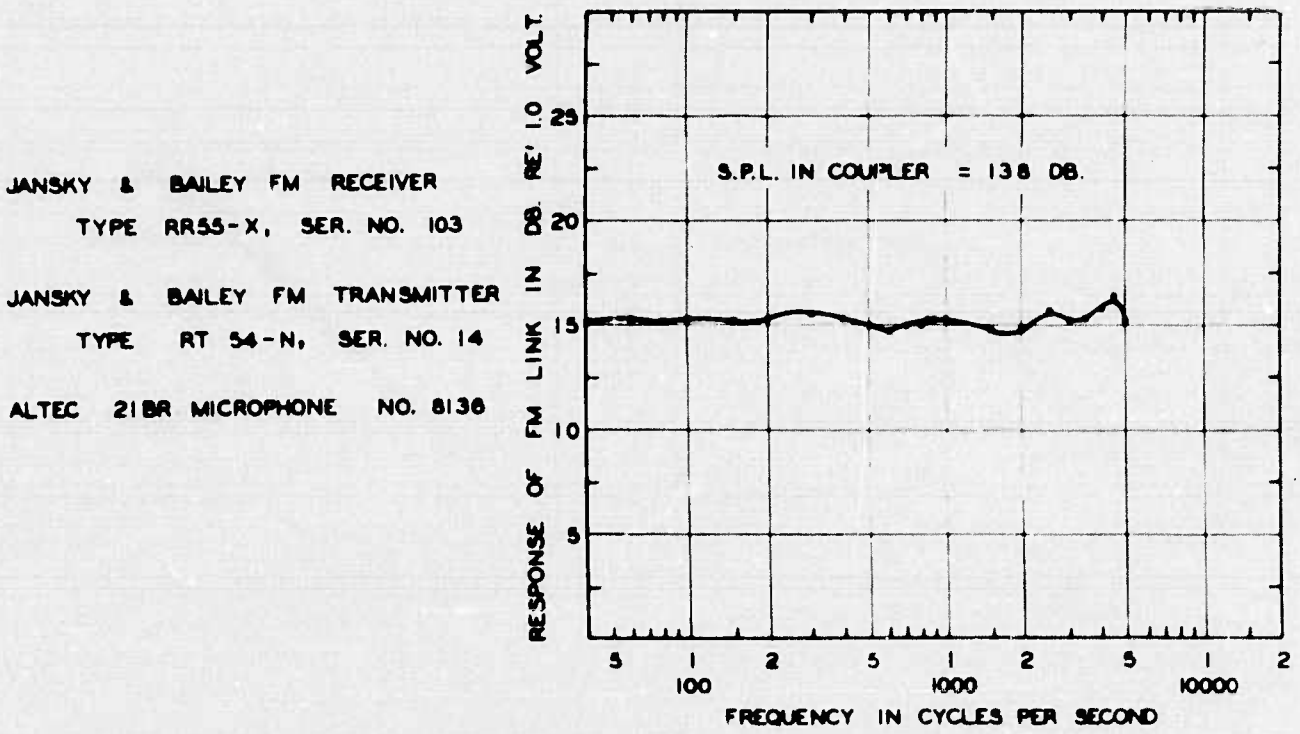


FIGURE 3.15 - Frequency response of complete FM link with a sound pressure level of 138 db at the microphone.

3.2 Cox, J.R., Nonlinear analysis of the condenser microphone, Quarterly Progress Report, Acoustics Laboratory, MIT, October - December 1951, 3-4.

Field measurements were made at the McDonnell Aircraft Corporation, to determine the dynamic range of the FM link while the entire transmitter was immersed in an intense sound field. The output of the FM link was compared with the output of the "standard" M-14 system, which by previous measurements had been proved reliable. The microphone used on the FM transmitter during the field measurements was an Altec 21BR-180, No. 8136 which is 0.5 db less sensitive (sensitivity at 1 kc: -74.6 db re 1.0 volt/dyne/cm^2) than microphone No. 8069 used on the "standard" M-14 system during this comparison and previously for the laboratory measurement on the FM link. The rms sound pressure level, which in the laboratory determined the upper limit of the FM link, was 153.9 db when using No. 8069. Thus, for equal performance of the transmitter in the field, the sound pressure level of a pure tone, which determines the upper limit of the FM link, should be an rms sound pressure level of 154.4 db.

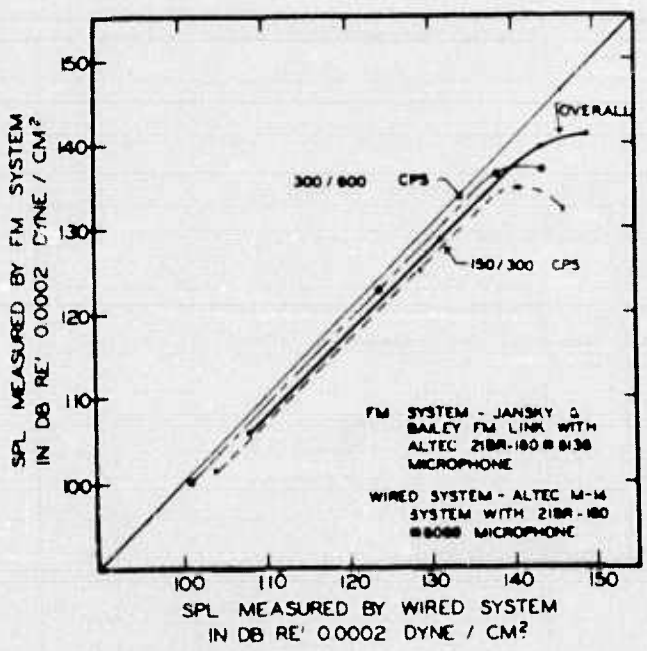


FIGURE 3.16 - Linearity measurements of the FM link obtained with the entire transmitter in the sound field: 150-300, 300-600 cps, and overall.

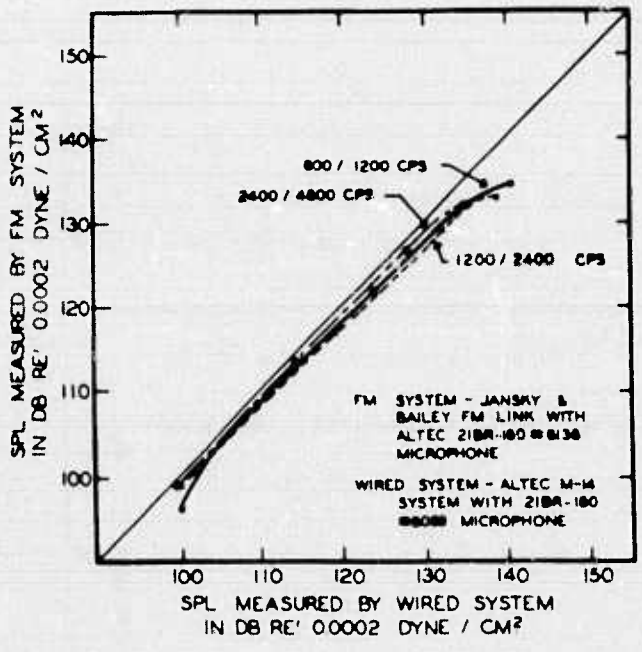


FIGURE 3.17 - Linearity measurements of the FM link obtained with the entire transmitter in the sound field: 600-1200, 1200-1400 and 2400-4800 cps.

Figures 3.16 and 3.17 show the results of the field measurements. There is a small constant error between laboratory and field measurements which may be the result of a rather imprecise field calibration and therefore can be neglected. The upper limit of the FM link is equivalent to an rms sound pressure level of 144 db measured by the "standard" microphone system. The difference between the peak-to-rms ratio of wide band jet noise and the pure tone used in the laboratory is about 8 db. Therefore, the predicted overload level for wide band jet noise is an rms sound pressure level of about 146 db. The close agreement between the measured and predicted overload indicates that the FM link operated satisfactorily below the overload point. For the individual octave bands, the overload point occurs at a lower band level because the FM system must transmit the entire wide band noise and limiting should be expected in each band whenever the overall exceeds 144 db. The overload characteristic is less sharp for the noise than for the tone because an occasional peak of the noise may be clipped at comparatively low rms levels whereas the onset of the clipping of a pure tone is quite abrupt.

Modification of Tape Recorders

Several modifications of the magnetic tape recorders (two Model PT6-J Magnecorders) were necessary before the latter were useful for recording jet engine noise. First, the continuously variable gain control potentiometer was replaced by an equivalent having discrete 5 db steps. This allows the recording level to be changed by a definite amount. The comparatively large 5 db steps provide the added feature that any change will always be noticed when the tape is played back.

The second modification of the tape recorder (Figure 3.18) was the addition of overload indicators like those used by Kamoerman.[3.3] An indicator of this type had to be used since the standard V.U. meter responds to the mean value of the rectified signal and therefore is not adequate for signals that have a high peak to rms ratio. The overload indicators respond to peak signal voltage. They are Raytheon cold-cathode thyratrons that act both as a triggering device and glow lamp. The thyratron fires and stays lit when the recorder is overloaded. Reset buttons mounted near the thyratron can be pushed to extinguish the glow.

Construction of the Cumulator

An instrument called the "Cumulator" was designed and built to display the cumulative distribution of exposure levels shown in Figure 3.4. All three channels of the Cumulator are shown in block form in Figure 3.3, and one channel is shown in greater detail in Figure 3.19. (Appendix 3.2 gives complete circuit details).

The filter on the input to the Cumulator is a standard passive filter

3.3 Kamperman, G.W., Instrumentation for acoustical evaluation of jet engine test cells WADC Tech Report 55-115, April, 1955.

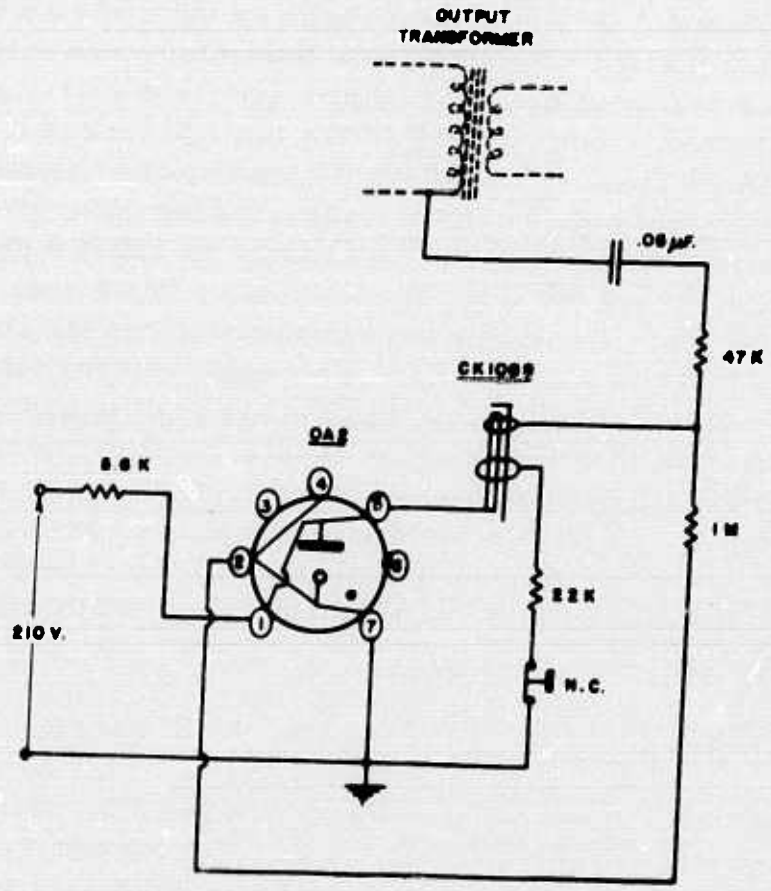


FIGURE 3.18 - Overload indicator for magnetic tape recorders.

with an 18 db per octave cut-off characteristic. An amplifier is necessary following this filter in order to provide the fixed minimum signal necessary to fire the gas tube. The amplifier was designed to have a voltage gain of approximately 40 db. In addition, it was made non-blocking. This feature assures that the amplifier will return to its normal operating condition within 0.1 second after the removal of any signal up to 30 db above the overload point.

The three pole, four position, non-shorting switch (S_{1A}, S_{1B}, S_{1C} in Figure 3.19) provides that each of the four capacitors be alternately (1) charged through the diode and resistor R; (2) presented to the cathode follower; and (3) shorted twice to neutralize the charge. Shorting the capacitors twice guarantess that the dynamic range of the Cumulator will not be limited by incomplete discharge of the capacitors as a result of "soakage" (see Appendix 3.2). By means of a motor-driven, spring-loaded gear arrangement, the switch is stepped to the next position once each second. This 1 second interval between steps (or "sampling time") was determined by a limitation imposed by the clocks.

The capacitors in Figure 3.19 are charged through the series-connected, silicon-junction diode and resistor. By proper choice of the RC combination, the charge on the capacitor after a 1 second interval can be made to be an indication of (1) the maximum value of the individual peak values of the input signal, or (2) the average value of the input signal. The

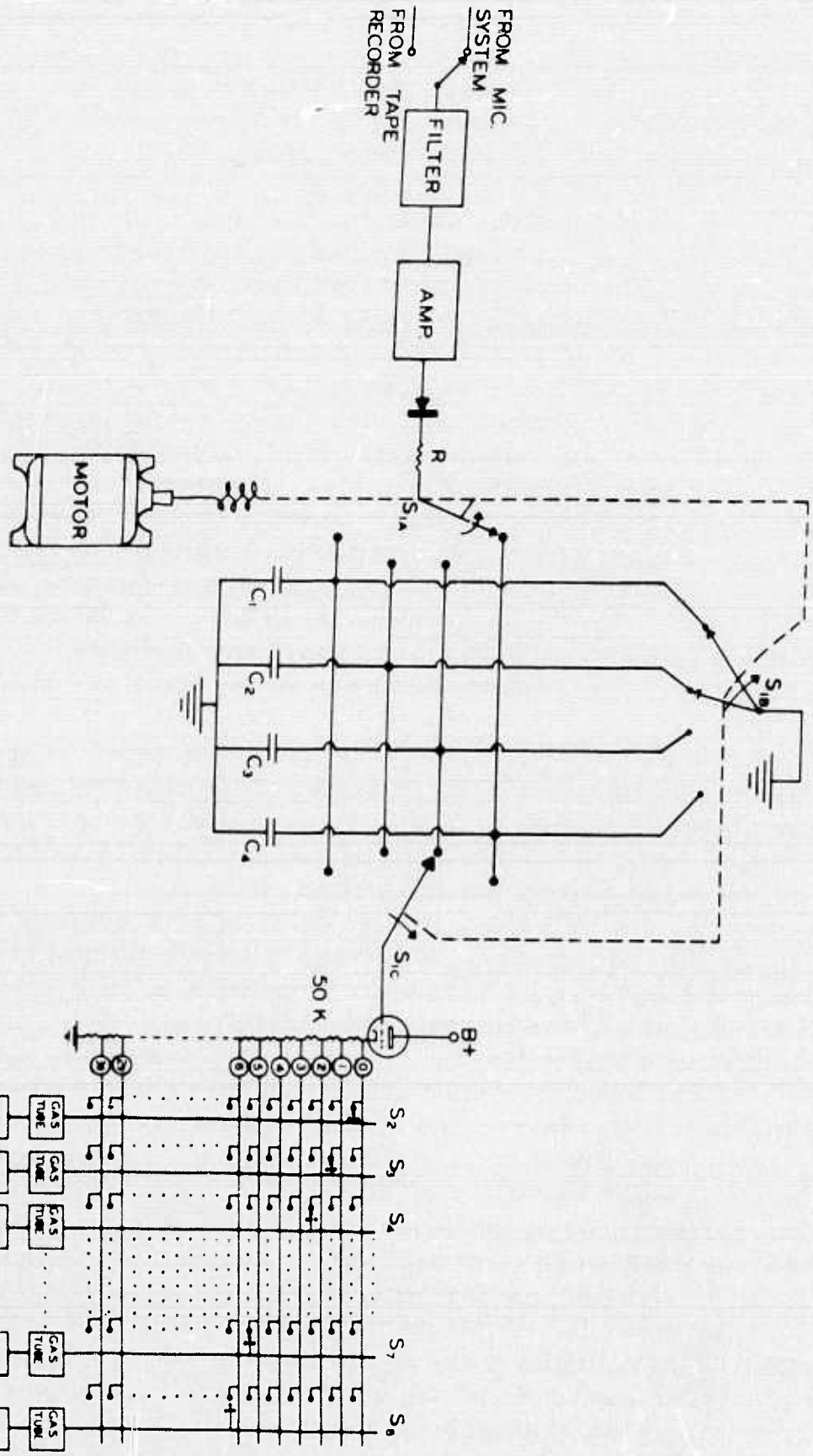


FIGURE 3.19 - Simplified electrical schematic diagram of one channel of the Cumulator.

decision to indicate the peak value was made primarily because it was electronically more simple. There does not seem to be at this time, however, any significant evidence that hearing loss correlates better with the average value than with the peak value of the sound pressure. If after some practical experience with the Cumulator this decision proves to be incorrect, the circuit should be modified.

The final voltage to which the capacitor charges at the end of a 1 second period is presented to the gas tube. If this voltage is large enough the gas tube will fire, causing the relay to close and the clock to run. Direct connection of the capacitor to the low impedance potentiometer at the input of the gas tube would cause the capacitor to discharge appreciably during the 1 second interval. Therefore, a cathode follower with very high input impedance and low output impedance was inserted between the capacitor and gas tube. The output of the cathode follower is across a 50,000 ohm resistor, tapped in 1 db intervals with 30 db total. However, only those taps were used that were necessary for SPL intervals of 1, 2, 4 and 5 db (see Appendix 3.2 and Figure 3.32). The switching arrangement following this resistor (S_2 through S_8) provides that the input of any gas tube can be placed on any of these taps. The 30 db dynamic range of one of the three channels can be increased to 60 db with a second tapped resistor and a second amplifier. Provision is made for this addition in the other two channels later as required.

The gas tubes (2D21 thyratrons) were used because of the good on-off characteristics necessary for relay service. Data supplied by the manufacturer specifies an ionizing time of 0.5 μsec. and a deionizing time of 55 μsec. Hence, the error introduced by the gas tubes is small compared to that which is introduced by the relays and clocks.

The relays have a 0.05 sec. average delay in both opening and closing, hence the average error is zero. However, it was found that the variations in this error were as much as 0.05 sec. Nonetheless, this error was still small compared to the error introduced by the clocks.

The clocks, sold by the Haydon Manufacturing Company, consist of a Haydon motor geared to a five-digit counter which is manufactured by Veeder-Root, Inc. The clocks read in tenths of minutes up to 9999.9 min. Exhaustive tests were made on 21 of the clocks, and the average start-stop error for all the clocks was 0.1 sec.

This start-stop error (a function of the "warm-up" time of the clocks) was different for each clock, and was neither constant nor predictable for any one clock. The maximum deviation of the average error for any clock from the average error for all clocks was also 0.1 sec. per start-stop. Consequently, in the Cumulator the sampling time of 1.0 sec. (e.g. a stepping rate for the switch S_1 of one position per second) ensured that the clocks, if turned on, would remain on for at least 1.0 second. The system error of the Cumulator is therefore limited to 10%. Counters could not conveniently be substituted for the clocks because the current required to step 21 counters simultaneously is prohibitively large. Even the clocks, which have small current requirements, produce a small interaction when

all but a few go off at once. Fortunately, this happens very infrequently.

FIELD TRIAL OF PROTOTYPE SYSTEM FOR THE MEASUREMENT OF NOISE EXPOSURE

A field trial of one channel of the system described in the previous section was carried out aboard the USS FORRESTAL in March, 1956. The prototype Cumulator was fed by a small Jansky and Bailey FM transmitter (type RT-54N) that was carried about the deck of the carrier. The weight of the complete unit is less than a pound and the size is similar to two king-size packs of cigarettes. The transmitter is tunable over a range of 10 megacycles which may be centered anywhere between 150 and 170 megacycles. The transmitter is modulated by sound pressure variations using an Altec 21BR high-intensity condenser microphone. It can transmit without difficulty up to several hundred feet, providing there are no significant obstructions in the path. We found that it is necessary to use this or some similar wireless system in monitoring the noise exposure of carrier personnel. The difficulty of moving wires about the deck during air operations rules out any other system that monitors directly the noise exposure of flight deck personnel. Indirect monitoring is not possible because of the variability of the sound pattern produced by jet aircraft on the flight deck.

The RT-54N FM transmitter worked satisfactorily in the field trials. Certain difficulties were encountered as a result of loose connections between the battery container and the transmitter. These difficulties can be overcome with a more rugged design of the transmitter. The frequency selected for operation of the transmitter did not interfere with other communications on board the carrier. The receiving antenna was placed on the catwalk adjacent to the starboard catapult. At this location, no difficulty was experienced in receiving signals from anywhere on the flight deck forward of the island. Figure 3.20 shows a typical record of the over-all sound pressure measured near the forward plane director during a typical launch of a jet aircraft.

Trials were conducted in which the prototype Cumulator was operated directly by the output of the FM receiver. These trials were compared with trials using a magnetic type link between the output of the receiver and the input to the Cumulator. It was found that the results of the "live" and the recorded trials were within the inherent variability of the Cumulator. Therefore, it is clear that tape recordings can be taken in the field and later analyzed. This procedure will be more convenient when portability of the measuring equipment is important. The technique of recording the noise exposure on tape also makes it possible to record more than one noise exposure at a time. Multiple noise exposure measurements recorded on tape may be analyzed later with one Cumulator. In addition, temporary failure of the Cumulator is not serious if the record of the noise exposure can be replayed.

The primary goal of field trials of the prototype Cumulator and FM

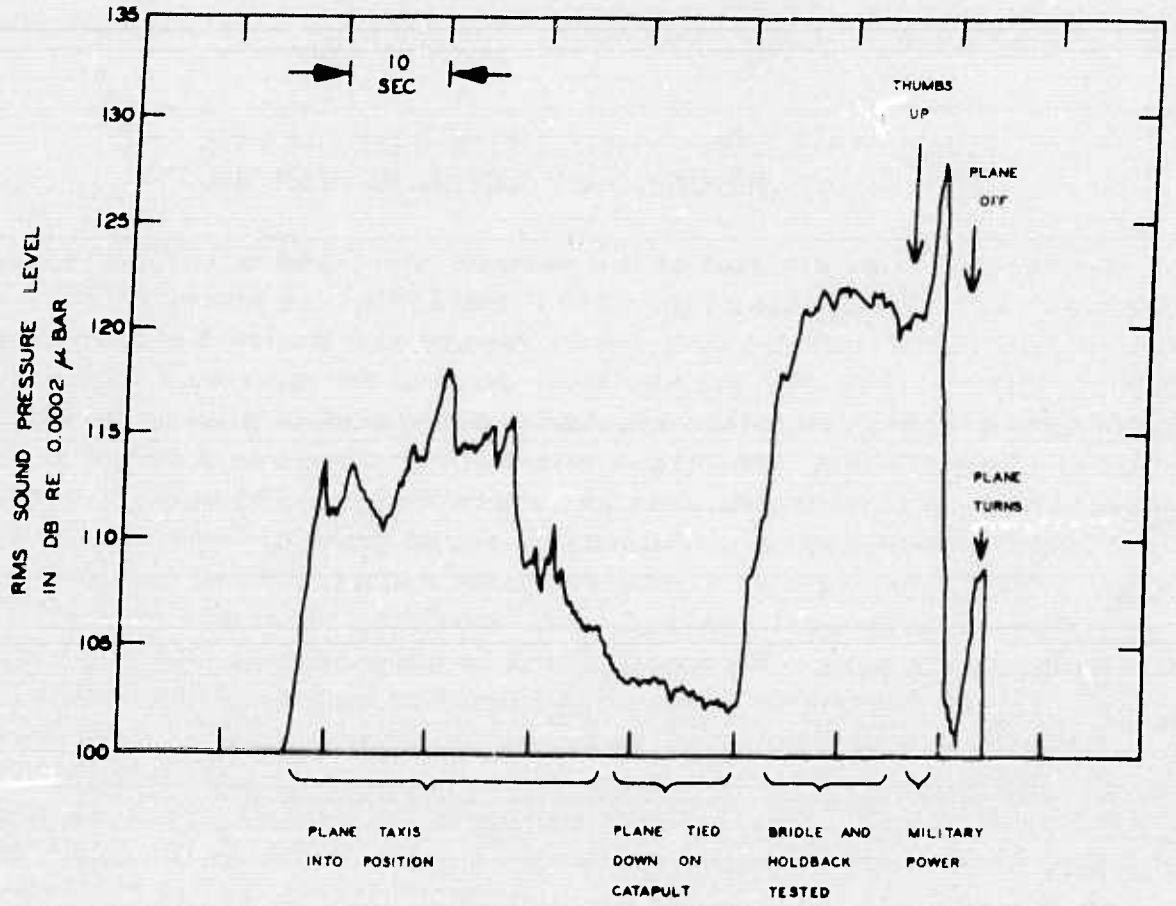


FIGURE 3.20 - Typical record of the over-all sound pressure level of a jet aircraft launch measured near the forward plane director. Record shows over-all RMS sound pressure level.

transmitter was to demonstrate the practicality of the method. A man carrying the transmitter shadowed closely several members of the flight deck crew. A few distributions of over-all intensity versus exposure time were obtained in this manner and are plotted in Figure 3.21. One curve is for the member of the catapult crew who attaches the holdback to the aircraft and another for the forward plane director (Director No. 1). For comparision, the exposure of the men stationed along the catwalk during the take-off of propeller-driven planes is also shown. The ordinate shows the sound pressure level of the peaks of the noise exposure received. The abscissa gives the average time that this exposure occurs during one launch. This average is computed by dividing the total exposure time during a period by the total number of planes launched from both catapults. Thus the catapult crews receive only severe exposures from about half the launches.

The data show that the exposure to very high-intensity noise is extremely brief. The most seriously exposed men on the flight deck (the forward plane director and the holdback man) experience peak levels in excess of 138 db for only about 3 seconds per launch. As many as 100 launches in a day would produce less than 5 minutes total exposure to such levels. Even exposure to peak levels above 113 db would total less than 1 1/2 hours daily.

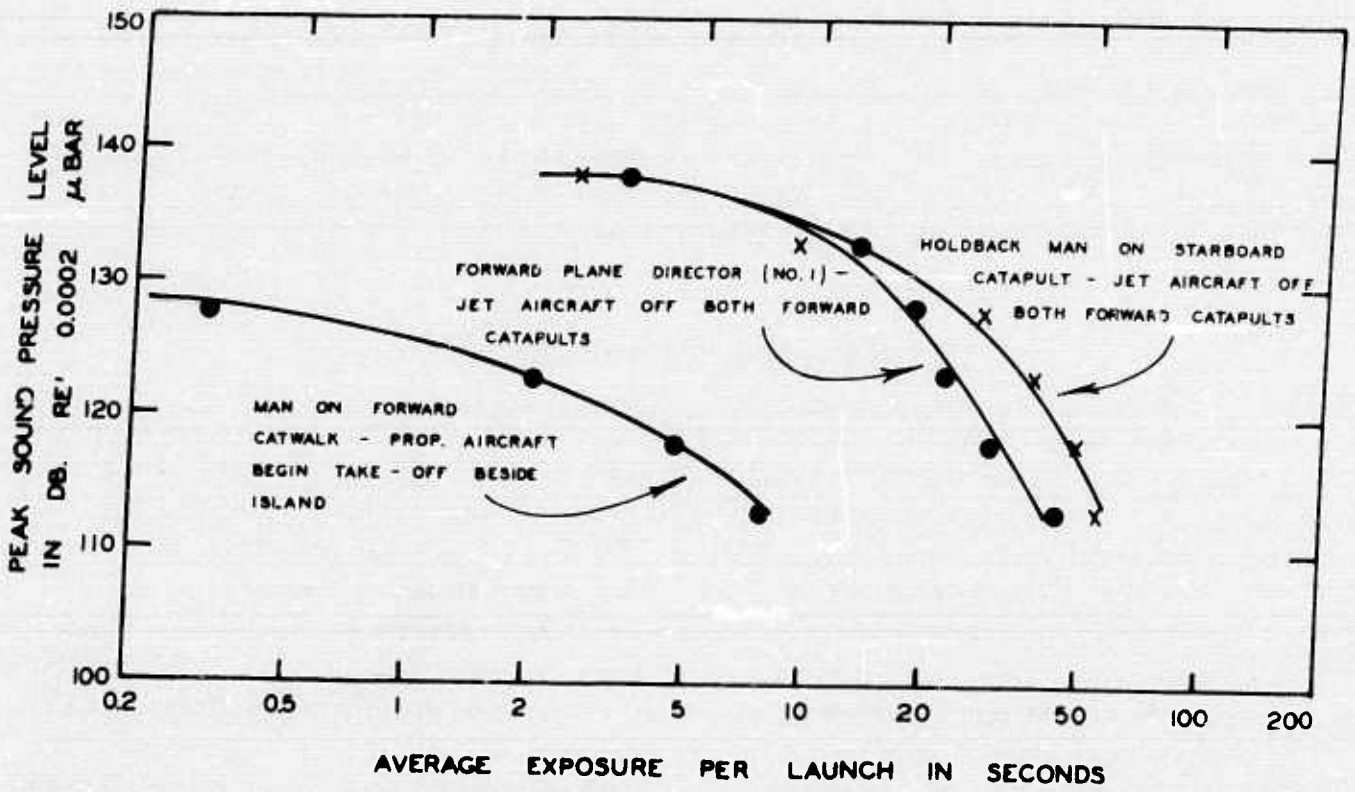


FIGURE 3.21 - Over-all noise exposure of several flight-deck personnel. The data are from the ''Cumulator'' and therefore represent peak levels which are about 11 db greater than RMS level for jet noise. Data from several launches are combined to obtain the average exposure time per launch

This exposure to noise is significantly less than had been asumed in consideration of the possible hazards associated with noise exposure aboard aircraft carriers. The brevity and infrequency of exposure to extremely high noise levels has a very important effect on the noise exposure. This effect can be demonstrated by estimates of the equivalent steady exposure experienced by a few members of the flight deck crew. The "equivalent exposure"[3.4] is the level of steady noise sustained throughout an 8-hour day that would deliver the same total sound energy to the ear as does the actual noise exposure. An average daily launching of about 40 jet aircraft is assumed. The exact number launched is not critical since a change in this number by 50% is no greater than the probable error of $\pm$1.5 db in the noise measurements. The equivalent over-all exposure level is shown below for the two men studied in detail:

	Over-all Equivalent rms SPL
Forward plane director - jet aircraft	105 db
Holdback man - jet aircraft	105 db

(NOTE: the equivalent exposure level is in terms of the root mean

3.4 Eldred, K.M., Gannon, W.J., and von Gierke, H.E., Criteria for short term exposure of personnel to high intensity jet aircraft noise. WADC Tech Note 55-355, September, 1955.

square (rms) sound pressure level (SPL) re 0.0002 microbar. For jet engine noise studied the rms value is about 10 db less than the peak level.)

The estimates given above hold only for exposures to the particular combination of planes aboard the USS FORRESTAL during March, 1956. They assume that afterburners are not employed.

OTHER NOISE MEASUREMENTS

In connection with the trails of the Cumulator system, measurements were made of the maximum sound pressure level found in the sound field to the rear of several jet aircraft. At the time of our measurements, the jet aircraft aboard were the FJ-3, F7U-3, F2H-3, F2H-2P (acoustically similar to the F2H-3) and AJ-2. The maximum sound pressure levels measured near the first four aircraft were approximately the same. The AJ-2, however, produced significantly less noise. The F7U-3 is equipped with afterburners but they were not used while the sound measuring team was aboard the USS FORRESTAL. Figures 3.22, 3.23 and 3.24 show the measured overall sound pressure levels observed in a number of positions behind the aircraft. (Figure 3.25 shows the exact measurement locations on the carrier deck.) These data are compared in the figures with data taken from land-based measurements. Note that the deviations are fairly small in all cases, indicating that the static sound field on the flight deck can be predicted satisfactorily from measurements made on land. Note also that the highest sound pressure level measured on board the USS FORRESTAL was 144 db. This measurement was taken 40 feet from the tail and 30 degrees from the axis of the jet blast behind the FJ-3 airplane.

The spectra of the sound measured from these aircraft is quite similar to the spectra measured on land (Figure 3.26).

Measurements were made of some newer aircraft, the F3H and the F4D, during carrier trails aboard the USS TICONDEROGA in September, 1955. Because of the heat and fumes, measurements were not obtained as close to the aircraft as was done on the USS FORRESTAL. These measurements are reported in Figures 3.27 and 3.28. Note that a sound pressure level of 152 db was obtained at a distance of 45 feet and at an angle of 45 degrees from the jet behind an F3H operating with afterburner. Very nearly the same results were obtained on the F4D. This is not surprising since the power plants of these two aircraft are the same. It appears that the sound pressure level produced by these new aircraft will be nearly 10 db higher than the sound pressure level measured at corresponding locations aboard the USS FORRESTAL.

Of course, the measurements of maximum sound pressure level yield little information about the noise exposure of personnel on the flight deck. They only set the limit of the highest noise level encountered. No one is normally exposed to the maximum sound pressure level for more than an instant as the plane passes by during a launch.

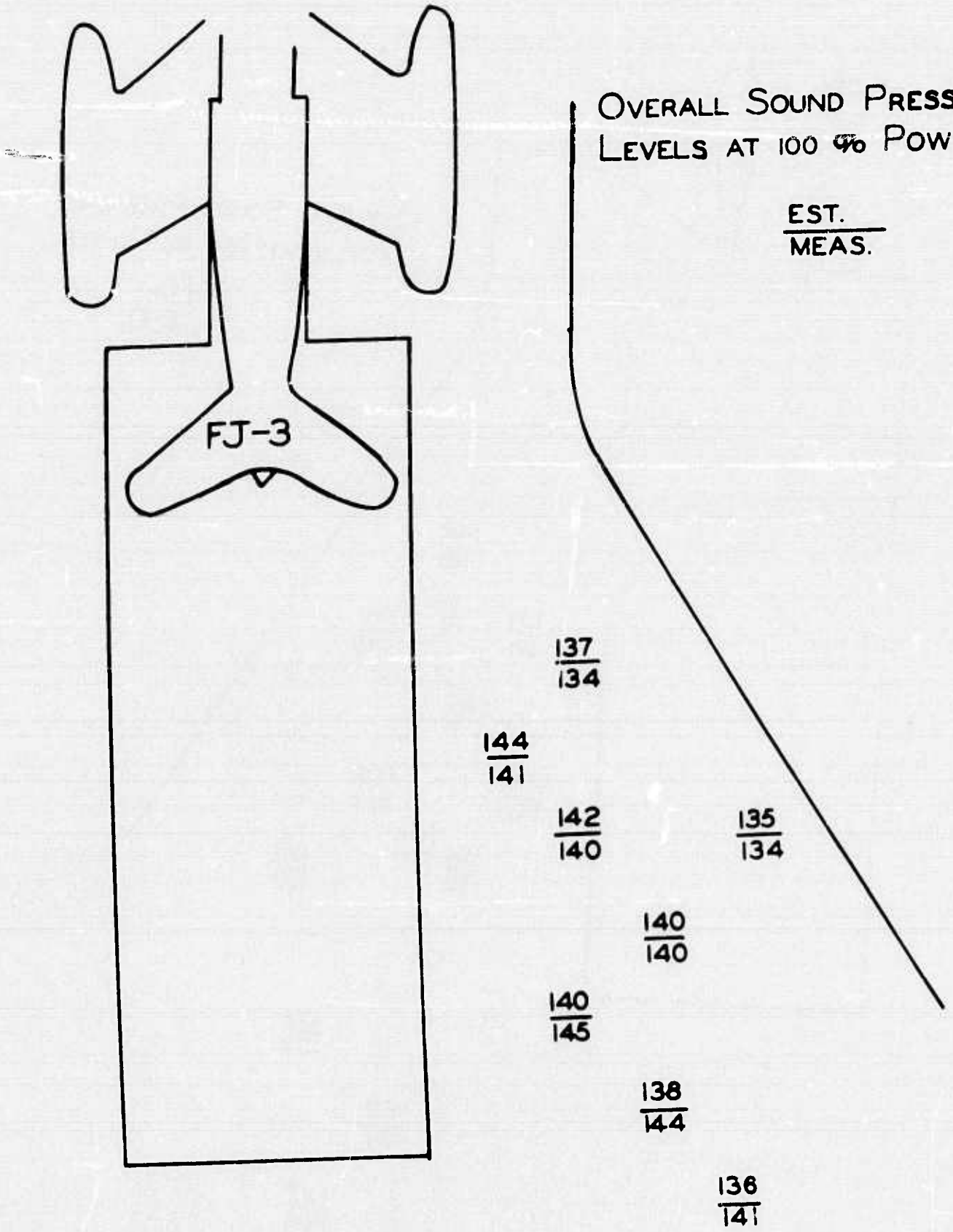


FIGURE 3.22 - Over-all sound pressure levels of an FJ-3 jet airplane measured aboard the USS FORRESTAL.

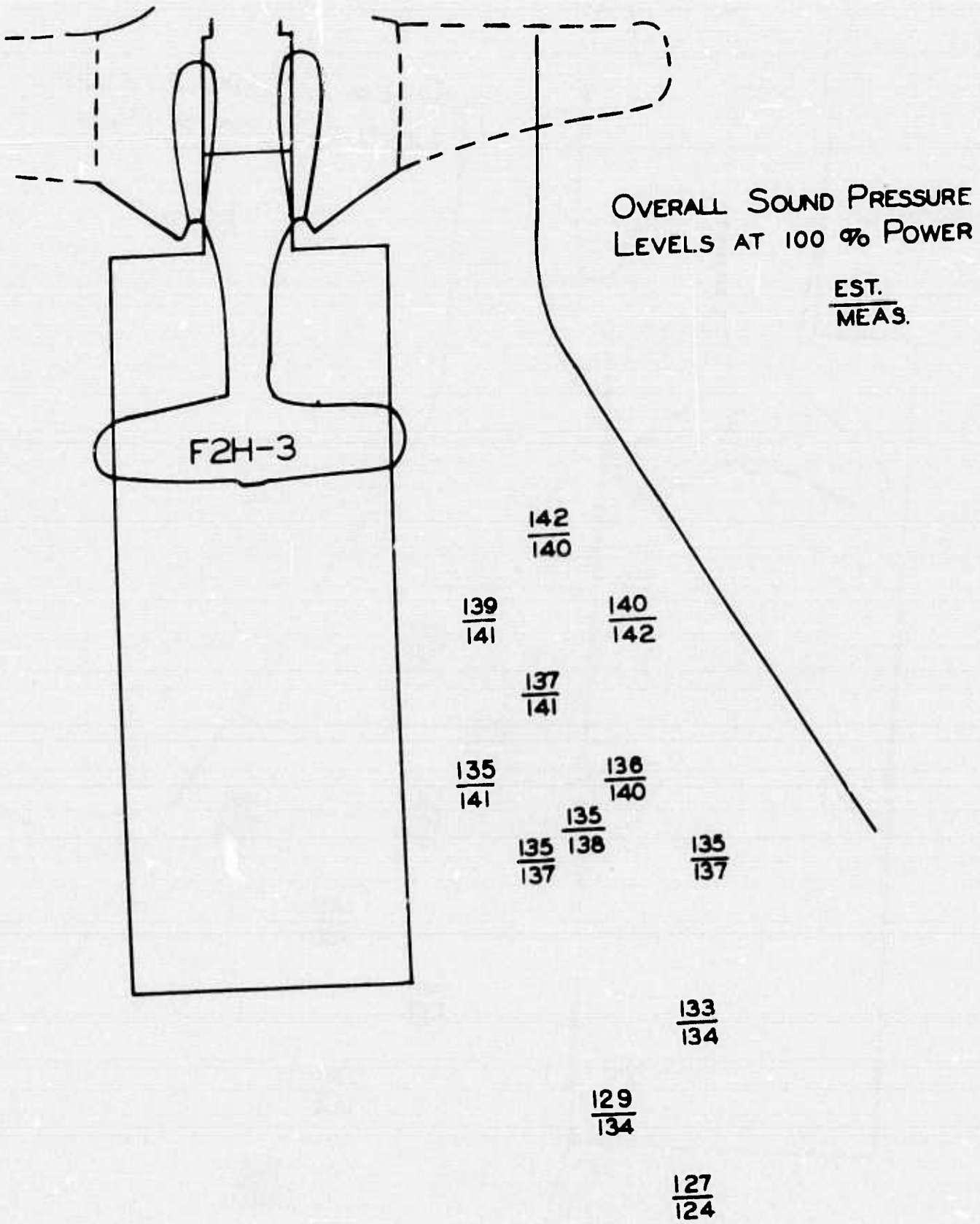


FIGURE 3.23 - Over-all sound pressure levels of an F2H-3 jet airplane measured aboard the USS FORRESTAL.

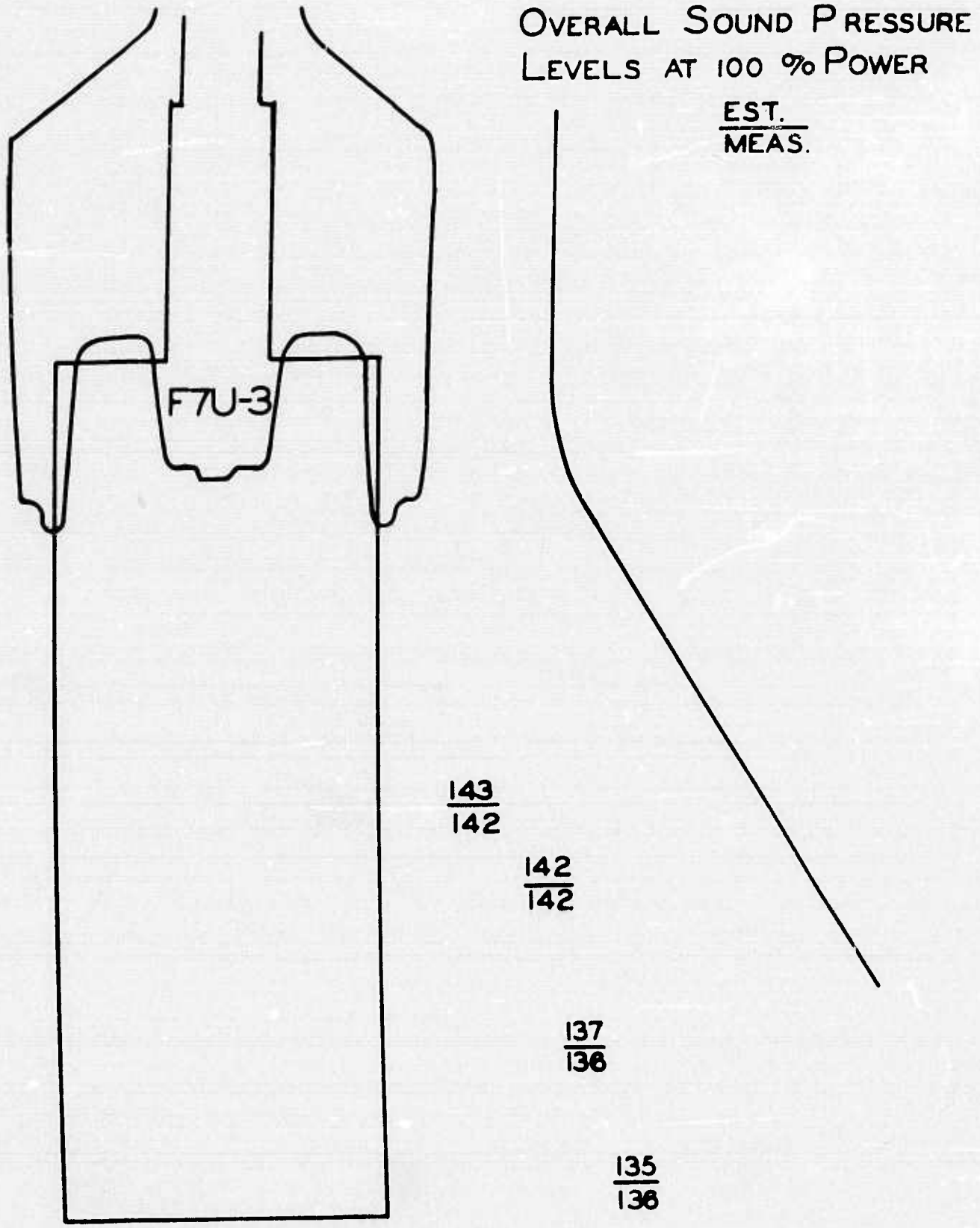


FIGURE 3.24 - Over-all sound pressure levels of an F7U-3 jet airplane measured aboard the USS FORRESTAL.

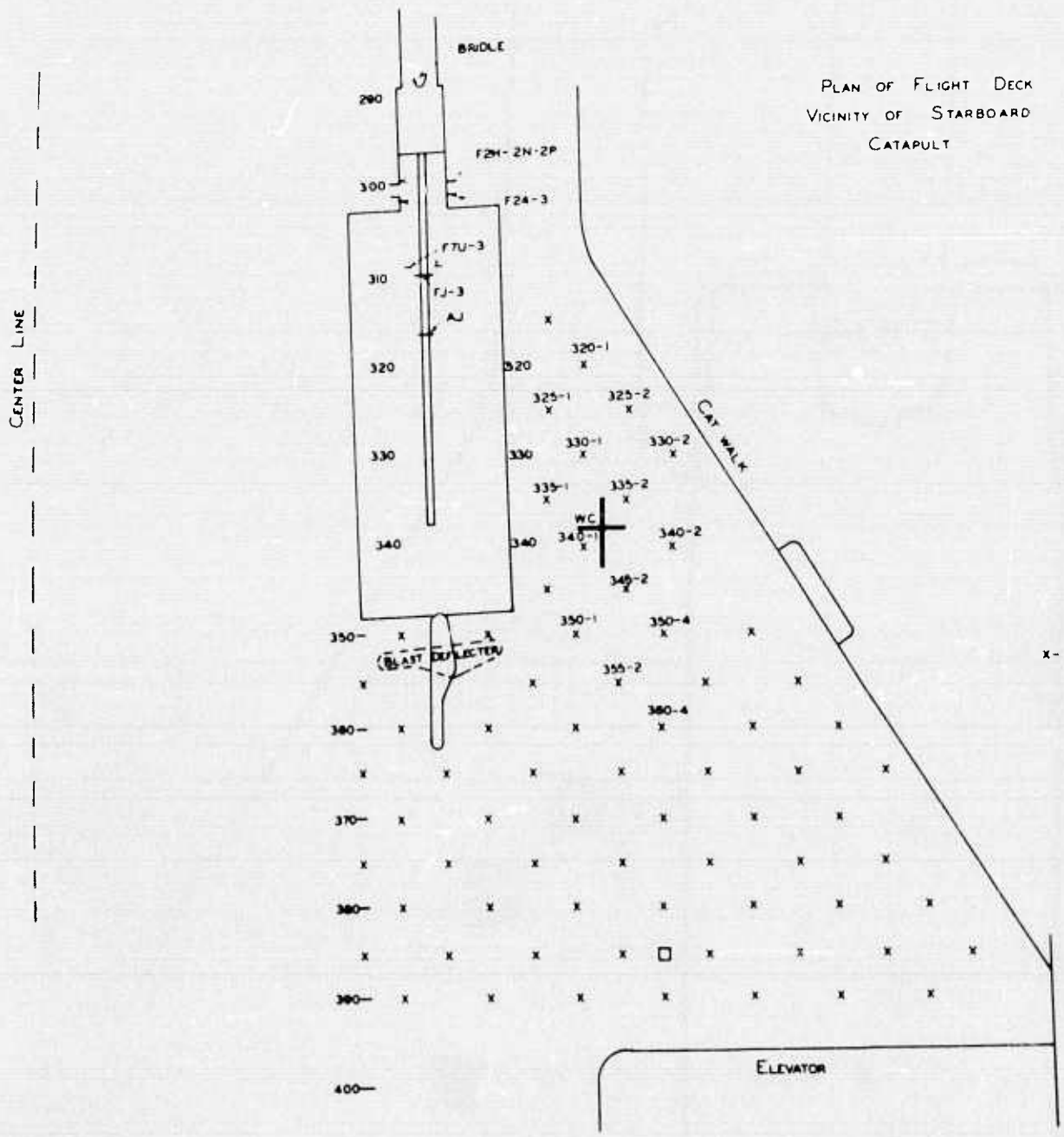


FIGURE 3.25 - Exact location of measurement stations on the deck of the USS FORRESTAL.

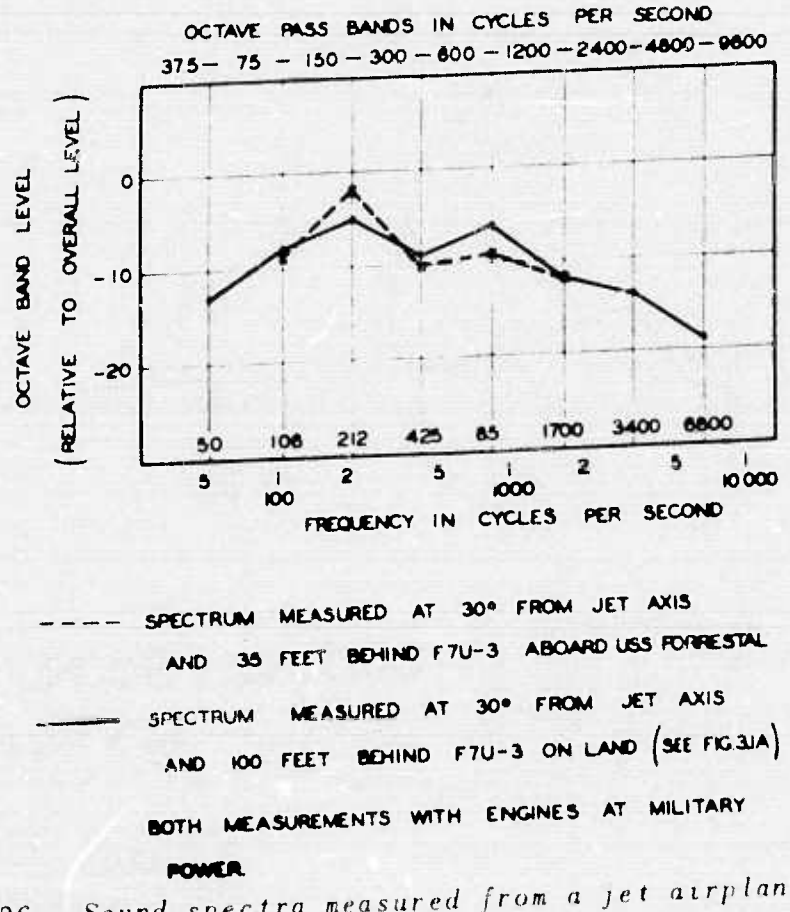


FIGURE 3.26 - Sound spectra measured from a jet airplane on the USS FORRESTAL compared with the spectra measured on land.

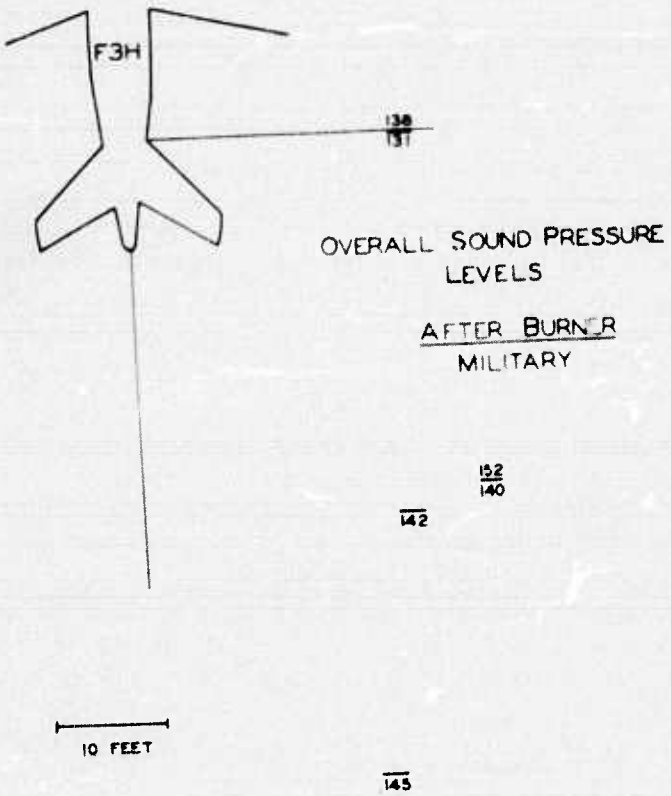


FIGURE 3.27 - Over-all sound pressure levels of an F3H jet airplane measured aboard the USS TICONDEROGA.

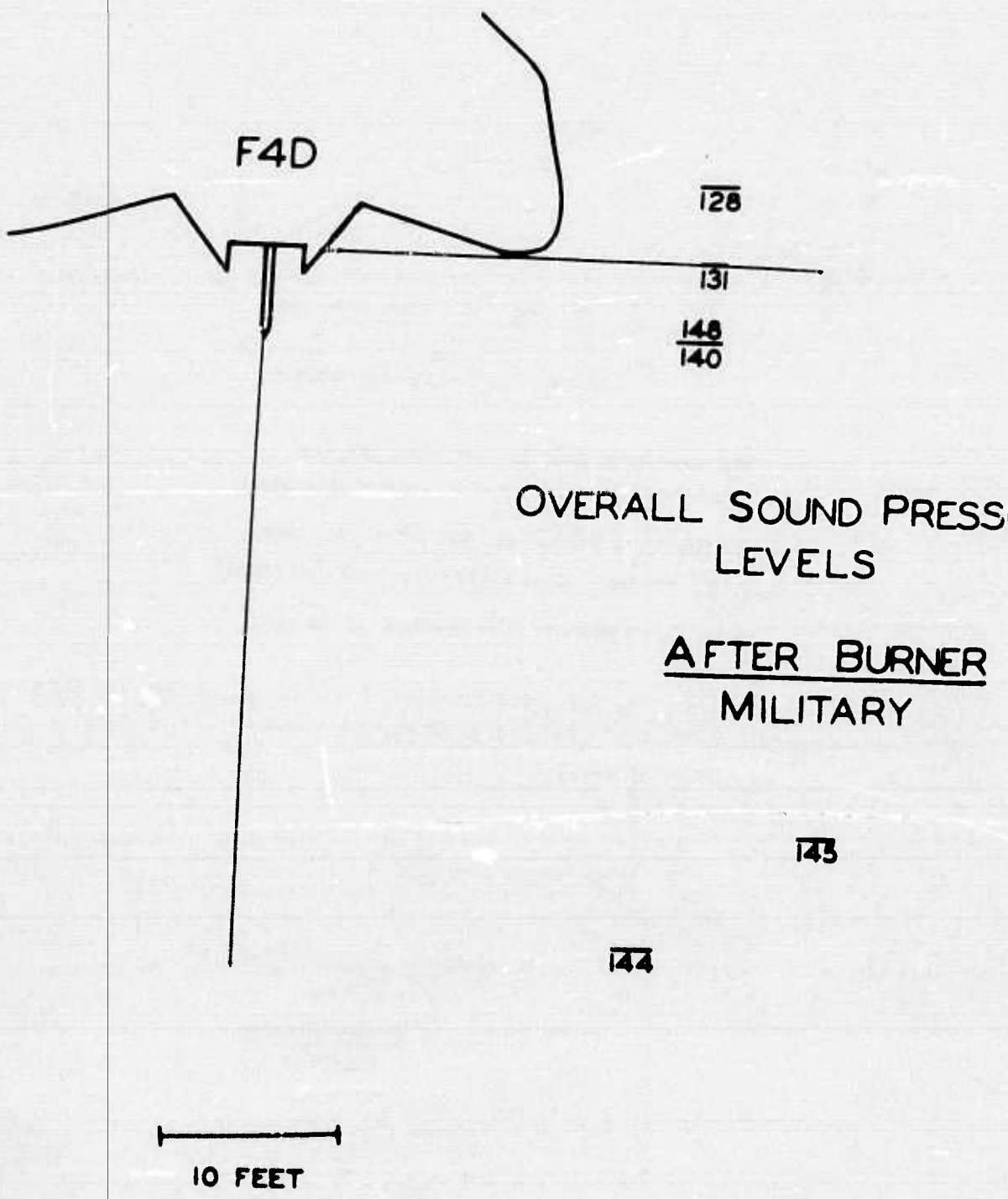


FIGURE 3.28 - Over-all sound pressure levels of a F4D jet airplane measured aboard the USS TICONDEROGA.

RECOMMENDATIONS FOR THE USE OF THE MEASUREMENT SYSTEM

FM Transmitter

Experience during the field trials indicates that the construction of the FM transmitter is not sufficiently rugged. Microphonics of the transmitter components are not a significant problem for present sound pressure levels. The connections between the battery case and the transmitter case are, however, a source of difficulty in the present model. Flexing of the connecting wires and vibration of battery and transmitter cases may cause interruption of the connections between these two components. Future transmitters should be procured with improved battery connections. A potted construction may be advisable to minimize the danger of the failure of wiring within the transmitter.

Helmets for mounting the Transmitter

Two helmets have been procured (from Protection, Inc., Inglewood, California) in which the FM transmitter may be mounted. These helmets have a large space at the rear in which it will be possible to install permanently the transmitter and battery case, the connecting leads and the antenna wires. This should minimize the chances of failure of the system.

Ear Protection

The helmets have been fitted with ear muffs (modified Wilson Products muffs) so that they serve as a combined transmitter housing and ear protection system. These muffs utilize a liquid seal and, therefore, little pressure against the head is necessary for good noise reduction. It has been found, however, that it is extremely difficult to adjust the muffs inside the helmet. Each person requires a slightly different positioning of the muffs and this must be done by trial and error. Although the helmets themselves are the largest size available, the addition of the earmuffs makes an extremely tight fit. It is recommended that other methods of mounting the earmuffs inside the helmets be investigated.

Multiple Microphone Systems

With a multiple microphone system the noise exposures of several people can be recorded simultaneously. Since the operational situation will be the same for all exposures recorded at the same time, precise comparison of noise exposures can be made. It is therefore recommended that plans be made to provide more than one microphone system.

Watchdog Function of the Cumulator

In addition to investigating the relations between hearing loss and noise

exposure, the Cumulator will be useful in monitoring current noise exposures. A realistic indication of a sudden increase in the severity of shipboard noise exposure can be obtained from measures provided by the Cumulator. The Cumulator should logically be used whenever a new airplane is introduced in the fleet or a change is made in launching procedures. The results of these measures might then be the signal for intensified audiometric and psychophysical monitoring activities. It is also possible that the Cumulator could give sufficient information about shipboard noise exposure to permit the calculation of the probable noise exposures that would result from the introduction of new aircraft aboard ship by using the basic sound pressure level measurements of the aircraft, the typical carrier launching schedule and various personnel flight deck assignments. This possibility could simplify the "watchdog" function of the Cumulator and perhaps predictions of future noise exposure would be possible.

Temporary Threshold Shift

The Cumulator can be an aid in correlating temporary threshold shift with noise exposure. It is very likely that this research would be performed on land in a favorable setting. Quick results could be obtained since it is not necessary to await the development of permanent hearing loss. Techniques learned during this kind of study could then be applied to the more difficult problem of correlating permanent hearing loss with noise exposure. In addition, tests to determine the validity of neglecting the pattern of the noise can be carried out by comparing groups that incur noise exposures with the same intensity distribution, but with different scheduling of the quiet and noisy periods.

Analysis of Data

The ultimate purpose of the Cumulator is to provide a method for correlating hearing loss with the measurements of noise exposure. Without such a method, it is possible only to correlate hearing loss with a particular job which uses particular equipment. Data from the Cumulator allow the grouping of similar noise exposures arising from widely different jobs, using different equipment. Distributions of noise exposures, such as those reported in Figure 3.21, can be obtained for any job around any type of aircraft. At first it may be helpful to use the Cumulator in the field for on-the-spot, preliminary screening of noise exposures. Immediate reduction of the data will point out those noise exposures which show similarities and those which show wide differences, and will probably make it possible to reduce the total number of measurements necessary.

The reduction of the data produced by the Cumulator results in a manageable number of variables that can be handled by conventional statistical techniques. A complete description of the original data would require so many parameters that even elaborate statistical methods would be useless. Analysis of the variables reported by the Cumulator should give information

that will make it possible to select those variables sufficient to describe a noise exposure. Once the most important variables have been identified, the task of correlating hearing loss with noise exposure becomes possible.

SUMMARY

A method has been developed for the specification of the noise exposure of personnel who work in the vicinity of jet aircraft. This method utilizes microphone systems capable of operation in over-all sound pressure levels up to at least 145 db and a device, called the Cumulator, which provides a statistical description of the noise exposure in terms of the length of time that the noise exceeds each of a set of predetermined levels. A prototype Cumulator was tested aboard the USS FORRESTAL early in 1956 and was found to give satisfactory performance. Preliminary results on the two flight deck jobs that involve the most serious noise exposure show that the exposure to high-intensity noise is extremely brief. Based on an 8-hour day, an equivalent noise exposure for each of these jobs would be produced by a steady noise with a similar spectrum, but with an over-all sound pressure level of approximately 105 db. Such a noise exposure would probably produce auditory effects that would not be inconsistent with the results of Chapter 4.

APPENDIX 3. 1

ANALYSIS OF THE OVERLOAD CHARACTERISTICS OF THE FM SYSTEM

Theory [3 5]

Let the instantaneous FM signal be

$$e_s = A\cos\left[\omega_c t + (kA_m/\omega_m)\sin\omega_m t\right] \tag{1}$$

where A = peak amplitude of the signal,
$\omega_c/2\pi = f_c$ = carrier frequency,
A_m = peak amplitude of modulating signal,
$\omega_m/2\pi = f_m$ = modulating frequency
and k = proportionality constant.

The signal e_s can be expressed in a Fourier series

$$e_s = AJ_o(\alpha)\cos\omega_c t + A\sum_{n=1}^{\infty} J_n(\alpha)\left[\cos(\omega_c + n\omega_m)t + (-1)^n\cos(\omega_c - n\omega_m)t\right] \tag{2}$$

where α = deviation ratio = kA_m/ω_m,
J_n = Bessel function of the first kind, of order n
and n = any positive integer.

The Bessel functions, being independent of time, are amplitude coefficients of the carrier and side frequency components of the FM spectrum. The signal, e_s, therefore consists of discrete frequency components whose spacing is determined by the modulating frequency, ω_m, and whose amplitude is determined by the Bessel functions.

Examples

Jansky and Bailey specifications indicate that the deviation frequency $\Delta f_c = \alpha f_m = 3$ kc for 0 dbm receiver output. A sound pressure level of 125.9 db at the diaphragm of 21BR-180 No. 8069 produced 0 dbm receiver output. From this information, the graphs in Figure 3.29 were drawn, wherein the effects of separately holding the modulating frequency and deviation frequency (respectively frequency and sound pressure level of the acoustic input) constant for a given deviation ratio, α, are shown.

The value of the Bessel function, $J_n(\alpha)$, rapidly approaches zero when n becomes greater than α.[3 6] Consequently, in the FM spectrum, the frequency components lying outside a band of width $2\alpha f_m = 2\Delta f_c$ become unimportant. The transmitted signal, therefore, will have a bandwidth of twice the deviation frequency centered at the carrier frequency. The intermediate frequency (IF) bandwidth of the receiver as specified by Jansky and Bailey is 150 kc. Hence, for the bandwidth of the FM signal to be greater than the IF bandwidth we have the condition that the deviation frequency

3.5 Electrical Engineering Staff, MIT, Applied Electronics, New York: John Wiley, 1949. P. 703

3.6 Jahnke, E., and Emde, F., Tables of Functions With Formulae and Curves New York: Dover, 1945 4th Edition.

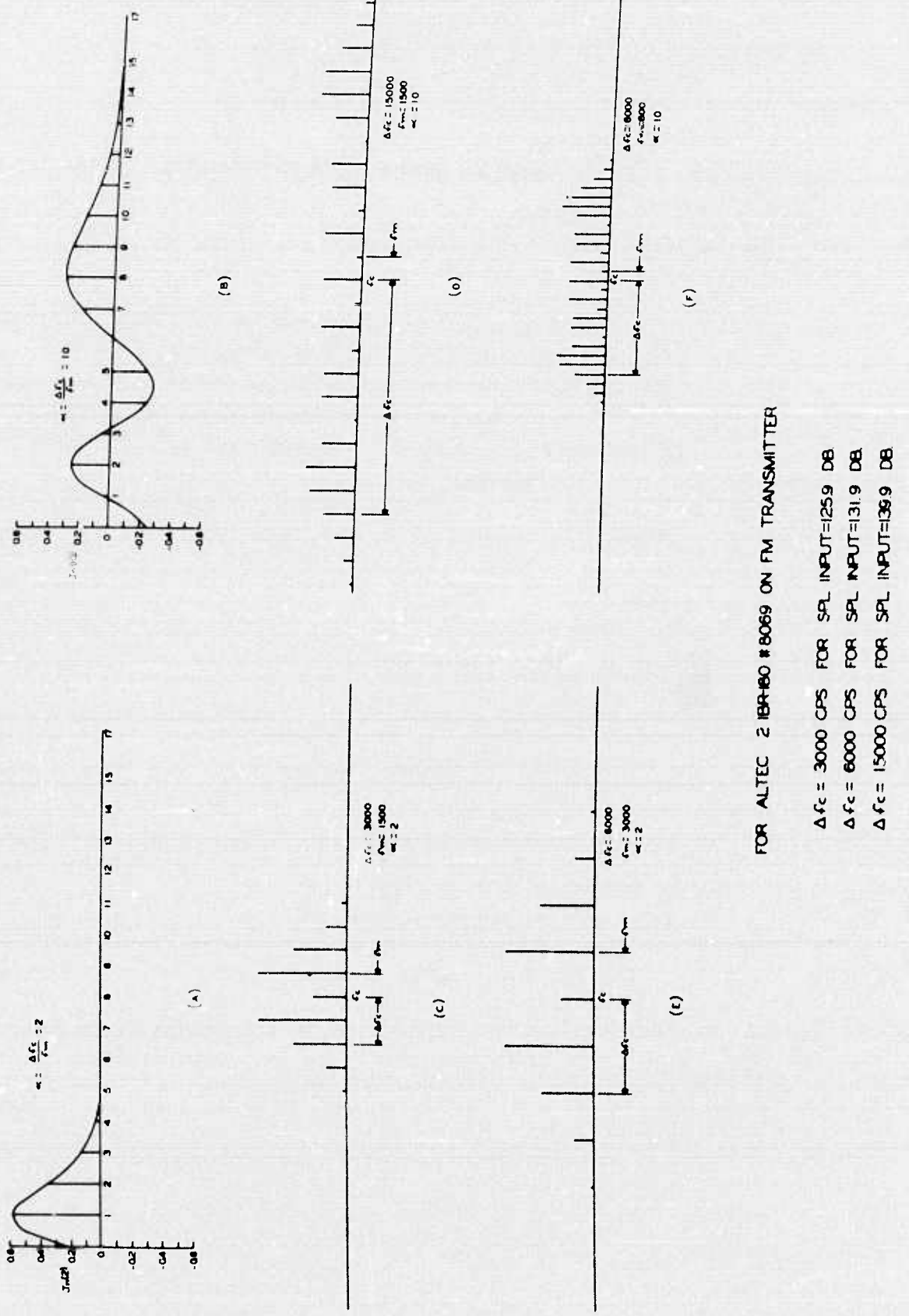


FIGURE 3.29 - Spectrum of FM transmitter calculated for various input sound pressure levels.

$$\Delta f_c < 75 \text{ kc.} \qquad (3)$$

But for an rms SPL of 125.9 db

$$\Delta f_c = 3\text{kc}$$

acoustic input to 21BR-180 No. 8069 as mentioned previously. Thus for an SPL of 153.9 db

$$\Delta f_c = 75 \text{ kc.}$$

Hence, whenever the rms sound pressure level input to the FM transmitter exceeds 153.9 db, condition (3) is satisfied and the output of the receiver should begin to become nonlinear. Laboratory measurements leading to Figures 3.11, 3.12, 3.13, and 3.14 and field measurement leading to Figures 3.16 and 3.17 indicate that, within measurement error, these conclusions are borne out experimentally.

APPENDIX 3.2

CIRCUIT DETAILS OF NOISE CUMULATOR

CIRCUIT DETAILS OF NOISE CUMULATOR

The over-all scheme of operation of one channel of the Cumulator is shown in Figure 3.19. The device is subdivided into five parts: (1) three filters; (2) four non-blocking amplifiers (provision is made for the future addition of two more amplifiers); (3) a motor-driven switching circuit serving all three channels; (4) 21 clock assemblies mounted in three separate chassis; and (5) a power supply.

Filters

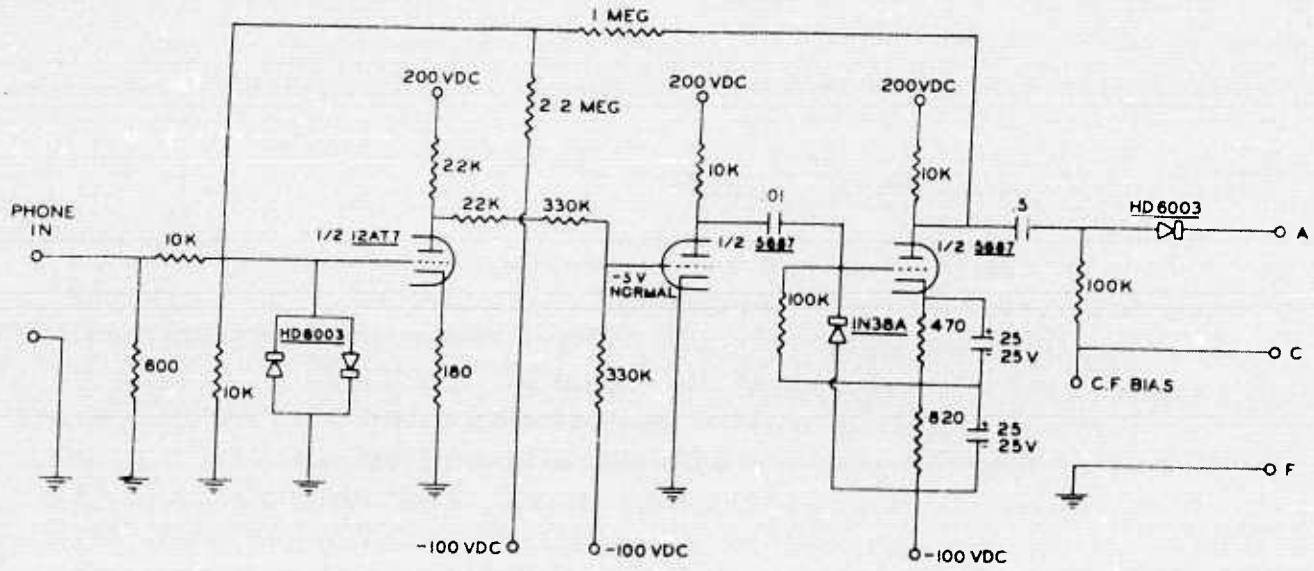
The filters are Allison Labs Model 2-A and 2-B. The filter in Channel 1 (Model 2-A) can be adjusted to cutoff frequencies that are one octave lower than the filters in Channels 2 and 3 (Model 2-B). The filters must see a resistive source impedance of 600 ohms. In addition, the three inputs must be sufficiently well isolated from one another so that the frequency dependent input impedance of one filter does not affect the voltage supplied to another. This result can be accomplished most simply by driving all three filters with a 10 watt power amplifier. An attenuator with a minimum attenuation of approximately 10 db should be inserted between the amplifier and each filter to provide for individual gain adjustments and to prevent interaction between the filters. The output of the filters must be terminated in 600 ohms. this is accomplished by means of a connection at the back of the filters to a 600 ohm resistor across the phone jacks at the input to each amplifier.

Non-Blocking Amplifiers

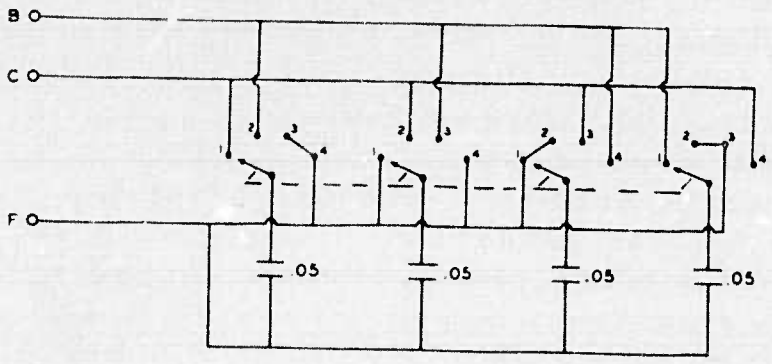
Three non-blocking amplifiers are wired as shown in Figure 3.30. For simplicity, the amplifier is AC coupled but designed in such a way that it can recover from a 30 db overload in approximately 0.1 seconds. At the input a pair of 10k resistors isolate the input circuitry from the filter and provide a high source impedance. A pair of silicon junction diodes connected in opposition serve as a symmetrical limiter for all signals greater than about 1 volt peak-to-peak. The first stage, one half of the 12AT7, is a voltage amplifier that is direct coupled to the second stage. The plate voltage should be approximately 100 volts so that the coupling network produces a bias of approximately -5 volts at the grid of the second stage, one half of the 5687. Up to this point, there is no problem of recovery from overloads since the circuit contains no capacitors.

The second stage is a conventional voltage amplifier and is condenser coupled to the third stage, the other half of the 5687. A double-biasing arrangement in the cathode of the third stage produces more or less symmetrical clipping of peaks at the input to this grid. Positive peaks are clipped by the low grid resistance when the grid voltage becomes positive. Negative peaks are clipped by the diode when the grid voltage becomes less than -100 volts. The choice of the resistors in the cathode circuit produces

NON-BLOCKING AMPLIFIER



ROTARY SWITCH



CATHODE FOLLOWER

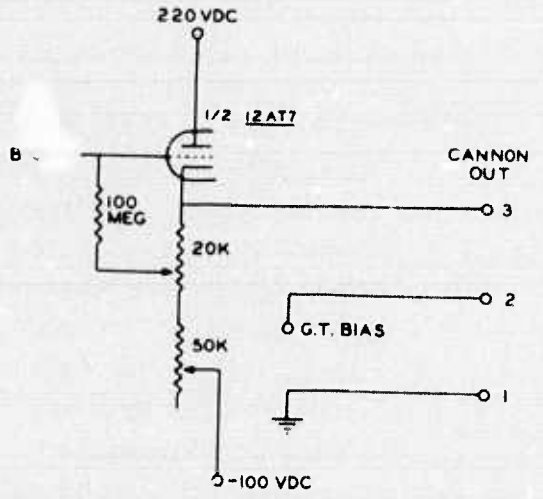


FIGURE 3.30 - Schematic diagram of one of the non-blocking amplifiers. The second amplifier in Channel 1 has no 600-ohm input resistor but a series potentiometer has been added. The lower part of the figure shows the wiring of the rotary switch and the cathode follower.

very small DC changes at the grid of the final stage when a large overload is applied to the input.

Feedback from the plate of the final stage through a 1 megohm resistor assures that the amplifier will operate linearly up to the overload point. A 2.2-megohm resistor returned to the -100 volt supply minimizes the DC voltage that would otherwise appear at the grid of the first stage.

A 1/2 mfd capacitor couples the output signal to a 100k resistor that is returned to the cathode follower bias supply (C. F. Bias). Another silicon junction diode is used to charge the capacitors in the switching circuit.

Switching Circuit and Cathode Follower

A rotary switch, driven by a ratchet mechanism, is wired in such a way that one and only one .05 mfd capacitor is connected to the output of each of the 3 amplifiers (Figure 3.30). Thus, the capacitor is charged to the highest voltage that appears at the output of the amplifier. At the end of a 1 sec. interval, the switch rotates one position so that the charged capacitor is presented to the grid of a cathode follower (the second half of the 12AT7 used as the first stage of the amplifier). Since the cathode follower presents a very high impedance to the capacitor, it maintains its voltage during the next 1 sec. interval. At the end of this period, the switch rotates one more step where the capacitor is shorted to the low side of the C. F. Bias supply. The next rotation of the switch shorts the capacitor again. This precaution may not have been necessary since soakage of the capacitors does not seem to be a serious problem. (In addition, polystyrene capacitors are now available that will eliminate the soakage problem.) There are four capacitors associated with the output of each amplifier. One is always connected to the output of the amplifier, one is always connected to the input to the cathode follower, and two are always shorted. When the switch rotates, each one of these four capacitors advances one position.

Since the cathode of the cathode follower is generally slightly more positive than the grid, a small leakage current will tend to flow from the cathode to the grid of the cathode follower. In addition, a small amount of grid current will flow through the tube in the opposite direction. Depending on which effect predominates, the capacitor voltage will gradually be increased or decreased. The effect of this current is eliminated by means of a 100 meg resistor that is returned to the arm of a 20k potentiometer in the cathode circuit. The leakage and grid current can then be balanced out by means of a high resistance path to either a more negative or a more positive potential than that of the grid. Since a 100 meg resistor is used, the input impedance of the cathode follower remains high.

Most of the current from the cathode follower passes through a load resistor that is in the chassis with the clock assemblies. However, part of the cathode current flows through a 20k and then a 50k potentiometer to the -100 volt supply. This insures that enough current will flow so that the operating point of the cathode follower will always be above the non-linear region on the plate characteristics. Adjustment of the 50k potentiometer

allows the voltage across the load resistor to be set to zero for zero signal input.

Channel 1 has a second amplifier that is wired in the same fashion as the first amplifier except for a minor modification of the input circuitry. This second amplifier increases the dynamic range of the Cumulator by 30 db. The 600 ohm input resistor is eliminated and a potentiometer is substituted so that the gain of the amplifier can be adjusted to provide an output voltage that is exactly 30 db higher than the output voltage of the first amplifier. The second amplifier feeds the fourth section of the rotary switch which, in turn, feeds a fourth cathode follower. The operation is exactly the same as discussed above. Provision has been made for the installation of two more such amplifiers in Channels 2 and 3 if it is necessary.

Clock Assemblies

The output of each of the cathode followers is connected to the load resistor by means of a cable fitted with Cannon connectors. The load resistor is tapped as shown schematically in Figure 3.31. A 5 meg potentiometer and a series 1 meg resistor feed the grid of a 2D21 gas tube. The 5 meg potentiometer provides a slight adjustment to overcome the individual variations among the gas tubes. Since the bottom of the tapped resistor and the 5 meg protentiometer are returned to the gas tube bias supply (G. T. Bias), it is necessary that a positive voltage be applied to fire the gas tube. With a bias of about -4.5 volts, a 2 to 3-volt signal will generally fire the gas tube. The plate of each gas tube is supplied from a 110 volt AC isolation transformer. Current through the gas tube operates a sealed, miniature, 5000-ohm relay. When the input to the gas tube drops below the firing voltage, the gas tube will shut off after the next reversal of the AC plate voltage. The contacts on the relay connect the 110 volt AC line to an indicator light and the clock. To minimize starting transients in the clocks, a series resistor and a shunt capacitor are used. Figure 3.32 shows the layout of the terminal board inside the chassis housing the gas tubes and relays. The color coding of the wiring to this terminal board identifies the last digit of the number of the position on the rotary switches to which the wire is connected.

Power Supply

The power supply (Figure 3.33) provides regulated voltages at +200 and -100, unregulated voltage at approximately +230 volts, C. F. Bias at -3 to -10 volts, G. T. Bias at -0 to -7 volts. In addition, AC filament voltages are supplied from separate transformers to each of the three clock assembly chassis and the filaments of the amplifiers. A 110 volt isolation transformer supplies the plates of the gas tubes. A separate switch on the non-isolated 110 volt line makes it possible to energize all the clocks simultaneously. A clock and an indicator light in the power supply are turned on simultaneously to provide a measure of the total time that

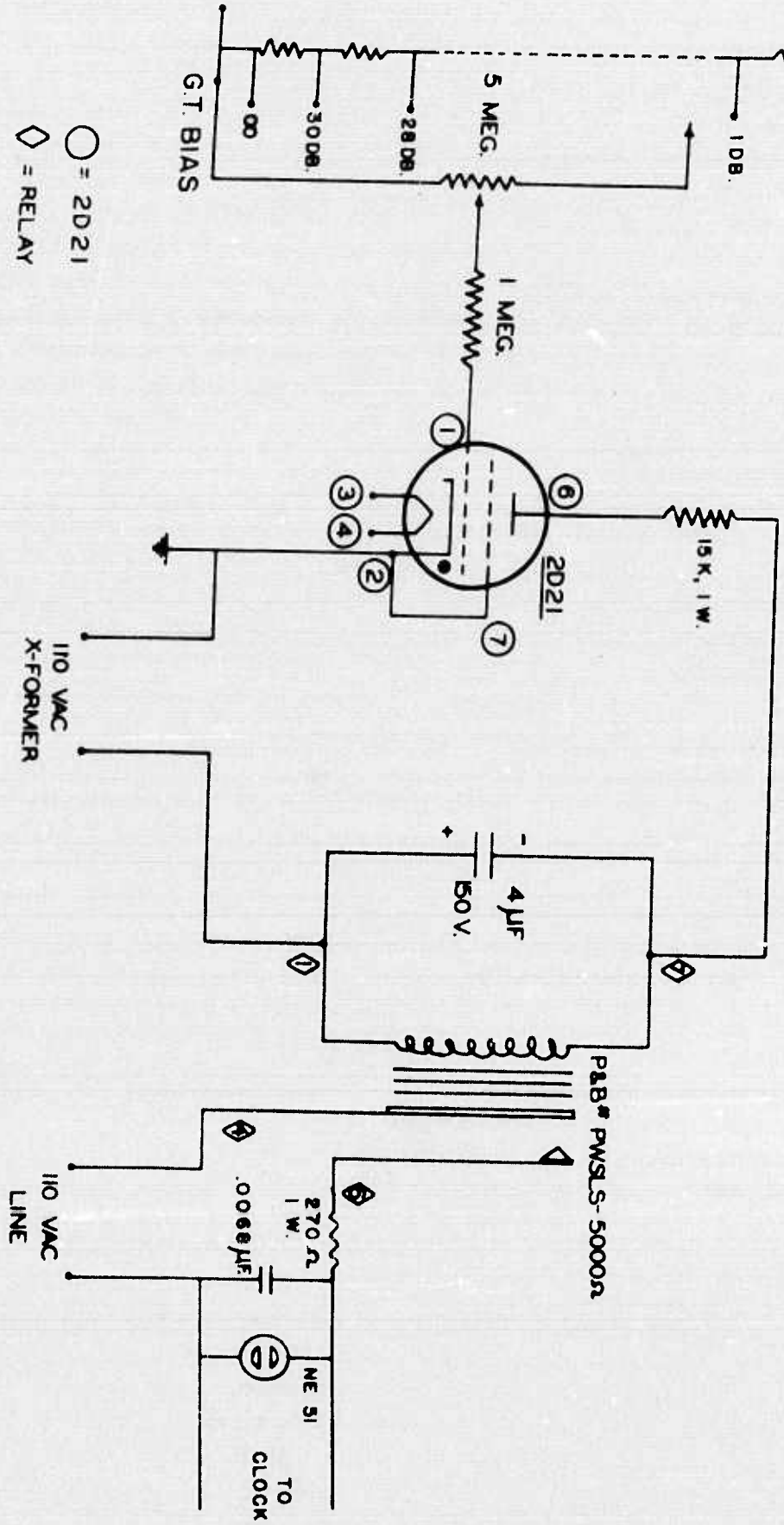


FIGURE 3.31 - Schematic diagram of one of the 21 clock assemblies.

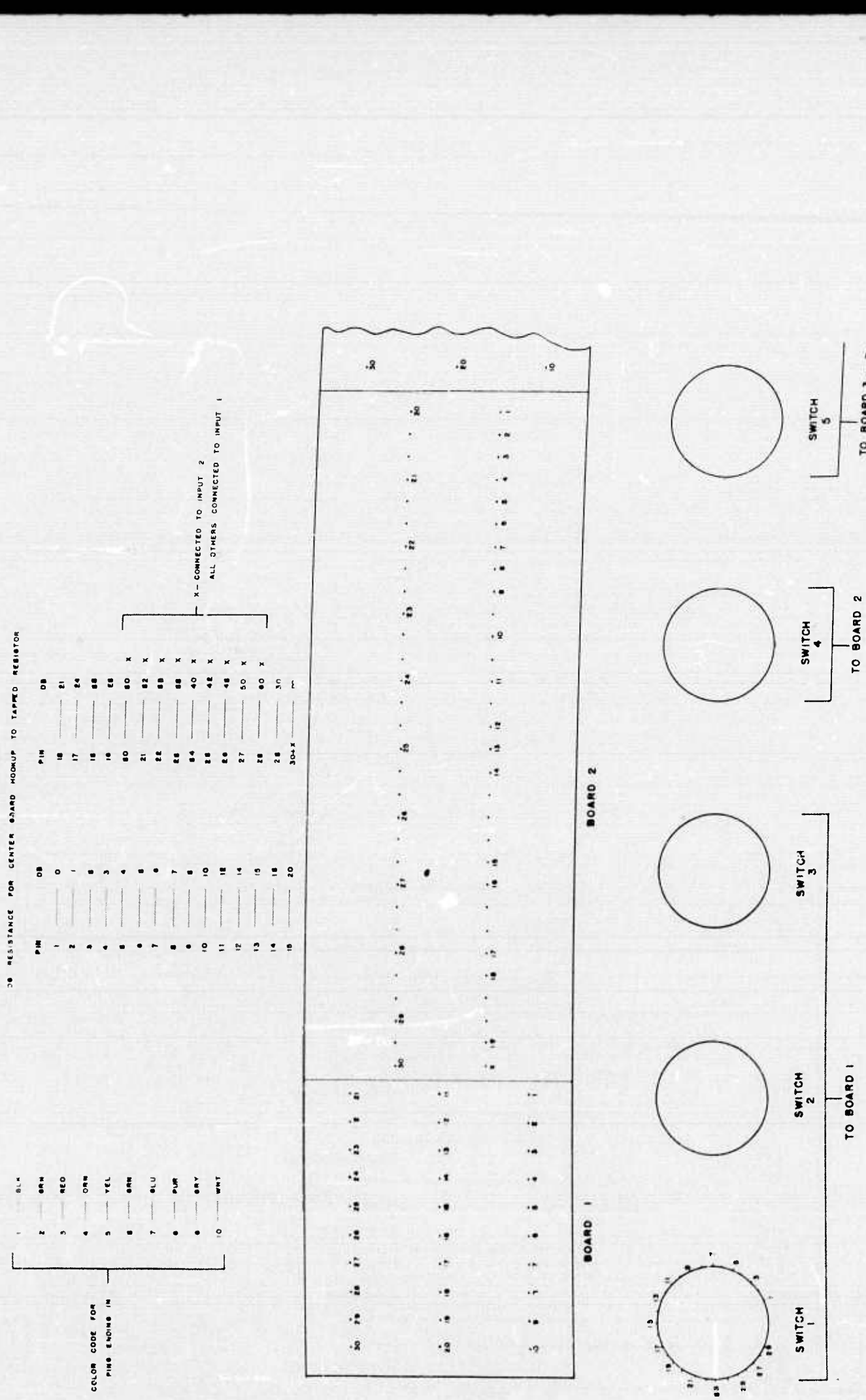


FIGURE 3.32 - Layout of the terminal board that supports the tapped, load resistor shown in Figure 3.31. The numbers on the terminals refer to the numbered wires leading to the switch positions shown at the bottom of the figure.

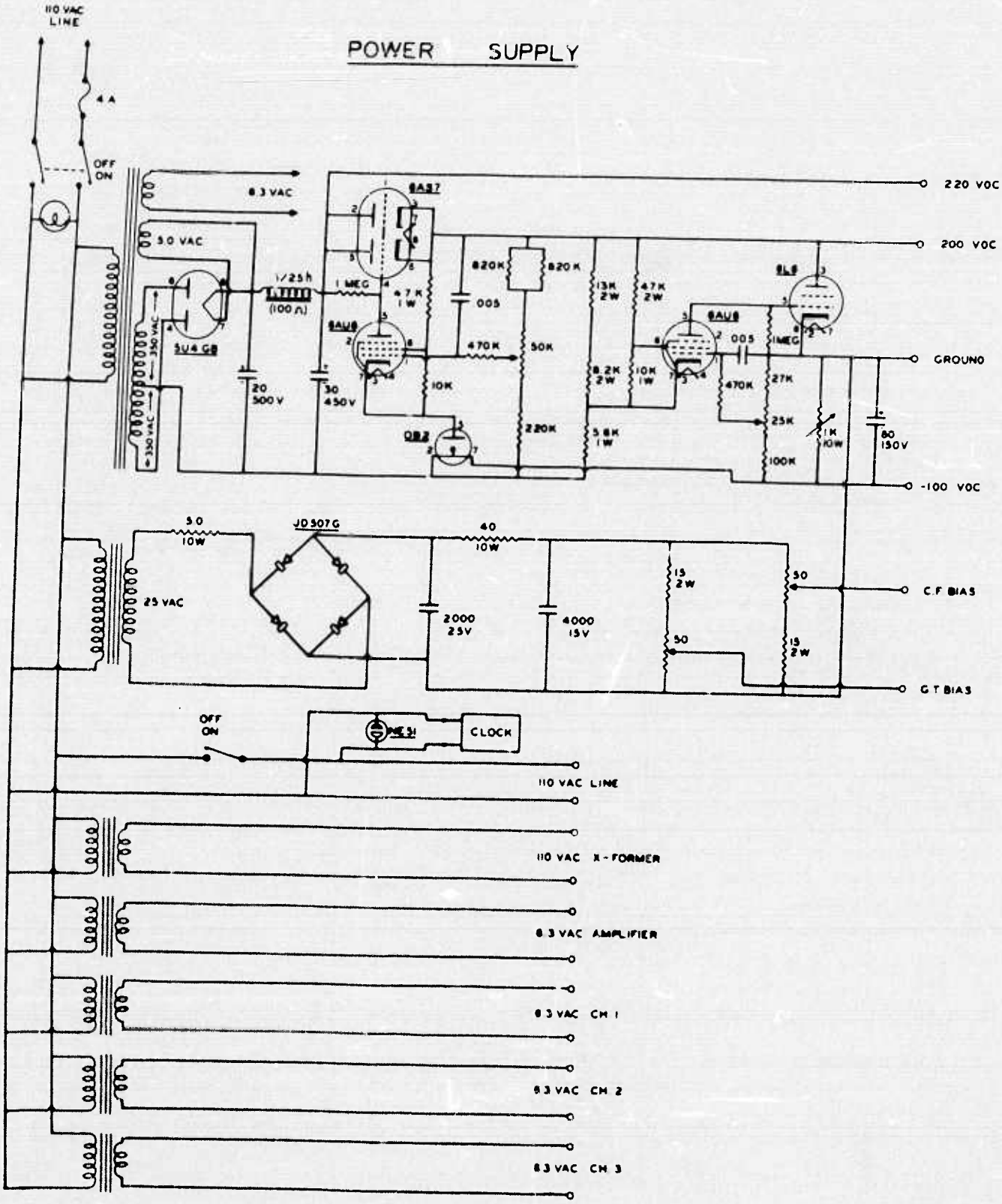


FIGURE 3.33 - Schematic diagram of the power supply.

the Cumulator is in operation.

The ∕200-volt and the -100-volt terminals of the DC supply are fed by a conventional regulator circuit employing an 0B2 regulator tube, a 6AU6 amplifier tube, and a 6AS7 control tube. A 6L6 between the ∕200-volt terminal and the ground terminal feeds just enough current into the 1k power resistor to maintain a voltage drop of 100 volts between ground and the -100 volt terminal. When all 12 tubes are in use and the maximum amount of current is returned from the amplifiers through the ground terminal, the 6L6 will be almost cut off. When the amplifier is disconnected, approximately 100 milliamperes will flow through the 6L6 maintaining a 100-volt drop across the 1k resistor. This arrangement decreases the range over which the 6AS7 must regulate the voltage at the ∕200 volt terminal.

CHAPTER 4

THE HEARING OF NAVAL AIRCRAFT MAINTENANCE PERSONNEL

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INTRODUCTION

It has long been known that even brief exposures to high-intensity noise will produce a temporary hearing loss. Similarly, cross-sectional studies on men working in noisy industries have indicated that these men, on the average, exhibit hearing losses that are greater than in the average population. It has never been clear, however, whether hearing loss in the individual case only appears suddenly as a result of a particular acoustic insult, or may in some cases develop gradually with repeated and prolonged exposure. Only a longitudinal study in which the same men are tested repeatedly (including an initial pre-exposure test) can possibly answer this question.

The studies to be reported here represent the beginning of such a longitudinal approach. Some naval aircraft maintenance personnel are now being exposed for brief periods to intensities above 140 db SPL, (see Chapter 3), often with little or no ear protection. Pilot studies[4.1] on exposed personnel indicated the need for further study.

Following the development of the mobile trailer laboratory[4.2] and the Group Audiometer[4.3, 4.4] (see Chapters 2 and 3), a large sample study was undertaken. This was done as a final field test of the apparatus and as a first step in assessing the danger of the newer jets. Changes in sensitivity associated with seven months of normal operating routine were determined for aircraft maintenance personnel at NAS Cecil Field, Florida. These men were receiving more intense exposure to afterburning jets than were carrier personnel at that time. The first test was made in August, 1956, and a second in March 1957.

TESTING PROCEDURE

In the first tests groups composed of 10 men were given auditory questionnaires patterned after that used by the Subcommittee on Noise in Industry[4.5] (see Appendix (4.1).) At the same time, a quick otological examination was mady by a navy hospital corpsman, and each man was asked how long it had been since he was last exposed to noise. Hearing was then tested by means of the method of single descent,[4.3, 4.4] using the following schedule: 2, 3, 4, 7, 8, 1, 1.5, 2, 3, 4, 6, 8 kc; right and left ears alternately. Briefly, in this method the subject is instructed to

4.1 - Ades, H.W., et al., The Benox Report. An exploratory study of the biological effects of noise. Contract N6 ori-020, Task Order 44, ONR Project NR 144079: The University of Chicago, 1953.

4.2 - Cox, J.R., Benson R. W., and Niemoeller, A. F., A mobile laboratory for group hearing tests. Noise Control, 3: 44-48, March 1957.

4.3 - Ward, W. D., The method of "single descent" in group audiometry. J. Acoust. Soc. Amer., 29: 371-376, 1957.

4.4 - Ward, W. D., The single-descent group audiometer. Noise Control, 3: 15-18, May 1957

4.5 - Glorig, A., and Quiggle, R., A hearing conservation data card. Noise Control, 2: 34 - 42 November 1956.

press a button "just as the beeps disappear;" the stimulus is an interrupted tone decreasing in intensity at the rate of 3 db/sec.

The procedure was the same in the follow-up tests, except for the use of a much shorter questionnaire covering only exposure to noise and gunfire during the intervening period.

Voltage across the phones was checked before each testing session, and the fitting of headsets was closely supervised to minimize acoustic leaks and uneven pressure on the ears. Earphones were calibrated using a standard 6-cc coupler before and after the studies. No significant changes were observed.

In addition, a type of 'real-ear' calibration was used just before the first tests and just after the last. Incoming naval cadets (who had been screened for abnormal hearing at induction centers) were tested at Pensacola. The results of these control tests are shown in Figure 4.1. Hearing losses are given in decibles relative to the ASA standard 'normal' for PDR-8 earphones in MX-41/AR cushions,[4.6] which is the combination used here.

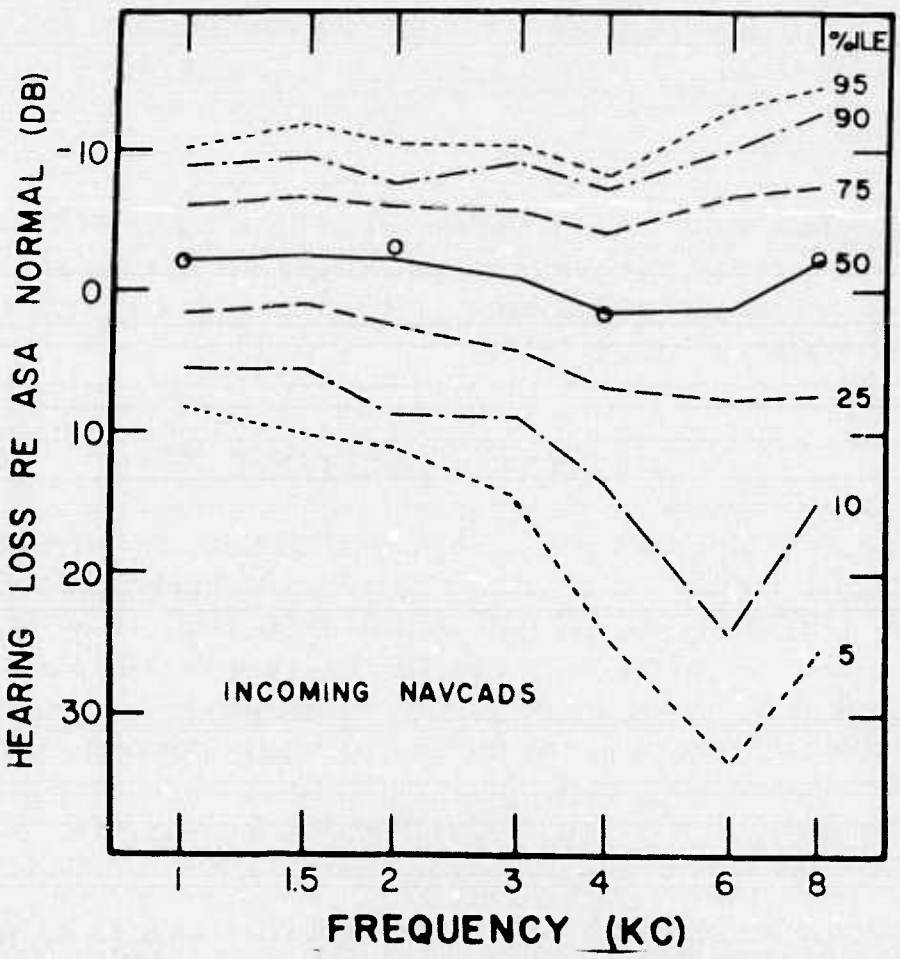


FIGURE 4.1 - Hearing-loss distribution for incoming naval aviation cadets. The lines show various precentiles for 50 men tested in June 1956, and the circles are medians for 20 men tested in April 1957.

4.6 - American Standard Z24 12-1952, Pure-tone Audiometers for Screening Purposes. New York: American Standards Association, 1952

Various percentiles for 50 men tested in June, 1956 are given by the lines; medians for 20 men tested in April, 1957 are indicated by the circles. The close agreement indicates that earphone cushion characteristics, headband tension, and ambient noise from the ventilating system had not changed during the interim.

In the pre-exposure tests (August, 1956), 1209 enlisted men were tested. The breakdown by squadrons is given in Table 4.1, together with the percentage of men working near the planes who wore earplugs "always" or "frequently." Our chief interest was in the squadrons with afterburner: VA-12 and VA-34 (F7U-3 Cutlass), and VF-101, which changed from the F2H-2 Banshee to the F4D Skyray immediately following the first tests. Squadron VF-41 was not included in this study (even though its equipment

TABLE 4.1

Men Tested at NAS Cecil Field (August 1956). Bold face type indicates that the squadron was completely tested. Under "Protection" is given the percentage of men working near planes who used ear protection "always" or "frequently."

SQUADRON	MEN TESTED	AIRCRAFT	PROTECTION (%)
VF-11	64	F2H-4	8.3
VA-12	145	F7U-3	13.4
VF-13	74	F9F-8	20.8
VF-14	56	F3H-2N	88.2*
VA-15	96	AD-6	5.7
VA-34	136	F7U-3	30.2
VA-36	42	F9F-5	6.3
VF-101	80	F2H-2	11.4
VF-103	44	F9F-8	7.4
VA-104	47	AD-6	2.5
VA-105	86	AD-6	0.0
NAS	339	—	—
TOTAL	1209		2.9**

* Use of ear protection mandatory in VF-14.

** Excluding VF-14.

the F3H-2N Deamon, is as powerful as the F4D) since it was known this squadron would not be available for retest in the follow-up study. Other squadrons and NAS personnel were also tested in order to make a conventional cross-sectional analysis of hearing loss.

A special effort was made to test every man in some squadrons, since men aware of hearing loss might tend to avoid examination, thereby biasing the results. Bold-face type in Table 4. 1 indicates that complete coverage was attained. In these squadrons, only men on leave and those assigned to temporary additional duty off the station were not tested. However, this precaution proved to be unnecessary. The last stragglers to be tested had hearing that was no different from those who appeared when first assigned, and the average hearing of the squadrons only partially tested was neither better nor worse than the hearing of those with complete coverage. For this reason, all men were included in the cross-sectional analysis. For a given squadron, of course, only men working near aircraft were considered to be noise-exposed. The non-exposed squadron personnel were placed in the control group.

The follow-up study in March 1957 involved only those previously-tested men in VA-12, VA-34, and VF-101 who were still on the station. Again all the men except those on leave or temporary additional duty were tested: 71 from VA-12, 89 from VA-34, and 61 from VF-101. It can be seen from the rate of attrition (39% of the original men had been reassigned) that a study involving a longer test-retest period would be almost impossible in this setting.

THE INITIAL STUDY, (NAS CECIL FIELD)

A survey such as the ANEHIN study results in a vast amount of data. If we are interested in extracting the effects of a single factor that is thought to produce hearing loss, then we must take great pains to ensure that the two groups obtained by splitting the data in terms of this variable are comparable in regard to all other factors known to be related to hearing loss. In the following sections, we shall attempt to extract the effects of aircraft noise from the initial survey data by eliminating or balancing out other relevant variables.

Excluded Subjects

Preliminary analyses were made in order to eliminate from the data, insofar as possible, factors extraneous to the question of the long-term effects of noise exposure. Audiograms of men falling into the following categories were not used in subsequent analyses:

(1) Less than overnight rest from noise. Although the personnel of the three 'key' squadrons were tested early in the morning before operations began, many of the men in other squadrons came in for testing directly from the noise. Since practically no ear protection was employed (Table

4. 1), temporary threshold shifts were present in many of these audiograms. (Because of a confusion in scheduling, three men originally tested after a night's rest from noise were later re-tested with only a half-hour rest. All three showed bilateral shifts averaging 5 db from 1 to 3 kc, 13 db at 4 kc, 8 db at 6 kc, and 6 db at 8 kc.) Although one would prefer a rest even longer, the 16-hour criterion was the best compromise between scientific accuracy and operational expediency that we could obtain.

(2) Observed open rupture of eardrum. An observed open rupture was the only type of otological abnormality that was associated with a hearing loss (and not consistently, at that). Scar tissue, inflammation of the drum, excessive wax, and fungus are all symptoms that were audiometrically irrelevant.

(3) Surgery on ear. One case only.

(4) Civilian employment in noisy jobs. In order to limit the findings to the effects of navy life, all men employed a year or more in a noisy civilian job were eliminated.

(5) Particular incident. The five men who, in the last questionnaire item, reported auditory difficulty after a firecracker exploded near their ears, and the nine who reported an unusually severe blow on the head or ear, were also excluded. However, men reporting a particular incident involving gunfire or aircraft noise were retained. Had any men indicated auditory difficulty after an illness, they would have been excluded; however, none so reported.

The following items on the questionnaire were found to have no significant correlation with hearing loss and were therefore ignored: (1) aural pain, (2) family history of deafness, (3) unconsciousness from blow (unless reiterated under "particular incident"). It is fortunate that unconsciousness was found irrelevant, since otherwise we would have lost 237 more men from the study.

After the above exclusions, 958 men remained. Of these, 566 were working or had worked near aircraft, 285 (largely NAS personnel with non-aviation rates) had not, and the remaining 107 were men who denied noise exposure, but who held aviation rates (petty officers).

The "Biological Baseline"

None of the men in this study had histories that could be called 'audiologically innocuous.' All had been through boot camp, which entails a certain amount of gunfire, and more than 75% had gone hunting or engaged in target practice more than 10 times. There were, however, 91 men under 25 years of age with no more than the above, i.e., no history of noise exposure, no tinnitus or conversational difficulty, and no large-caliber gunfire.

The hearing of these 91 men, again in terms of the ASA normal,[4.6] is given in Figure 4.2. The medians for 20-29-year-old men from two other mass surveys are also included: all men in this age bracket in the

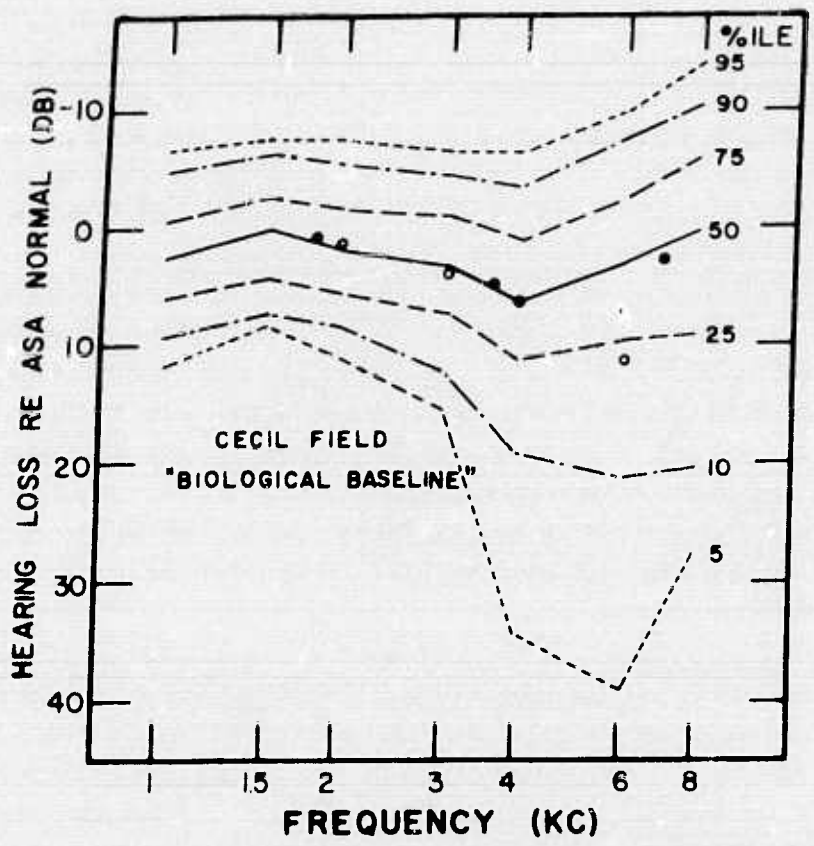


FIGURE 4.2 - Hearing losses of NAS Cecil Field "normals" (see text) in August 1956. The open circles are medians from the 1954 Wisconsin State Fair Survey;[4.7] *closed circles are medians from the San Diego County Fair Survey*[4.8] San Diego County Fair Survey,[4.7] and a selected low-exposure group of men from the 1954 Wisconsin State Fair Survey.[4.8]

This set of curves will be called the 'biological baseline'; the ensuing comparison between noise-exposed and non-noise-exposed men will be expressed in reference to this 'young navy normal.'

The fact that the 4 kc 'notch' appears at all percentiles might lead one to suspect an error in calibration. However, the phones were calibrated on four different 6-cc couplers and microphone systems, and at 4 kc all gave the same results, within a decibel.

Age

Hearing acuity decreases with age, statistically speaking. Whether this is due more to 'presbycusis' (some natural process of slow degeneration) or to the greater probability of acoustic trauma because one has lived longer, is a question upon which much more evidence must be gathered before a decision can be reached. At any rate, we must break the population

4.7 - Webster, J. C., Himes, H. W., and Lichtenstein, M., San Diego County Fair Survey, J. Acoust. Soc. Amer., 22: 473-483, 1950

4.8 - Gloria, A., Quiggle, R., Wheeler, D. E., and Grings, W., Determination of the normal hearing reference zero. J. Acoust. Soc. Amer., 28: 1110-1113, 1956.

down by age groups when making comparisons in regard to some other parameter, especially if there is any possibility that different age groups have been exposed to different amounts of acoustic hazards other than the hazard of immediate interest. In the present case, it is highly likely that men who were in the service during World War II and the Korean conflict were exposed to more gunfire than those entering in 1953 or after.

Use of the conventional 10-year age groups would probably lose much information, in this case. On the other hand, there are so few men in the present sample that a 1-year age grouping would not give reliable measures of central tendency. In order to obtain an estimate of the best compromise in regard to age grouping, the 285 men with no history of noise exposure were divided into 3-year age groups, and the thresholds at 4 kc were tabulated.

The results are shown in Figure 4.3. There is little change until age 28; from there on, the median loss increases at the rate of about 1 db/year. On the basis of these trends, the decision was made to use 6-year age groups: 17-22, 23-28, 29-34, and 35 and above. The 17-22 group had no wartime service, the 23-28 group Korea only, the other two both Korea and World War II.

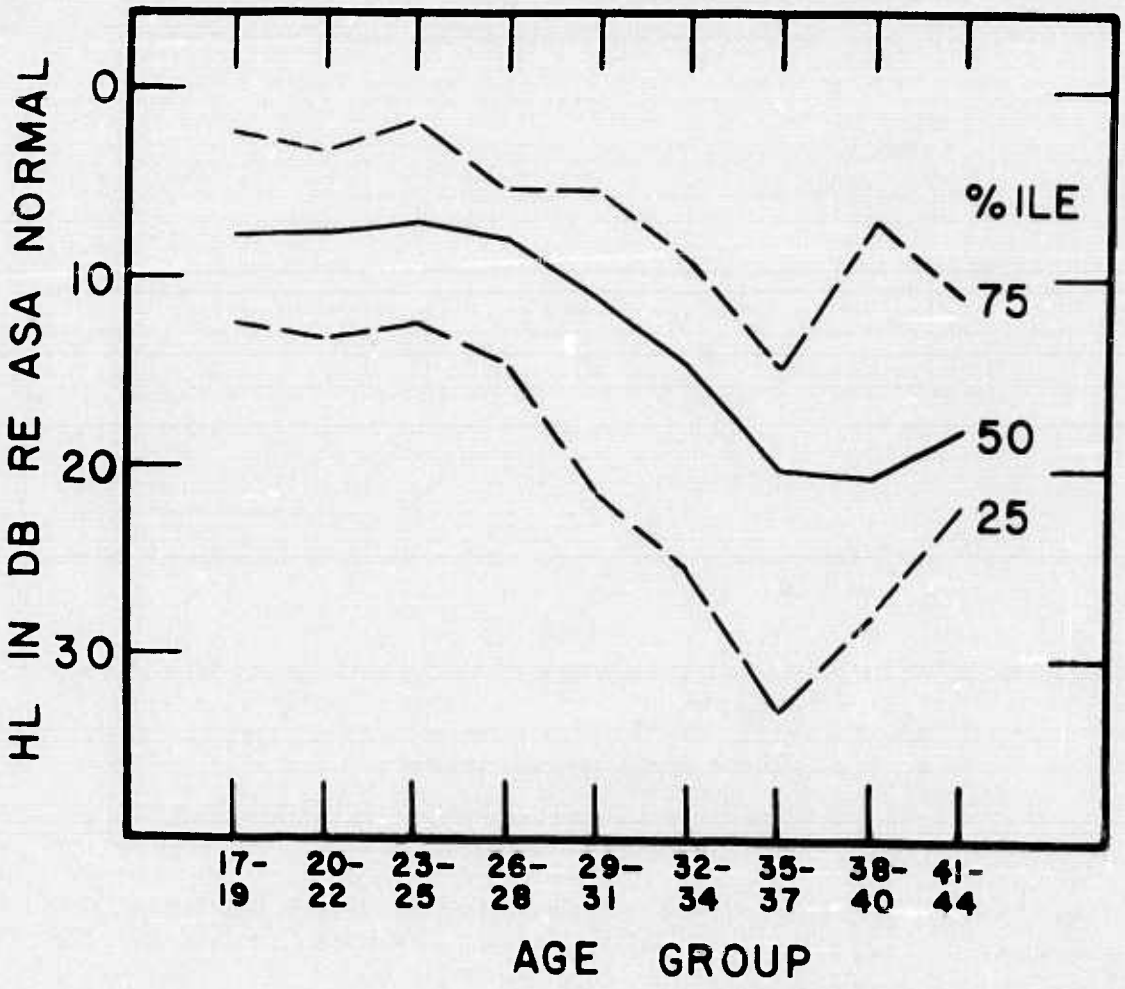


FIGURE 4.3 - Distribution of HL at 4 kc for different age groups of non-noise-exposed enlisted Navy personnel.

Noise Exposure

In the major comparison between the noise-exposed and non-noise-exposed groups, the 107 men who indicated no noise exposure but who held aviation rates were included in the non-exposed group, except for 13 men with AD rates (engine mechanic). While it is conceivable that AT's (aviation electronic technicians), AE's (aviation electricians), AM's (structural mechanics), and AO's (aviation ordnancemen) might be exposed only casually, becoming rated as an AD must involve some noise exposure. There were, then, 579 men with some history of regular exposure, and 379 with little or none.

Figure 4-4 shows the hearing losses of these two groups, by frequency and age, relative to the corresponding 'biological baseline' values of Figure 4.2. It is clear that older navy men have a good deal of high-frequency hearing loss, and that those exposed to noise have more than those not exposed. The open circles in Figure 4.4 show data on non-engine-room submarine personnel:[4.9] evidently all navy men with no sustained exposure to noise seem to have about the same hearing levels. The squares

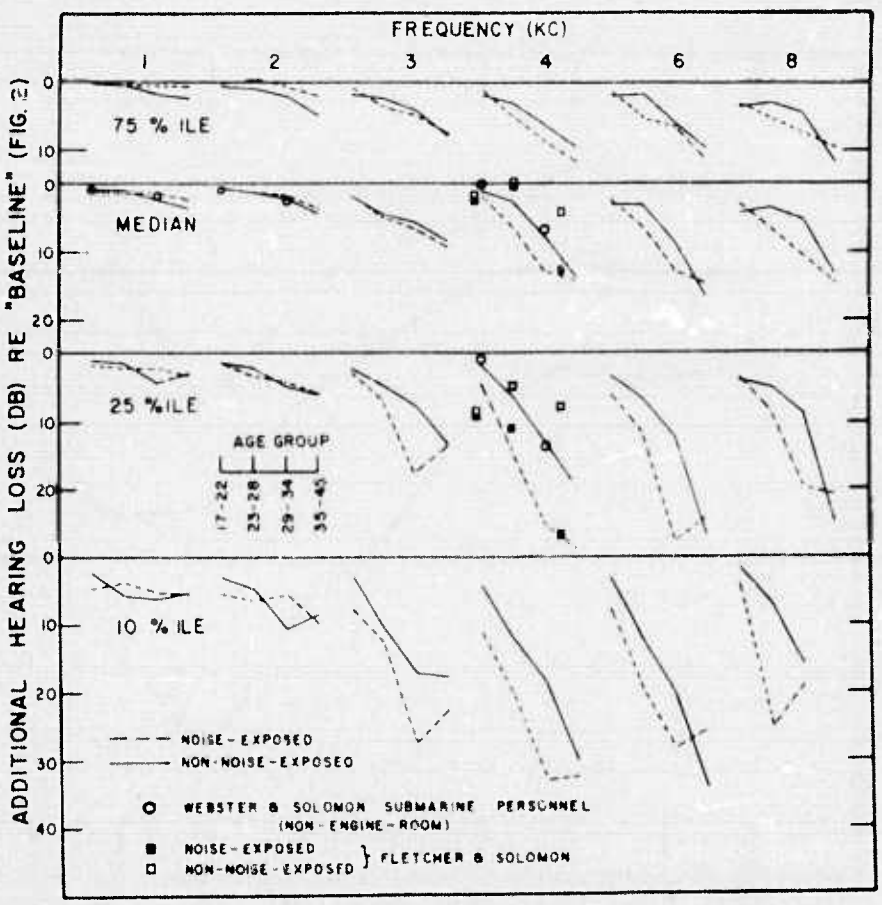


FIGURE 4.4 - Comparison of hearing losses of navy enlisted personnel. All losses are calculated relative to the corresponding percentile points in Figure 4.2.

4.9 - Webster, J. C., and Solomon, L. N., Measurements of hearing acuity among submariners and noise levels in working compartments. J. Acoust. Soc. Amer., 27: 466-469, 1955

represent data from a recent study on army armor personnel:[4.10] open squares indicate non-exposed personnel, solid squares indicate noise-exposed.

It is difficult to grasp the import of a graph such as Figure 4.4. Perhaps a more meaningful presentation could be attained by giving the percentage of ears exhibiting a hearing loss greater than some fixed value. A recent Navy Instruction[4.11] dealing with routing audiometry of noise-exposed personnel suggests that 20 db HL (hearing loss in terms of the ASA normal) be the dividing line between "normal" and "abnormal." This value is also the critical number distinguishing "Class A" and "Class B" hearing in the Air Force.[4.12] Accordingly, in Figure 4.5 is shown the percentage of ears with losses exceeding 20 db HL (which, for example, is 15 db above the 'biological baseline' at 4 kc) as a function of frequency; age is the parameter. Since, from Figure 4.4, the hearing of the oldest age group is independent of professed noise exposure, only one combined curve is given.

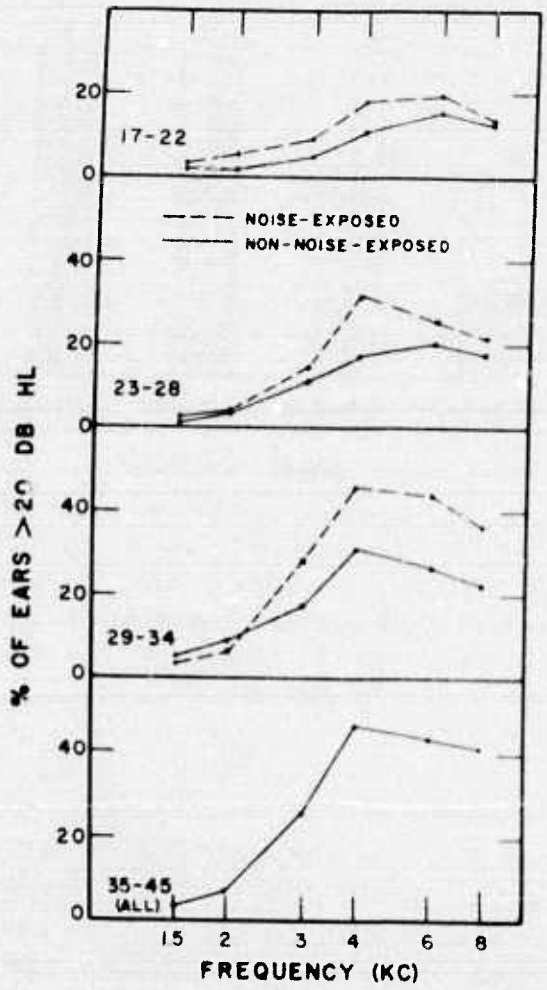


FIGURE 4.5 - Percentage of ears with 20 db HL or more (re ASA standard) as a function of frequency, noise exposure and age.

4.10 - Fletcher, J. L., and Solomon, L. N., A survey of hearing losses among armor personnel. Army Medical Research Laboratory, Fort Knox, Report No. 282, Project 6-95-20-001

4.11 - BuMed Instruction 6260.6, Washington, 13 December 1955.

4.12 - Air Force Regulation No. 160-3, Hazardous noise exposure. Washington: Department of the Air Force, 29 October, 1956.

In Figure 4.6 is shown the percentage of ears with 20 db HL or more at any frequency from 1 to 6 kc. Also shown by cross-hatching is the percentage with 30 db HL or greater at one of these frequencies. The difference between the noise-exposed (E) and non-noise-exposed (C) groups is significant (χ^2 test) at the .01 level of confidence for the 23-28 and 29-34 age groups, but only at the .10 level for the 17-22 group. The percentage of abnormal hearing among the noise-exposed personnel is about the same as that observed on similar men aboard the USS CORAL SEA.[4.13]

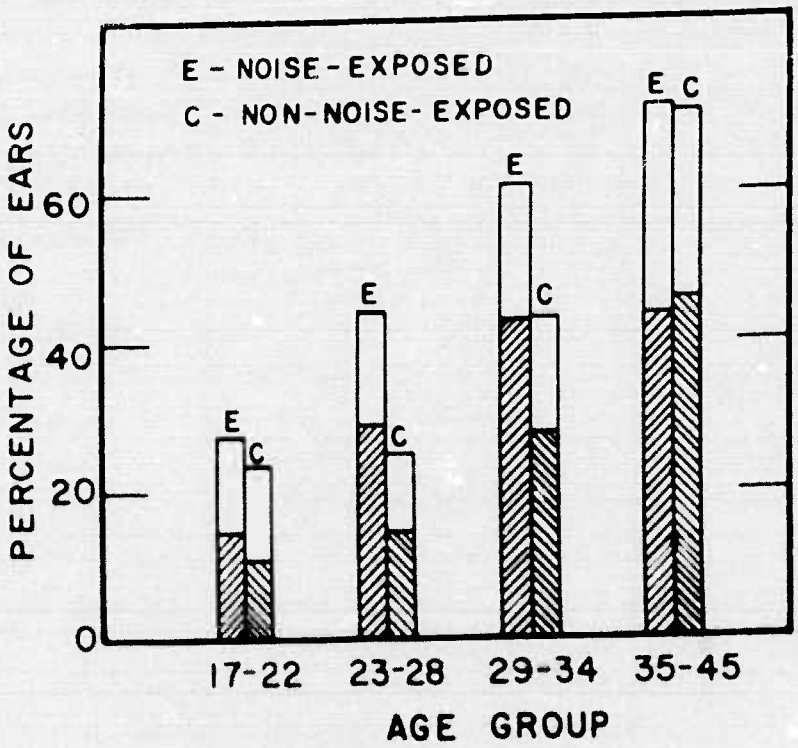


FIGURE 4.6 - Comparison between noise-exposed (E) and non-noise-exposed (C) Naval personnel as a function of age. The total height of the bars indicates the percentage of ears having 20 db HL or more at some frequency between 1 and 6 kc; the height of the cross-hatched sections represents the percentage with 30 db HL or more.

Gunfire

Figures 4.4 - 4.6 indicate conclusively that noise-exposed personnel have greater hearing loss than their non-exposed naval counterparts. It does not follow, however, that the noise has caused the hearing loss, unless the histories of the men in the two populations are equal in all other respects.

In this case, the groups are not equal in terms of exposure to large-caliber gunfire. Table 4.2 shows the percentage of men reporting hunting 10 times or more, target practice 10 times or more, and exposure to large-

4.13 - Davis, H., Eldredge, D. H., Glorig, A., and Halstead, W., Bio-acoustic studies of high intensity aircraft engine noise at Patuxent River N.A.S. and aboard USS Coral Sea. Memorandum Report, Contract N6ori-02044. The University of Chicago, 20 November 1953.

TABLE 4.2

Percentage of Men Reporting Exposure to Various Types of Gunfire. E indicates noise-exposed personnel; C indicates non-noise-exposed.

GROUP	% HUNTING	% TARGET PRACTICE	% LARGE-CALIBER
17-22 E	70 3	72 2	26 6
17-22 C	70 6	69 0	14 1
23-28 E	67 0	68 9	59 6
23-28 C	64 0	65 0	34 1
29-34 F	68 0	69 9	75 5
29-34 C	64 3	61 5	70 5
35-45 E	70 2	70 2	75 5
35-45 C	73 6	71 0	87 0

caliber gunfire, broken down by age and noise exposure. There are no significant differences in exposure to small arms, but, almost twice as many noise-exposed personnel in the 17-22 and 23-28 age groups have been subjected to large-caliber gunfire as their non-noise-exposed counterparts.

Because of the relation between large-caliber gunfire and HL implied by Table 4.2 and Figure 4.6, each of the eight main groups was divided in terms of absence of presence of exposure to large-caliber gunfire. If the large-caliber gunfire were indeed the cause of the greater hearing losses, then there should be significant differences between those exposed and those not.

Table 4.3 gives the results of this analysis. The figures do not support the notion that large-caliber gunfire has had much direct influence on the production of hearing loss. At this point, it would appear that the source of the difference between our main groups must be the amount of exposure to noise.

TABLE 4.3

Comparison of Incidence of Abnormal Hearing, by Age and Noise-Exposure Groups, Between Men Exposed to Large Caliber Gunfire (L) and Those Not Exposed (-). E. indicates noise-exposed men, C indicates non-noise exposed.

GROUP	NO OF EARS		PERCENT >20 DB HL		PERCENT >30 DB HL	
	L	-	L	-	L	-
17-22 E	144	396	28 5	27 0	13 9	14 4
17-22 C	48	306	33 3	21 9	10 4	10 5
23-28 E	142	76	38 0	51 3	25 4	34 2
23-28 C	64	124	23 4	27 4	17 2	16 1
29-34 E	160	52	58 1	56 4	40 6	46 2
29-34 C	102	38	45 0	39 4	31 4	18 4
35-45 E	142	46	72 0	71 8	45 8	30 4
35-45 C	64	12	70 3	75 0	43 7	62 5

TABLE 4.4

Percentage of Men Reporting Tinnitus Following Gungire (Tg) and Following Noise (Tn) as a Function of Age and Noise Exposure.

ITEM		AGE GROUP			
		17-22	23-28	29-34	35-45
NOISE-EXPOSED	% Tb % Tn	30 22 5	38 27	44 32	37 19
NON-NOISE-EXPOSED	% Tg % Tn	20 10	24 5 7 5	33 13	37 18 5

TABLE 4.5

Percentage of Men Reporting Tg as a Function of Age, Noise Exposure and Large Caliber Gunfire (L). The number of men in each subgroup concerned is given in parentheses.

ITEM	AGE GROUP							
	17-22		23-28		29-34		35-45	
	L	NO L	L	NO L	L	NO L	L	NO L
NOISE EXPOSED	47 (72)	23 (198)	38 (71)	39 (38)	50 (80)	27 (26)	43 5 (71)	13 (23)
NON-NOISE-EXPOSED	12 5 (24)	21 (153)	37 5 (32)	19 5 (62)	39 (51)	16 (19)	37 5 (32)	33 (6)
ALL	38 6	22 2	37 9	27 0	45 8	22 2	41 8	17 2

TABLE 4.6

Percentage of Ears With More Than 20 and 30 db HL at Some Frequency Between 1 and 8 kc, Among Men Reporting Tinnitus After Gunfire. Breakdown by noise exposure, age, and exposure to large-caliber gunfire (L).

GROUP		NO. OF EARS	% >20 db HL	% >30 db HL
NOISE EXPOSED	17-22; L	68	38	22
	17-22; no L	92	50	31 5
	23-28; L	54	40 5	22
	23-28; no L	30	60	46 5
NON-NOISE-EXPOSED	17-22; L	6	(17)	(0)
	17-22; no L	64	26 5	11
	23-28; L	24	41 5	29
	23-28; no L	24	54	37 5

Tinnitus

However, the story is not yet complete. The dichotomous information in regard to gunfire obtained with this questionnaire unfortunately gives no indication of the degree of exposure. A man who had engaged in target practice 150 times falls into the same category as one who had done so only 15 times. There are also probably wide variations in what the men regard as "exposure to large-caliber gunfire." However, we can get at least some idea of the relative severity of exposure among groups by tabulating the occurrence of tinnitus. It has been shown that a relatively long-lasting tinnitus following gunfire or noise is often associated with a permanent hearing loss.[4,10] Although there probably are individual differences in predisposition to tinnitus, we may assume that in a reasonably large group this factor will balance out.

Table 4.4 gives the percentage of men reporting tinnitus following gunfire (Tg) and tinnitus following noise (Tn) for the eight main groups. It is evident that the gunfire exposure of the noise-exposed men (except for the 35-45 age group) has been more severe than that of the non-noise-exposed; the differences are all significant at the .05 level. That this is not simply because of the difference in the number of men exposed to large-caliber gunfire (l) is shown in Table 4.5. Here the eight groups have been divided into two subgroups each on the basis of such exposure, and the percentage of men reporting Tg calculated. Although the incidence of tinnitus is greater in the L subgroups, there is also more Tg among the noise-exposed non-L groups than among the non-noise-exposed. Two conclusions are possible: (1) that noise-exposed personnel have been exposed to more severe gunfire, both large- and small-caliber, than have the non-noise-exposed; or (2), that a given gunfire exposure may produce more tinnitus (and perhaps more hearing loss) after several hours of exposure to aircraft noise than it would have if the ear were "fresh." By determining the incidence of abnormal hearing among men reporting Tg, one can compare the relative traumatic correlates of Tg following large- vs. small-caliber gunfire. Results of this comparison are given in Table 4.6. These data imply that tinnitus is more likely to be associated with a permanent loss when it follows small-arms fire than when it follows large-caliber gunfire. (The difference may actually be greater than indicated here, since some of the men with large-caliber exposure probably had tinnitus following only small-arms gunfire.)

In order to see whether Tn was as indicative of permanent loss as Tg, all noise-exposed men from 17 to 28 years of age were divided in terms of reported tinnitus: Tg, Tn, Tb (tinnitus following both noise and gunfire), and $\overline{T}$ (no tinnitus). The percentage of ears in each group that showed a loss in excess of 20 db HL are given in Figure 4.7.

From the significant difference between the Tg and Tn groups, we can conclude that many (if not all) of the high-frequency losses observed in these men can be attributed to gunfire. However, there is some indication that noise exposure severe enough to cause tinnitus may tend to produce a

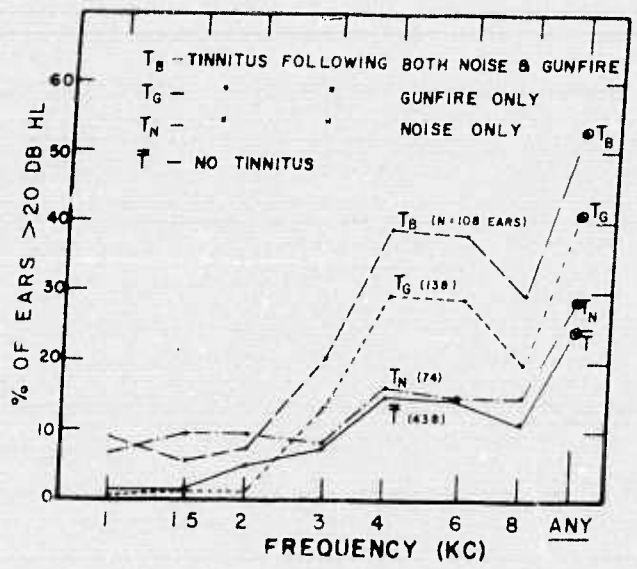


FIGURE 4.7 - Percentage of ears with 20 db HL or more as a function of frequency. The parameter is type of tinnitus reported. Noise-exposed personnel only.

uniform loss independent of frequency (flat, at least, from 1 kc to 8 kc). This flat loss is in agreement with results obtained aboard the USS CORAL SEA[4,13] and with the observations reported earlier (see excluded subjects), in regard to the three men who were re-tested after only a half-hour rest from the noise.

To what extent, then, can the difference in gunfire exposure account for the difference between the hearing of the E and C groups? If one could assume that an absence of Tg meant that the individual had not suffered hearing loss from gunfire, then one could simply eliminate the men reporting Tg; the difference between the E and C groups would then indicate the effects of noise. This is a very unlikely hypothesis, from what we know about individual differences in regard to tinnitus; nevertheless, let us perform some calculations along this line.

Of the 758 ears in the 17-22 and 23-28 E groups, 241 (31.8%) were abnormal (20 db HL or more at some frequency). Of the 542 ears in the 17-22 and 23-28 C groups, 132 (24.3%) were abnormal. This difference is significant at the .001 level of confidence (χ^2). In the E group, 122 men reported Tg; of these 244 ears, 112 (46.0%) were abnormal. In the C group, 59 men reported Tg; of these 118 ears, 41 (34.7%) were abnormal. The probability of chance occurrences of this difference is approximately .01. Considering now the men <u>not</u> reporting Tg, 129 of the 514 ears (25.1%) in the exposed (E) group are abnormal, and 91 of the 424 ears (21.5%) in the control (C) group; this difference is not significant (P = .20). And if it were true that only 70% of the men actually injured by gunfire experienced (and reported) tinnitus, even this non-significant difference would become zero.

In short, it seems that gunfire may very well have contributed enough to the hearing losses so that the airplane noise alone cannot be held responsible.

Conversational Difficulty

Next to tinnitus, the questionnaire items showing the best correlation with hearing loss were those concerned with temporary losses severe enough to produce noticeable difficulty in understanding normal conversation. The men indicating such difficulty had more hearing loss than those not so reporting. However, it could hardly be otherwise; men with permanent bilateral high-tone losses, whatever their cause, would be more likely to notice a given additional temporary loss than an individual with otherwise normal hearing. So we cannot with any assurance conclude, simply because a man's only difficulty with conversation followed noise exposure, that the noise caused his hearing loss.

Susceptibility

Similarly, even the conclusions in regard to tinnitus must be tempered by the possibility that tinnitus is often no more than a manifestation of a pathological ear, and that therefore men reporting tinnitus may have suffered the measured loss some time before, perhaps during a childhood illness.

The data indicate that more men report tinnitus from both noise and gunfire than would be predicted from the relative occurrence of Tg and Tn. Tg was reported by 30.3% of the men in this study, Tn by 19.1%. The expected rate of occurrence of Tb would then be (.303) x (.191) = 5.8%. The observed rate was 12.2%, a difference significant far beyond the .001 level of confidence.

However, this could mean that any (or all) of the following are true: (1) Some individuals with a given audiometric status are more susceptible to tinnitus than others with the same hearing; (2) men with permanent losses are more likely to suffer tinnitus than those with normal hearing; (3) combined exposure to noise and gunfire on a given day may increase the likelihood of both Tg and Tn; or (4) the individuals exposed to the highest noise levels have also been exposed to the most severe gunfire. Now we have seen that the noise-exposed personnel as a group reported a higher incidence of Tg, and that this tinnitus was more likely to be associated with a hearing loss, indicating that the gunfire (and the tinnitus) was more severe. Unless we make the rather unlikely assumption that there is some selection process operating whereby tinnitus- and injury-susceptible men are assigned to aircraft maintenance, we cannot discard the possibility that the correlation between noise- and gunfire-exposure found for groups applies to individuals as well. However, the argument for real differences in susceptibility is enhanced by the fact that the 2:1 ratio of observed to predicted Tb held not only for each age subgroup among the E group, but also for each age subgroup within the C group, in which the men reporting Tn presumably heard it after a casual exposure.

At any rate, a realistic choice among the four alternatives cannot be made from survey data. A long-term study using volunteers and carefully-

controlled exposures is mandatory.

Discussion

The evidence that noise exposure has produced any permanent hearing loss is exceedingly flimsy at this point. If one uses the clinical approach, interpreting each individual audiogram in terms of what 'probably' caused that particular hearing loss, then there are cases in which one feels quite confident that aircraft noise was the responsible agent. But in the absence of pre-exposure audiograms, one cannot be sure. Several other analyses were made of the data. There were no significant differences among men working near (a) jets, (b) jets with afterburner, and (c) reciprocating engines. "Distance from the plane that you usually work" (Appendix 4. 1) also proved irrelevant. Division of men on the basis of ear protection gave the same result recently reported by Fletcher and Solomon:[4.10] men reporting usage "always" or "frequently" had slightly worse hearing than those indicating "seldom" or "never." It would appear that these men must begin having a good deal of trouble with their hearing before they will consider using ear plugs. It should be kept in mind that there was no check on the accuracy of the information given in the questionnaire nor on the relation of questionnaire information to actual noise exposure.

These results are all consistent with the hypothesis that aircraft noise was, at the time of this study, much less dangerous to the hearing of naval personnel than was gunfire. However, none of these men had had very much exposure to afterburner, and, as indicated above, there were many instances in which noise exposure was the only reasonable a posteriori explanation for a given loss. It was hoped that the results of the second test on these men would give more conclusive answers.

THE FOLLOW-UP STUDY, (NAS CECIL FIELD)

In the retest on the three key squadrons, the following facts are relevant: (1) Simultaneously with the beginning of the tests, bad weather set in. There was therefore much less flying and test-firing of planes than at the time of the first test, and so most of the men had been away from the noise longer at retest. At the time of retest, then, there was probably less temporary threshold shift than at the time of the initial test. (2) Only a month or two after the first tests, a large number of Clark protective helmets [4.14] had arrived and had been distributed to the men in the squadrons, so that protection was much more generally used. (3) Squadron VA-34 had changed from the F7U to the A4D (a non-afterburner plane) about three months before the retest; VA-12 still had the F7U; VF-101 had been using the F4D about five months. (4) Insofar as practicable, all men were

4.14 - Webster, J C , Thompson, P O , and Beitacher, H R , Noise bands versus pure tones as stimuli in measuring the acoustic attenuation of ear protective devices. J. Acoust. Soc. Amer , 28: 631-638, 1956

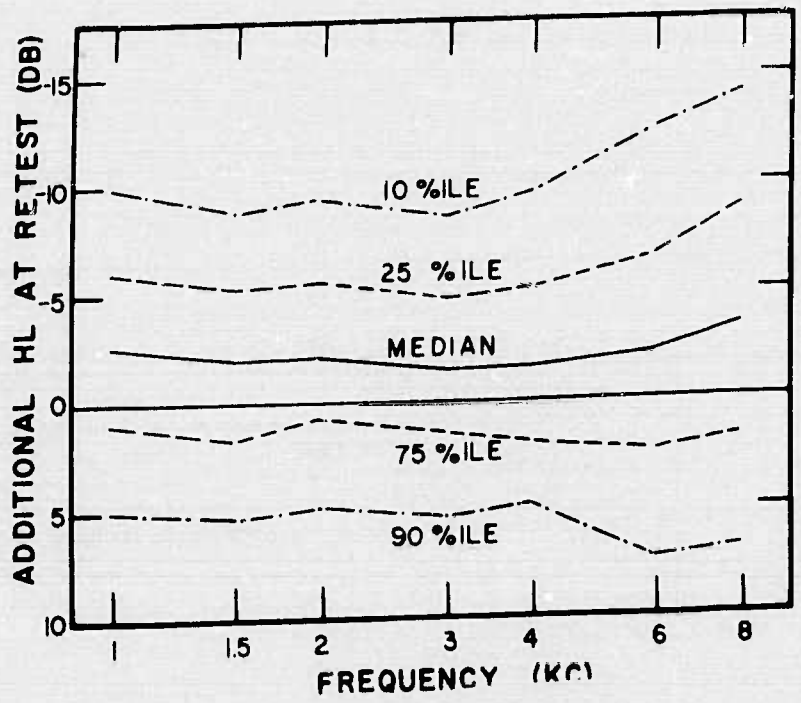


FIGURE 4.8 - Change in hearing of all men in three squadrons after 7 months of normal exposure to noise from jets with afterburner. The fact that the medians are all negative means that the average acuity of these men improved during 7 months (but see text for explanation).

retested at the same listening position as in the initial test, in order to keep the effect of slight differences in earphones at a minimum. Only about 15% of the men were retested in a different listening position.

Figure 4.8 shows various percentile shifts at each frequency for the entire group. The main feature is a significant median improvement at all frequencies. In view of the greater average rest from noise at time of retest, and the increased use of protection, this improvement was not unexpected. If one ignores the average improvement, the test-retest median deviation is about 3.5 db from 1 to 4 kc, 4.5 db at 6 kc and 5.5 db at 8 kc, values only slightly larger than those reported by Harris[4.15] in a situation where the retest was done on the same day.

Change as a Function of Exposure

The improvement at all frequencies tends to confirm the results of Figure 4.5; that jet noise exposure tends to produce a broad temporary hearing loss instead of the "boilermaker's notch" at 4 or 6 kc that is characteristic of gunfire and impact-noise exposure. Nevertheless, since 4 and 6 kc are at least as significant as other frequencies, a score for each man was calculated by simply averaging the shifts for both ears at these two frequencies. This would tend to reduce the inherent test-retest variability associated with any single frequency.

4.15 - Harris, J. D., Group audiometry. J. Acoust. Soc. Amer., 17: 73-76, 1945.

TABLE 4.7

Mean Shifts at 4 and 6 kc Associated With Seven Months of Normal Exposure to Jet Noise. Positive values indicate greater hearing loss at retest. The number of men in each subgroup is given in parentheses.

TYPE OF EXPOSURE	SQUADRON			
	VA-12	VA-34	VF-101	ALL
NON-EXPOSED	-1.4 (13)	1.8 (13)	-0.5 (7)	0.2 (33)
RELIEVED FROM EXPOSURE	-2.6 (6)**	-2.1 (9)***	-2.9 (9)***	-2.5 (24)***
1-4 HRS./WK	-2.9 (15)***	-0.5 (18)	-1.4 (13)	-1.6 (46)**
5-40 HRS/WK	-0.8 (37)	-1.3 (49)*	-2.0 (32)**	-1.4 (118)**
ALL	-1.5 (71)*	-0.8 (89)	-1.8 (61)***	-1.31 (221)***

* $p > .05$

** $p > .01$

*** $p > .001$

The men were first divided into four groups on the basis of exposure between test and retest: (1) men who were not working in noise at either time; (2) those working in noise at the time of the first test, but who had since been transferred to a non-noisy job; (3) those spending one to four hours a week in noise (light exposure); and (4) those exposed five to forty hours per week (severe exposure).

Table 4.7 gives the mean shift for each of these groups, by squadron. Shifts significantly different from zero (t test) are indicated by asterisks. There is nothing startling in these figures. The men not exposed to noise at the time of either test show no shift; those relieved from exposure show the greatest improvement. However, when the difference in shift between the light- and severe-exposure groups is calculated, the only significant difference is in Squadron VA-12, where only those with light exposure showed improvement.

Afterburner Exposure

If hearing loss tends to be produced by short but particularly intense stimuli (as in the case of gunfire), the group that should show the greatest loss during the intervening period would be the men with the most unprotected afterburner exposures. There were 22 men who professed 20 or more afterburner exposures without ear protection: 4 from VA-34, 2 from VF-101, and 16 from VA-12. The mean shift (4 and 6 kc) for this group was /0.1 db (i.e., no change). It is possible that this group had a noise-induced loss at the time of the first test, and that this loss was not intensified during the period between tests.

Tinnitus

Thirty-one men reported tinnitus lasting half an hour or more since the

first test. Their average hearing was 0.4 db worse. Apparently the single occurrence of a half-hour tinnitus is not a sufficient condition for production of a large permanent hearing loss.

Ear Protection

Considering only men exposed to noise 5 hours or more per week, a significant difference among squadrons in amount of ear protection was observed. Percentage of these men reporting protection 40% or more of the time was as follows: VA-12 (F7U), 21.5%; VA-34 (A4D), 57%; VF-101 (F4D), 72%. The order agrees with the noise levels generated (without afterburner) by each aircraft: More men working near the noisier planes wear ear protection. Forty-six men alegedly wore protection 80-100% of the time; their mean shift at 4 and 6 kc was -2.35 db, i.e., the same improvement as the men who had been reassigned to non-noisy jobs (Table 4.7). For the 59 men reporting 0-30% protection, the mean shift was -0.85 db. The 1.5-db difference between these groups is significant at the .05 level of confidence (t test).

Apparently some fruition is coming from the efforts being made by the Navy to convince its personnel that the new jets are dangerous to hearing, and that failure to use proper protection when available is more foolish than courageous. No doubt the fact that the Navy considered the problem serious enough to initiate this testing program made some impression on these men, too. There was, however, no relation between intelligence and use of ear protection: Mean GCT scores were identical for the high- and low-protection groups.

Relation to Auditory Status at First Test

One of the questions that is of great importance in both military and industrial situations is this: "Are men with a pre-existing but non-critical hearing loss more likely to suffer further loss in a noisy situation than men with normal hearing?" That there are individual differences in resistance to permanent damage is fairly well established. It therefore has seemed reasonable to assume that men with a hearing loss have shown themselves to have 'tender ears,' comparatively speaking. However, it is just as reasonable to suppose that most of these men just happened to get a particularly severe exposure, one that would affect even the least susceptible of ears.

The men were divided into two groups: those with normal hearing at the time of the first test, and those with abnormal hearing (20 db HL or more at some frequency between 1 and 6 kc). Comparison of the shifts at retest showed a non-significant difference in the opposite direction from that predicted by the 'susceptibility' hypothesis: The 90 men with abnormal audiograms showed slightly more improvement than the normals. One should not place much faith in this negative result because of the confusion generated by temporary threshold shifts and use of ear protection. Never-

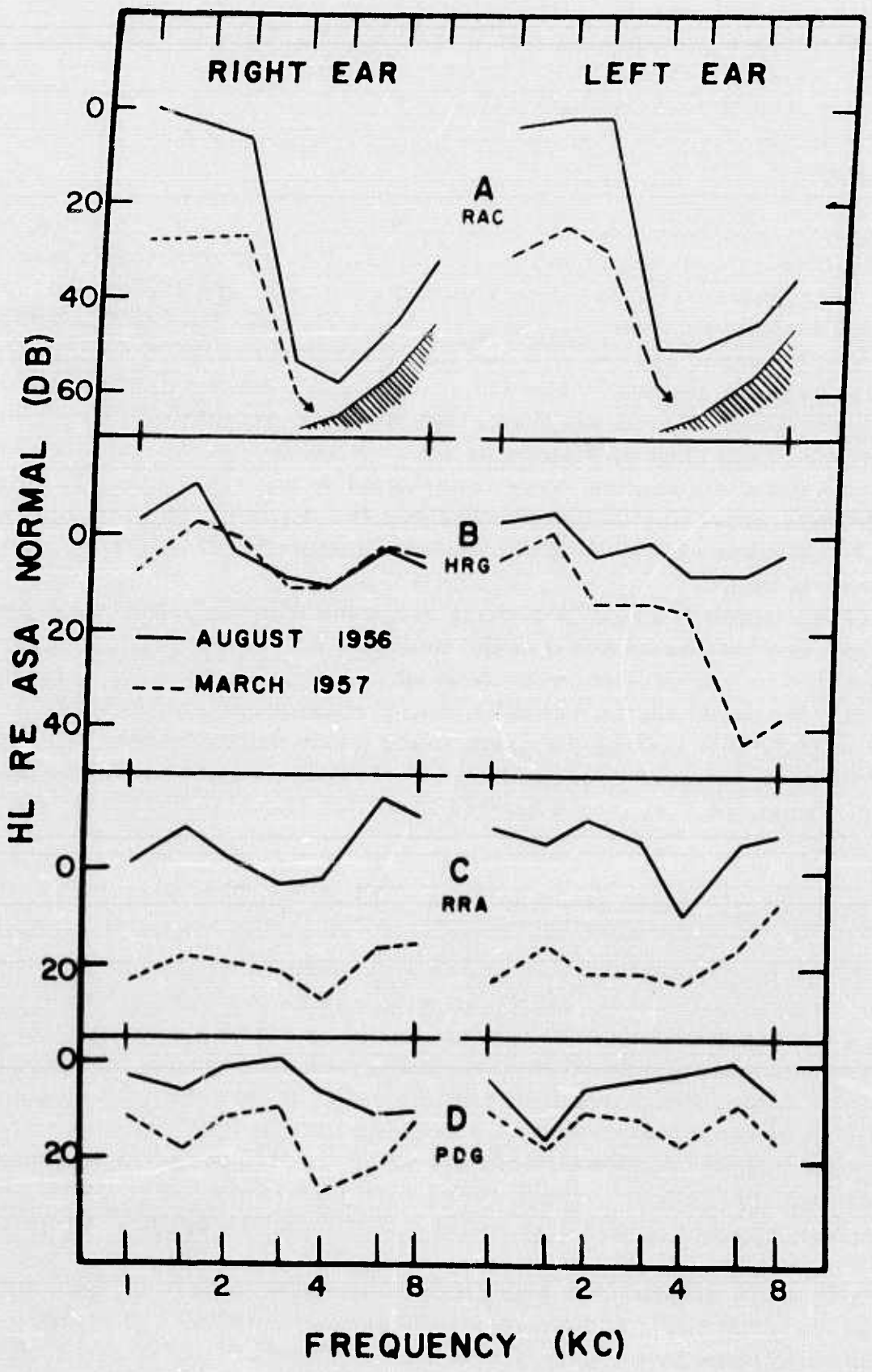


FIGURE 4.9 - The four most severe cases of additional HL incurred from seven months of noise exposure. A, C, and D are probably noise-induced temporary losses; B is almost certainly a gunfire-induced 6 kc tonal gap.

theless, there is no indication that men with pre-existing losses are more likely to suffer additional loss than men with normal hearing.

Individual Changes

No average additional losses, then, occurred during the 7-month interval, indicating that if permanent damage occurs slowly, a much longer test-retest interval must be used to detect these changes. But as in the cross-sectional study, there were individual cases in which fairly large changes show that the noise can be dangerous.

Figure 4.9 shows the four men with the greatest additional loss at retest. Figure 4.9A shows the audiogram of a 34-year-old airman (AN). His hearing was poor enough in August, but if the additional low-frequency loss in March does not disappear with rest, he is in serious trouble. (Above 3 kc, his HL in March exceeded the range of the group audiometer.) His questionnaire showed that he spent about 30 hours per week near jets with protection 30% of the time, and had been exposed to 35 afterburner shots with 100% protection. However, under "particular incident" he complained that his plugs were too small (and he did not use the muffs). In view of this, it is not surprising that he had had a good deal of noise-induced tinnitus, and reported trouble understanding conversation for two hours after exposure about 35 times since the first test!

The only sizable high-frequency notch that appeared during the seven months is shown in Figure 4.9B. Under the last item in the questionnaire ("particular incident") he had written "target practice with a .45."

Figure 4.9C represents a 21-year-old AN who reported 5 hrs/wk noise exposure and a total of 15 afterburner run-ups, all without ear protection. Figure 4.9D is a 19-year-old AN: 5 hrs/wk and 50 afterburner shots with 20% and 40% protection by earplugs, respectively. These flat losses probably are not permanent, since they are representative of the type and magnitude of loss that disappeared between test and retest in about a dozen men who used ear protection regularly during the interim.

Bilateral Asymmetry

One interesting facet of the survey data has not yet been mentioned: the generally greater sensitivity in the right ear, except at 8 kc. Table 4.8 shows the difference in db between the medians for right and left ears (all men). Also included are similar data from the Wisconsin State Fair (WSF) surveys.[4.8] The order of testing of ears in the Wisconsin surveys was randomized. However, order of testing does not seem to have any effect on the difference, since Fletcher and Solomon[4.10] got comparable results using a procedure in which the left ear was tested first.

It is difficult to explain this difference. Certainly the comparison of right and left ears of the same observers is the most well controlled analysis that one can make. Calibration data for the earphones showed that the disparity was not due to differences in earphone response. The difference,

TABLE 4.8

Difference Between Median Right- and Left-Ear Thresholds as a Function of Frequency. A positive value means that the right ear was the more sensitive.

FREQUENCY (kc)	DIFFERENCE		
	PRESENT STUDY	1954 WSF 4.8	1955 WSF 4.8
1	0 7	0 8	-0 2
1 5	0 8	0 3	——
2	1 4**	1 4	1 4
3	1 6*	2 8	2 9
4	2 5**	2 8	3 4
6	0 6	4 1	-0 5
8	-2 6	——	-3 6

* $P > .05$

** $P > .01$

moreover, was the same for all 10 listening positions.

The first explanation that comes to mind is that somehow the average left ear has been subjected to more acoustic trauma than the average right ear. This possibility can be tested by comparing the cumulative distribution of thresholds in right and left ears. If the disparity is due to acoustic trauma, then the distributions should diverge; that is, the difference between corresponding right- and left-ear percentiles should become progressively greater as HL increases. (If the distributions were normal, the situation would simply be that the left-ear variance should be larger.)

The greatest median right-left difference was found at 4 kc (Table 4.8). Therefore, decile points were calculated at this frequency for all men in the study (including those with less than overnight rest from the noise). The difference between right- and left-ear distributions at 4 kc was 2.0, 2.8, 2.0, 3.0, 2.5, 2.3, 2.2, 2.3, and 1.3 db for the 10, 20, 30, 40, 50, 60, 70, 80, and 90 percentiles, respectively.

These figures dispose of the possibility that differential exposure is responsible for the difference.

If some structural characteristic is involved, it would be interesting to compare thresholds among a large number of identical twins, to see whether the left-handed twins have better hearing in the left ear. With the present data the nearest approach is to compare right- and left-handed men. There were 115 left-handed men in the total group of 1209. Figure 4.10 shows the percentage of men with right ear more sensitive, as a function of frequency, for these 115 left-handed men and for a randomly-selected group of 115 right-handed men. Also shown are the .01 & .05 confidence limits for a ratio significantly different from 50%. For the right-handed men, the results are what would be expected from Table 4.8: a significantly greater number of

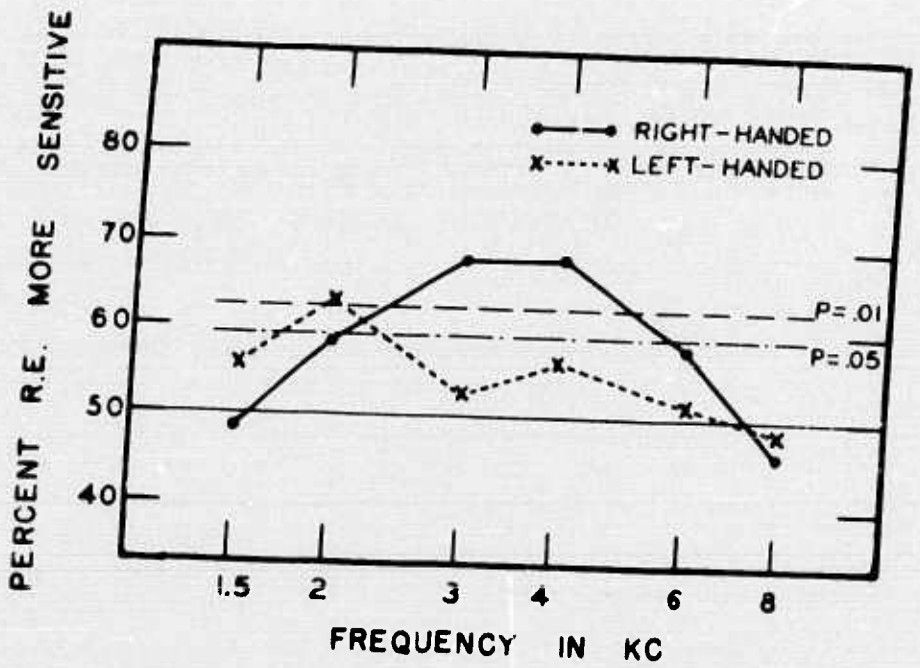


FIGURE 4.10 - Percentage of men with greater sensitivity in the right ear, as a function of frequency and handedness.

men with better right ears in the 2-4 kc range. The left-handed men show a difference only at 2 kc, however. The difference between the two groups is significant at 3 and 4 kc, so apparently handedness has something to do with the right-left disparity, although more study is needed to resolve the puzzle.

A STUDY OF FLIGHT-DECK PERSONNEL (USS FORRESTAL)

Prior to the survey at NAS Cecil Field, a three-month study of the hearing of flight-deck personnel had been conducted aboard an aircraft carrier. The results of this study were in concordance with those reported above, so a separate report does not seem necessary.

A total of 326 men aboard the USS FORRESTAL were tested early in January, 1956, and 296 of these were re-tested late in March, at the end of a training cruise. The group included all men who worked on the flight deck regularly and most of the men who worked there even occasionally.

In the Cecil Field study, the first tests were conducted in hot weather during heavy flight operations, while the follow-up audiograms were obtained in cold weather with little flying. Just the reverse was true aboard the FORRESTAL. The baseline audiograms were obtained in cold stormy weather, so that all men had at least a day's rest from aircraft noise. The final audiograms were taken while the ship was returning to its home base from Guantanamo Bay, Cuba. No flight operations were originally scheduled for these two days, but bad weather during the preceding week forced a change in plans so that few of the men had more than an hour's rest from noise at time of retest.

We could reasonably expect, then, that the changes in threshold would be just the opposite of those found at Cecil Field. And indeed such was the case. The average hearing was about 5 db less sensitive from 1 to 3 kc, dropping to zero shift at 6 kc. Eight men showed additional bilateral 'flat' losses of about 20 db (as in Figures 4.9C and 4.9D), but there is no reason to think that these are even partially permanent. Again the only man developing a high-frequency notch reported tinnitus only following gunfire in the intervening three months.

Although differences were not statistically significant, an analysis in terms of working location showed that the men with the most severe exposures had more temporary loss than those working in less noisy spots. The greatest loss occurred among the crew of 'chock men' who stood between the forward catapults and especially the 'holdback' and 'bridle' men who have to get underneath each plane to attach the catapult gear.

A group of 20 men were tested before and immediately after a normal day's flight operations (no afterburner). A temporary loss of about 5 db at all frequencies was found.

It is not surprising that the 'pre-exposure' hearing of the flight-deck personnel was quite comparable to that of the men in the Cecil Field study, since the same types of noise exposure are involved in both groups. HL as a function of age is almost exactly the same as on the corresponding curves in Figure 4.4. Two men were found to have complete unilateral deafness; the fact that these men probably entered the service with these losses underscores the need for complete abolition of the 'whisper test' at the pre-induction physical examination, and the use instead of an audiometer of some sort.

CONCLUSIONS

The main conclusion to be drawn from these studies is that gunfire, both large- and small-caliber, has probably been the major cause of hearing loss among the naval personnel studied here. Although men with a history of exposure to noise from reciprocating and non-afterburner-jet engines have more hearing loss than non-exposed men of the same age, the difference becomes statistically insignificant when one takes into account the fact that these men have also been exposed to more gunfire.*

Aircraft noise exposure produces temporary hearing losses that are flatter (i.e., approximately the same from 1 to 8 kc) than the shifts caused by gunfire and other impulse noises. Whether there are cumulative effects from repeated temporary losses can only be answered by further research. None was found after seven months of normal exposure.

There was not very much exposure to afterburner noise during this

* During the course of the follow-up study, baseline audiograms were determined on another squadron which was due to receive jets with afterburner. Those men indicating Tg were asked what type of gunfire produced the tinnitus. The two most-blamed sources were the .45 pistol and the 5-inch guns, which were mentioned equally often.

period, so that we cannot conclude that there is no danger from the newest engines. However, the fact that no great losses occurred among the men who had the most afterburner exposures without ear protection tells us that the danger was not critical at the time of the tests.

The general improvement of hearing during the seven months, in the men who used ear protection, indicates that helmets incorporating Clark protective muffs afford ample protection against the worst noise encountered in early 1957 by squadron maintenance personnel. In contrast to their attitude toward earplugs, which was almost universally unfavorable, the men generally liked the helmets. Whether this acceptance will be as wholehearted during warm weather as it was during the winter remains to be seen.

Men with high-tone losses at first testing did not show any more additional loss after the seven months than did those men with normal hearing. It is therefore probably safe to allow men with pre-existing hearing losses at the higher frequencies to be assigned to noisy jobs, unless the deficit is so severe that any further loss would cause difficulty with ordinary conversation. However, the hearing of such men should be tested at frequent intervals.

It is interesting to note that results very similar to the present ones have been obtained in studies in which the same men exposed to aircraft noise have been monitored over a period of time. Senturia[4.16] followed the hearing of 100 Air Force cadets from induction to the completion of advanced training during World War II. He found temporary losses of the same type and degree as those reported here, but no marked permanent changes. Likewise, Sataloff,[4.17] in a five-year study of men working around jet-engine test cells, found only slight changes, and even those could not unequivocally be attributed to noise. Similar negative results were found recently by Kopra.[4.18]

These results simply emphasize the obvious: One cannot make a valid decision as to the effects of a particular noise environment unless adequate controls are employed. A causal relation between noise and hearing loss cannot be assumed simply on the basis of joint occurrence.

4.16 - Senturia, B. H., The influence of airplane noise on auditory thresholds. Ann Otol Rhinol & Laryngol., 61: 331-349, 1952.

4.17 - Staloff, J. The effect of prolonged exposure to intense noise on hearing acuity. Arch. Otolaryngol., 58: 62-80, 1953.

4.18 - Kopra, L., Hearing loss among Air Force flight line personnel. J. Acoust. Soc. Amer., 29: 1277-1283, 1957.

APPENDIX 4.1

AUDITORY TEST

AUDITORY TEST

The self-answering questionnaire seemed to work rather well with this population. Many of the men were asked essentially the same information in an interview, and the results were only rarely in disagreement.

The questionnaire that is given below, which is suitable for routine administration to naval aircraft maintenance personnel, is a shortened version of the one given to the men at Cecil Field. The original questionnaire contained questions on "distance from plane you usually work," aural pain, drainage from ears, surgery on ear or mastoid, unconsciousness from head blow, spontaneous tinnitus, and familial history of deafness. None of these items was found to be related to hearing loss unless they were entered in the last item ("particular incident").

If the questionnaire were to be expanded, it should be in the direction of quantifying and classifying exposure to, and aftereffects of, the various types of gunfire. Particular attention should be given to firearms producing the sharpest wave front. Mere division on the basis of caliber is probably useless, since the three-inch guns were found to produce much more tinnitus (and hence presumably more hearing loss) than those of larger caliber.

AUDITORY QUESTIONNAIRE

Position _____ Run # _____

NAME _____ RATE _____ SQUADRON _____ AGE _____
(Last, first, initial)

Job: (circle appropriate class)
Mechanic Ordance Line Structures Electrical Not-exposed-to-noise

Time since exposure to noise: How long has it been since you were last:
Within 50 feet of a firing afterburner? _____
Within 30 feet of jet (afterburner not firing)? _____

PREVIOUS NOISE EXPOSURE:

How long have you worked near planes with afterburner? _____ months.
How long had you worked near jets without afterburner? _____ years.
How long had you worked near prop planes? _____ years.
How many times have you been working within 50 feet of a plane while the afterburner was firing? (Try to estimate the number of planes as closely as possible) _____ planes

About what fraction of the time did you have ear protection _____ %
What type of protection?
_____ MUFFS PLUGS BOTH OTHER _____

In an average work-week, about how many hours do you spend within 30 feet of jets (idling to 100%; afterburner not firing)? _____ hours.

About what fraction of the time do you use ear protection? _____ %
What type of protection? MUFFS PLUGS BOTH OTHER _____
How long ago did you start using this ear protection? _____ months ago.

Have you had any exposure to gunfire from heavy arms (above 50 caliber)
YES NO _____
If so, did you use ear protection YES NO If so, what type? _____

Have you gone hunting 10 times or more in your life? YES NO _____
Have you engaged in target practice 10 times or more? YES NO _____
Are you a right-handed or left-handed shooter? RIGHT LEFT _____

Have you ever had a ruptured eardrum? YES NO If so, which ear? _____
Have you ever had a ringing in your ears that lasted half an hour or more?
YES NO _____
If so, was this after gunfire or after noise? GUNFIRE, NOISE, BOTH

After exposure to gunfire, have you ever had any trouble hearing ordinary conversation? YES NO

If so, how long did this condition last? _____

After exposure to noise other than gunfire, have you ever had trouble hearing ordinary conversation? YES NO If so, how long did this last? _____

If there is a particular incident of any sort that you think might have damaged your hearing (for example, an accidental explosion, a blow on the ear, or the like), please describe the incident below, mentioning about how long ago it happened.

_____

_____

_____

APPENDIX 4.2

SUSCEPTIBILITY TEST

SUSCEPTIBILITY TEST

The 'susceptibility' hypothesis is something like the following: "Given equal acoustic exposure, some men will suffer more permanent hearing loss than others." The hypothesis has not been directly tested, since it is difficult to find volunteers for an experiment in which exposures will be increased until a given fraction of the men have incurred significant permanent losses. Indirect evidence for its validity is that (1) given equal acoustic exposure, some men suffer more temporary hearing loss than others, and (2) in situations where our best guess is that the men all receive the same exposure, some men suffer more permanent hearing loss. It is obvious that, other things being equal, men with true conductive losses would be better protected than others, but other factors contributing to differences in over-all susceptibility are still in doubt.

In a field study such as ours, it is quite certain that no two men will receive stimulations more than remotely alike, even on the same day, due to the non-uniformity of the sound fields concerned. However, if a susceptibility test is ever to be validated, it must be used in situations such as ours, in which a chance of permanent damage is known to exist.

For this reason, some effort was given toward developing a test which could be given to the 10 men in a listening group. At the time, Rüedi had just published an intriguing article on the effects of stimulation with white noise on the threshold at 4 kc.[4 19] According to Rüedi, there is, for a given ear at a given time, some sort of critical intensity (CI) of white noise which if exceeded produces a threshold shift at 4 kc quite different from that produced at lower intensities.

Therefore, a set of studies was intitiated to see whether or not the method of threshold determination used here (the method of single descent) could be used to find this CI. Groups of 10 incoming cadets were stimulated for two-minute intervals with white noise (20-6000 cps) at intensities increasing from 80 to 110 db SPL in 5-db steps. Between each noise stimulation the threshold for 4 kc was determined as many times as possible during two minutes. The sequence then was: 2 minutes test at 4 kc, 2 minutes noise at 80 db SPL, 2 minutes test at 4 kc, 2 minutes noise at 85 db SPL, etc. Threshold at 4 kc was tested for 4 minutes after the 110-db noise exposure.

It soon became apparent that no discontinuities of the sort reported by Rüedi could be found for individual subjects, using our method. In the article by Rüedi,[4 19] his Figure 11 shows that once the CI is exceeded, TTS is constant; that is, there is no more fatigue from CI + 15 db than from CI + 5 db. Such results were not often seen in the present studies; more often, once the TTS began to rise as a function of intensity, further increases simply meant more TTS. Apparently CI must be found using the specialized technique described by Rüedi involving continuous tones in a

4 19 - Rüedi, L., Different types and degrees of acoustic trauma by experimental exposure of the human and animal ear to pure tones and noise. Trans. Am. Otol. Soc., 42: 186-210, 1954.

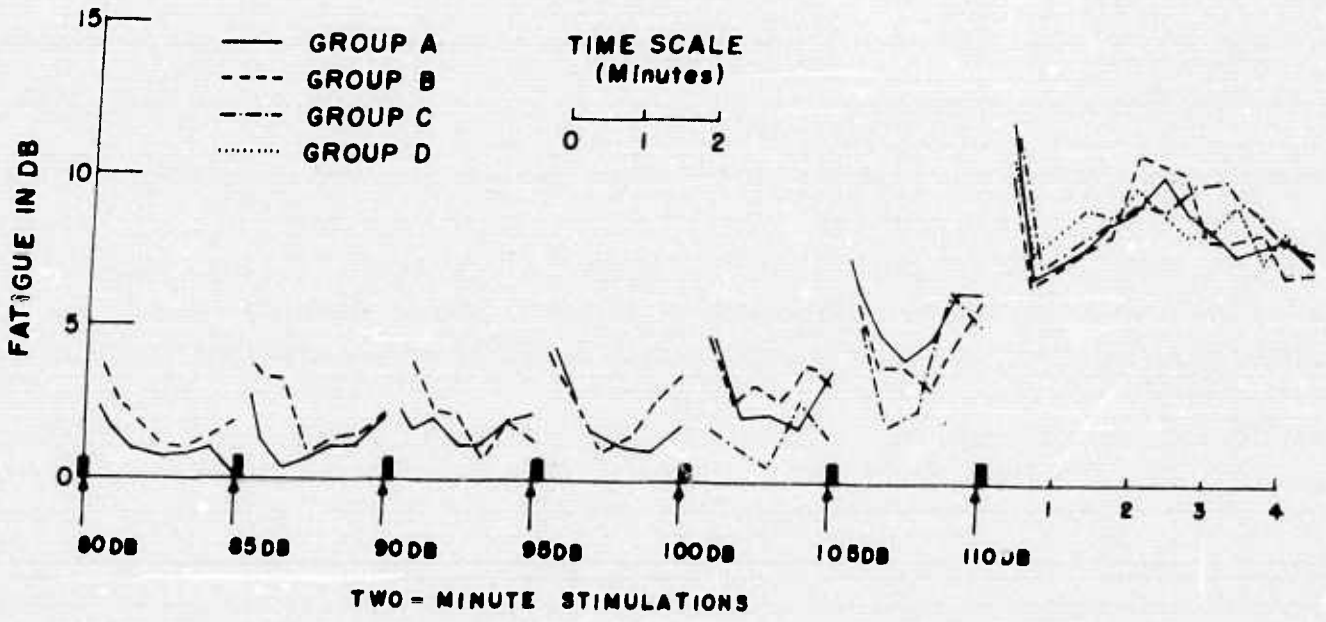


FIGURE 4.11 - Recovery curves for a 4 kc tone following two-minute stimulation by white noise at different levels.

Bekesy-type audiometer.

Mean results for four different groups of 10 men are shown in our Figure 4.11. Groups A and B went through the entire sequence as outlined above. Group C, however, was started at 100 db SPL, and group D was given only the 110-db stimulation. The agreement among groups shows that in a series of ascending-intensity fatigue tests, no significant cumulative effects are to be expected (at least up to 110 db SPL). The diphasic character of the recovery process (the 'bounce' at 2 minutes)[4.20] is clearly seen in all groups.

All 326 men tested aboard the USS FORRESTAL were given a susceptibility test consisting of noise at 110 db SPL for 2 minutes, the susceptbility index being the average TTS at 4 kc from 0.5 to 2 minutes following cessation of the noise. The observed shifts were normally distributed with a mean of 7 db and a standard deviation of 3.3 db. There was no average difference between right and left ears. The correlation between the shifts in the two ears of the same observer was 0.39, a highly significant value (P is much less than .001).

The TTS was not correlated with the threshold changes observed at the end of the cruise, nor with the temporary loss associated with a single day's work. This tells us nothing about the validity of this susceptibility test, though, because the individual differences in amount of noise exposure were so large. This lack of uniformity of exposure is so great that one may well question the advisability of trying to validate a susceptibility test on members of the armed forces.

4.20 - Hirsh, I. J., and Ward, W. D., Recovery of the auditory threshold after strong acoustic stimulation. J. Acoust. Soc. Amer., 24: 131-141, 1952.

CHAPTER 5

NON-AUDITORY EFFECTS OF EXPOSURE TO HIGH-INTENSITY NOISE

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INTRODUCTION

In the study of the non-auditory effects of exposure to high-intensity noise we were primarily interested in assessing the cumulative effects of repeated exposure to jet noise. Since there was practically no basis for deciding what specific types of performance, if any, would be affected, a variety of performance meansures were used. A broad survey of possible cumulative effects should tell whether jet noise was endangering the well-being of exposed personnel. It might also indicate what types of performance would most probably be affected when noise levels become even higher. Future investigators could then concentrate on monitoring these specific types of performance.

The selection of non-auditory tests was limited by a number of practical considerations:

1. Since the tests were to be given at several naval establishments, the equipment required for test administration had to be kept at a minimum.

2. One individual was to do most of the testing. Short tests (five minutes or less) were therefore essential, and group tests were desirable wherever possible.

3. Only tests that could be repeated were of value since subjects were to be retested after a period of exposure to noise.

The test battery was at first designed to cover all areas of performance that could be affected by exposure to jet noise. Selection of the specific tests was aided by information from subjective reports of exposed personnel, from the results of investigations of the effects of temporary exposure, and from the advice of experts in relevant scientific areas.

Over two hundred tests were carefully examined for possible use, and more than sixty of these were administered during preliminary investigations. Tests used in the preliminary investigations, but not included in the final battery, are listed in Appendix 5.1 along with the reasons for discarding them.

Several trials of the test battery were given in order to eliminate faulty tests and detect areas which should be covered:

1. Twenty-one tests were given to 33 enlisted men at NAS Pensacola (March, 1955).

2. Thirteen tests were given to 19 enlisted men aboard the USS TICONDEROGA (August, 1955).

3. Twenty-two tests were given to 40 enlisted men aboard the USS FORRESTAL (January, 1956).

4. Seven tests were given to 63 enlisted men aboard the USS TICONDEROGA (June, 1956).

A number of the men tested during these trials had been exposed to jet noise, but in most cases the exposure was at low noise levels and was of short duration. There was no large difference between the performance of exposed and non-exposed personnel on any of the tests.

It was soon apparent that a truly comprehensive survey of non-auditory performance was beyond the scope and capabilities of the present

investigation. Not enough personnel were available to administer a complete test battery. A program of psychiatric interviewing was initiated, but the psychiatrist was available for only a short time. Personnel and facilities were not available for the measurement of physiological stress reactions. Electrophysiological measures of stress were developed, but could not be used in field testing situations because of lack of time for the maintenance of equipment.

Experience gained from the above-mentioned field trials revealed the disadvantages of a cross-sectional comparison of exposed and non-exposed personnel. Differences between individuals in age, intelligence, and special skills could not be adequately controlled, since it was not possible to test large groups of subjects. We therefore decided to use the test-retest method where each subject would serve as his own control. Individuals would be tested before and after a period of noise exposure, and changes in their performance would be compared with changes in performance of subjects having either no exposure or less exposure during the period between tests. Such retests were to be given in the testing program aboard the USS FORRESTAL, but an unexpected change in the operating schedule of the carrier prevented this.

The final study, which was conducted at NAS Cecil Field, included a number of subjects who had been exposed for long periods of time to jets operating with afterburners. The study consisted of three parts:

1. A group of 16 psychological tests was administered twice to the same personnel, with an interval of six months between tests (test-retest method).

2. Sick-call records were analyzed according to the frequency of reports to sick call for the six-month period before the first psychological tests and for the six-month period between tests.

3. A group of nine paper-and-pencil tests was given during the final testing period.

The performance of noise-exposed subjects was compared with that of non-noise-exposed subjects. The results showed no large differences between exposed and non-exposed groups on any of the tests. Taking all of the test results into consideration, however, it appeared that there might be a slight general depression of performance for the noise-exposed groups as compared with the non-exposed groups. A complete discussion of the Cecil Field study is given on the following pages.

THE CECIL FIELD INVESTIGATION: PART I
TESTS GIVEN BY TEST-RETEST METHOD

In July, and August, 1956, a battery of non-audiotry tests was administered to 173 enlisted men at NAS Cecil Field. The test battery provided a somewhat unsystematic survey of non-auditory performance. It included only tests which gave reliable results, and which could be given easily and rapidly in the field situation. Tests of motor speed, motor coordination,

central nervous functions, complex intellectual functions, vision, equilibrium, tactual sensation, and emotional adjustment were included in the battery. Appendix 5.2 gives a brief description of each test, including scoring procedures.

Six of the tests were given during the group audiometric testing sessions. These tests were administered to 173 men, and were designated as large-sample tests. Ten tests, administered to 42 men during individual testing sessions, were designated as small-sample tests.

A number of the men tested had been exposed to high-intensity noise for a considerable length of time. Comparison of their test results with those of non-noise-exposed personnel revealed no significant differences in performance on any of the tests given during the initial testing period.

All of the original subjects who remained at Cecil Field were retested in March, 1957. Changes in performance from the initial test to the retest were related to estimates of the noise exposure incurred by these subjects during the six-month period between tests.

Subjects

Ninety-five enlisted men were given the non-auditory retests. All of the subjects were given the large-sample tests, and 31 of the subjects were given the small-sample tests. The ages of the men tested ranged from 17 through 37, with 62 men falling in the age range of 17 through 22. The group included men with duty assignments as mechanics (26 men), ordnance (8 men), structures (10 men), electrical (26 men), general line (13 men), and non-line personnel (13 men).

The number of subjects tested varied from one large-sample test to another, and also among several of the small-sample tests. In some cases it was not possible to administer all tests to all subjects in the allotted time, and in other cases the test results could not be used because of malfunction of apparatus or failure of some subjects to follow instructions.

Test and Measurement Procedures

The apparatus and procedures used for the retests were the same as those used for the initial tests except for the Digit Symbol Test. Here, Form I was used for initial tests and Form II (an equivalent form) was used for the retest. A brief description of apparatus, procedures of administration, and methods of measurement for each of these tests is given in Appendix 5.2.

Criteria of Hazardous Noise Exposure

As a first step in assessing changes in performance from the initial test to the retest, a measure of the amount of hazardous noise exposure incurred by each subject was necessary. At the present time, we cannot specify the combination of intensity and duration that will consititute

"hazardous" exposure in the sense of producing non-auditory performance changes. In the absence of a single well-defined criterion of hazardous exposure, non-auditory performance changes were related to the three separate criteria of noise exposure which are described below.

1. Hearing Loss as the Criterion of Hazardous Noise Exposure.

An exposure to jet noise that is sufficient to produce persistent hearing loss might not change non-auditory performance at all. Conversely, it is possible that non-auditory changes could occur in the absence of persistent hearing loss. On a priori grounds, however, high-frequency hearing loss known to be the result of exposure to jet noise seems to be the best criterion for the prediction of non-auditory effects.

In order to obtain a measure of change in auditory threshold that would represent noise-induced hearing loss, an average of the threshold shifts at 4 and 6 kc for both ears was calculated for each subject. According to the usual convention, an elevation of threshold (i.e., a loss of sensitivity from the first test to the retest) is presented as a positive quantity, and a lowering of threshold (improvement of sensitivity) from the first test to the retest is presented as a negative quantity.

The distribution of shifts in auditory threshold is given in Table 5.1. Almost half of the group showed an improvement of 2.1 decibels or better, indicating that many subjects had a temporary hearing loss at the time of the first test. Only 7 of the 95 subjects taking the large-sample tests suffered an average loss of sensitivity of 5 decibels or more. Since threshold shifts smaller than this could be attributed to chance variation, this group was designated as the "most-exposed" group for this criterion of hazardous exposure. The group of subjects exhibiting virtually no change in threshold (-2.0 to 2.0 db change) was designated as the "least-exposed" group. Since only four of the subjects who took the small-sample tests had hearing losses of more than 2.0 db, the small-sample test results were not analyzed according to this criterion.

TABLE 5.1

Average Shift in Auditory Threshold for Subjects Retested at NAS Cecil Field

SHIFT IN DECIBELS	NUMBER OF SUBJECTS	
	LARGE-SAMPLE TEST	SMALL-SAMPLE TEST
-5.0 and below* (gain)	18	6
-4.9 to -2.1	27	7
-2.0 to 2.0	34	14
2.1 to 4.9	9	0
5.0 and above** (loss)	7	4

* The largest gain was 18.5 db.

** The largest loss was 10.5 db.

TABLE 5.2

Estimated Noise Exposure During the Six-month Period Between Tests for the Subjects Retested at NAS Cecil Field.

NOISE EXPOSURE GROUP	NUMBER OF SUBJECTS	
	LARGE-SAMPLE TEST	SMALL-SAMPLE TEST
1. (no exposure)	13	3
2.	22	4
3.	12	6
4.	11	6
5.	21	1
6. (very high exposure)	16	11

2. Estimate of Noise Exposure as the Criterion of Hazardous Exposure

Each subject completed a questionnaire (shown in Appendix 5.3) which provided information as to intensity and duration of noise exposure, use of ear protection, duty assignment, and occurrence of traumatic noise exposure during the six-month period between tests. By means of these questionnaires a rough estimate was made of each man's exposure during the period between tests, and subjects were divided into groups according to the estimated severity of their exposure.

The group assignments cannot, however, be considered completely accurate. As stated previously, we do not know what conbination of intensity and duration constitutes hazardous exposure. In addition, considerable error can be expected in a man's subsequent estimates of the length of his exposures, his distance from the noise source, and the percentage of the time that he used ear protection.

Subjects were divided into six groups according to their estimated noise exposure, as shown in Table 5.2. These ranged from a group having had essentially no exposure between tests (Group 1), to a group having had a large amount of exposure to jets operating with afterburner during this period (Group 6). For the analysis of large-sample test results, Group 1 was designated as "least exposed" and Group 6 was designated as "most exposed." In order to obtain sufficient subjects for the analysis of small-sample test results, Groups 1, 2, and 3 were used as the "least-exposed" group, and Groups 5 and 6 were used as the "most-exposed" group.

3. Type of Noise Source as a Criterion of Hazardous Exposure

The subjects tested were taken from three different squadrons at NAS Cecil Field. At the time of the first test, Squadron VF-101 was using the F2H-3 Banshee, a non-afterburner jet which generated a relatively small amount of noise, even at full power. Immediately after the first test, this squadron received the F4D Skyray with afterburner and used it during the six-month period between tests. The Skyray and the F3H-2N Demon generated the most noise of any fighter or attack planes in use in squadron

strength by the Navy during 1956-7.

Squadrons VA-34 and VA-12 were both using the F7U-3 Cutlass with afterburner at the time of the first test. This jet generates considerably less noise, both with and without afterburner, than the F4D, but considerably more noise than the F2H-3 Banshee. During the six-month period between tests, Squadron VA-12 continued using the F7U-3 Cutlass. Squadron VA-34 also used the F7U-3 during most of this period, but began switching to the non-afterburner A4D Skyhawk toward the end of the period.

With regard to the plane used during the six-month period between tests, then, the men in Squadron VF-101 should have had a much larger increment of hazardous exposure than the men of Squadrons VA-34 and VA-12. The type of noise source was used as the final measure of probable hazardous exposure.

On the large-sample tests, 28 men from Squadron VF-101 and 67 men from Squadrons VA-12 and VA-34 were retested. On the small-sample tests, 15 men from Squadron VF-101 and 16 men from Squadrons VA-34 and VA-12 were retested. For this criterion of hazardous exposure, VF-101 personnel were the "most-exposed" group and VA-34 and VA-12 personnel were the "least-exposed" group. Personnel who did not work on the flight line were not included in this analysis.

Relationships Among the Three Criteria of Hazardous Exposure

Relationships among the three criteria of hazardous exposure are indicated in Table 5.3. There appears to be no systematic relationship among the three criteria. In no case does the "most-exposed" group of one criterion contain a disproportionately large number of members of the "most-exposed" group of another criterion. It can therefore be concluded that the three criteria are independent. This indicates that no one criterion provides an adequate index of hazardous exposure, and that conclusions based upon changes in performance resulting from noise exposure will be inaccruate, at least to the extent that the exposure criterion is inadequate.

Results

In order that the performance of noise-exposed and non-noise exposed personnel could be most clearly distinguished, only the results of the "most-exposed" and "least-exposed" groups for each criterion of hazardous exposure were statistically analyzed. Since no striking differences were found in the performance of these two groups, no further analysis was made of the results of intermediate groups.

The method of statistical analysis of the test-retest data will be discussed in some detail, since it differs from the conventional procedure used in Chapter 4 in assessing auditory shifts from test to retest. The test-retest method was used in this study in order that changes in performance of noise-exposed personnel could be compared with changes in performance of non-noise-exposed personnel. A measure of change can be calculated

TABLE 5.3

Relationships Among the Three Criteria for Noise Exposure, with the Number of Subjects in Each Category being indicated

a. Estimate of Noise Exposure vs. Auditory Threshold Shift

NOISE EXPOSURE GROUP	THRESHOLD SHIFT IN DECIBELS (Gain)				(Loss)
	-5.0 AND BELOW	-4.9 TO -2.1	-2.0 TO 2.0	2.1 TO 4.9	5.0 AND ABOVE
1. (no exposure)	1	4	7	1	0
2.	2	9	7	2	2
3.	3	3	3	0	3
4.	4	3	2	2	0
5.	4	4	9	3	1
6. (very high exposure)	4	4	6	1	1

b. Auditory Threshold Shift vs. Squadron Assignment

THRESHOLD SHIFT IN DECIBELS	SQUADRON		
	VF-101	VA-34	VA-12
-5.0 and below (Gain)	5	6	7
-4.9 to -2.1	11	9	7
-2.1 to 2.0	9	16	9
2.1 to 4.9	1	4	4
5.0 and above (Loss)	2	3	2

c. Estimate of Noise Exposure vs. Squadron Assignment

NOISE EXPOSURE GROUP	SQUADRON		
	VF-101	VA-34	VA-12
1. (no exposure)	3	6	4
2.	10	9	3
3.	4	6	2
4.	1	5	5
5.	5	8	8
6. (very high exposure)	5	4	7

by simply subtracting the initial test score from the retest score for each subject. On a test where the noise-exposed and non-noise-exposed subjects differ in their initial level of performance, however, this procedure could produce misleading results. Specifically, misleading results would occur on any test where the amount of change in performance was related to the initial level of performance. For example, an individual performing at a high level of skill on the first test might tend to show no improvement on the retest, whereas an individual performing at a low level of skill on the first test might tend to show a large amount of improvement on the second test.

Such a correlation between initial level of performance and magnitude of change from test to retest would be expected on a number of the non-auditory tests. As a means of correcting for any such correlations, the analysis of covariance procedure was used for statistical analysis of the test results.* By this procedure, the "most-exposed" and "least-exposed" groups were statistically matched in terms of their performance on the initial test. On the basis of this matching of initial test scores, an adjustment was made in the mean retest scores of each group. The statistical comparison of group performance was made in terms of these adjusted mean scores, where any influence of differences in initial level of performance had been removed.

Adjusted mean scores for the six large-sample tests, analyzed according to each of the three criteria of exposure, are given in Table 5.4. Although the "most-exposed" group performed worse than the "least-exposed" group on 14 out of the 18 comparisons, the difference between groups was statistically significant for only one comparison (5 per cent level of confidence). With 18 comparisons, one statistically significant difference would be expected to occur by chance.

Results of the ten small-sample tests are shown in Table 5.5. The criterion of auditory threshold shift was not used for this analysis, since only 4 subject showed an appreciable hearing loss. With the results analyzed according to the two remaining criteria of hazardous noise exposure, no significant differences appeared for any of the comparisons. The "most-exposed" group performed worse than the "least-exposed" group on seven of the ten tests analyzed according to estimate of noise exposure, but on only five of the ten tests analyzed according to squadron assignment.

A further analysis of the data was made by combining the three criteria for hazardous exposure and calculating a combined exposure score for each man. "Most-exposed" and "least-exposed" groups were selected on this basis, and the group differences were tested by analysis of covariance. No statistically significant differences were found, although the "most-exposed" group exhibited the poorest performance on 13 of the 16 tests.

The possibility of a slight, general depression of performance is indicated by the poorer performance of the "most-exposed" group on 26 of the 38 comparisons (or 39 out of 54 comparisons, including the combined

* The author is indebted to Drs. Lyle V. Jones and R. C. Davis for suggesting the use of this technique.

TABLE 5.4

Adjusted Mean Retest Scores for the ''Most-Exposed'' and ''Least-Exposed'' Groups on the Large-Sample Tests, Analyzed According to Each of the Criteria for Hazardous Noise Exposure. The Score of the Group Exhibiting the Poorest Performance for Each Comparison has been Underlined.

TEST	TYPE OF TEST*	CRITERION OF HAZARDOUS NOISE EXPOSURE					
		AUDITORY THRESHOLD SHIFT		ESTIMATE OF NOISE EXPOSURE		SQUADRON ASSIGNMENT	
		MOST-EXPOSED	LEAST-EXPOSED	MOST-EXPOSED	LEAST-EXPOSED	MOST-EXPOSED	LEAST-EXPOSED
Critical Flicker Frequency	H Score / N =	<u>38.9**</u> / 7	40.8 / 30	<u>40.6</u> / 15	41.3 / 12	40.5 / 24	<u>39.6</u> / 55
Tapping Speed	H Score / N =	20.8 / 7	20.8 / 30	<u>19.5</u> / 14	20.1 / 12	20.7 / 24	<u>20.1</u> / 54
Reaction Time	L Score / N =	<u>204.9</u> / 7	191.6 / 30	<u>218.2</u> / 14	201.1 / 12	<u>199.6</u> / 24	199.5 / 54
Fine Hand Steadiness	L Score / N =	<u>32.5</u> / 7	26.7 / 29	25.2 / 15	<u>31.9</u> / 10	<u>28.8</u> / 21	26.0 / 48
Gross Hand Steadiness	L Score / N =	<u>17.9</u> / 7	15.7 / 30	<u>15.2</u> / 15	14.7 / 10	<u>18.7***</u> / 22	14.8 / 49
Steadiness of Standing	L Score / N =	<u>35.4</u> / 7	28.9 / 30	<u>30.9</u> / 15	27.3 / 11	<u>31.4</u> / 21	31.0 / 50

* For a test designated as ''H'', a high score indicates good performance and a low score indicates poor performance; for a test designated ''L'', a low score indicates good performance and a high score indicates poor performance.

** The units of measure used for each test are given in Appendix 5.2.

*** The ''most-exposed'' showed significantly poorer performance (5 percent level of confidence) on this comparison.

TABLE 5.5

Adjusted Mean Retest Scores for the ''Most-exposed'' and ''Least-exposed'' groups on the Small-Sample Tests, Analyzed According to Two Criteria for Hazardous Noise Exposure. The Score of the Group Exhibiting the Poorest Performance for Each Comparison Has Been Underlined.

TEST	TYPE OF TEST*	CRITERION OF HAZARDOUS NOISE EXPOSURE							
		ESTIMATE OF EXPOSURE				SQUADRON ASSIGNMENT			
		MOST-EXPOSED	N	LEAST-EXPOSED	N	MOST-EXPOSED	N	LEAST-EXPOSED	N
Tactual Threshold	L	10.4**	11	5.8	13	8.2	14	8.5	14
Knox Cube Test	L	2.7	11	2.4	13	2.1	14	2.1	14
Dexterity Test	H	15.9	11	17.4	13	16.4	14	16.8	14
Digit Symbol Test	H	52.6	11	52.8	13	52.3	14	50.7	14
Taylor Anxiety Scale	L	10.7	11	6.3	12	10.1	14	7.5	12
Saslow Screening Inventory	L	1.6	11	2.5	13	2.6	14	2.0	13
Cornell Index	L	4.7	11	3.1	13	5.1	14	3.5	13
Visual Acuity	H	21.1	11	21.8	13	21.0	14	20.7	14
Visual Phoria	H	4.8	11	5.1	12	5.1	14	6.3	12
Depth Perception	H	6.1	10	5.1	12	5.2	11	5.5	13

* For a test designated as ''H'' a high score indicates good performance and a low score indicates poor performance; for a test designated as ''L'', a low score indicates good performance and a high score indicates poor performance

** The units of measure used for each test are given in Appendix 5.2.

criterion), but this by no means provides a conclusive demonstration of noise-induced deteriorations in performance on the test-retest measures.

THE CECIL FIELD INVESTIGATION: PART II
ANALYSIS OF HEALTH RECORDS

A direct assessment of the men exposed to jet noise was made from their health records. Each time that a naval enlisted man reports to sick call the complaint, diagnosis, and treatment are noted on his health record. A variety of complaints had been recorded for the men with whom this study is concerned. The most common were colds and minor injuries. A fairly large number of the men had never reported to sick call.

The reports to sick call by these personnel for a period of six months before our first set of tests (March through August, 1956) were compared with the number of reports during the six-month period between tests (September, 1956 through February, 1957). By using the three criteria of hazardous noise exposure which were discussed in the previous section, changes in frequency of reports to sick call could be related to the amount of hazardous exposure during the second six-month period.

For each subject the total number of reports to sick call per six-month period was determined. This type of analysis will reflect factors in addition to the general health of the individual. Hypochondriasis and accident-proneness would, if present, affect the frequency of reports to sick call, and such factors are obviously important for the present investigation.

An attempt was also made to analyze sick call records in terms of frequency of on-the-job injuries. This analysis has not been included here, because the frequency of such injuries was very low, and in many cases the duty status of the man at the time of injury could not be ascertained.

Subjects

The 183 enlisted men from Squadrons VF-101, VA-12, and VA-34 who had received the auditory retest were the subjects for this analysis.

Procedure

For each subject, the number of times he reported to sick call during the six-month period before the first tests and the number of times he reported during the six-month period between tests was determined. Repeated treatments required by the medical officer were counted as only one visit, and routine physical examinations were not counted.

Results

Groups receiving the most exposure and the least exposure during the second six-month period were selected according to each of the criteria of hazardous noise exposure shown above.

The selection standards were identical with those used for the analysis of large-sample test scores. Analysis of covariance was used to calculate the adjusted mean frequency of report to sick call during the second six-month period (by a statistical matching of groups in terms of frequency of reports to sick call during the first six-month period), and to calculate the significance of any differences between the adjusted group means.

The adjusted mean frequency for the "most-exposed" and "least-exposed" groups according to each criterion are shown in Table 5.6. All of the adjusted mean frequency fell within the narrow range of 1.0 to 1.5 reports to sick call per six months. According to two of the three criteria of hazardous exposure, the "most-exposed group showed a slightly higher incidence of reports to sick call, while the reverse was true for the remaining criterion.

The relatively low over-all incidence of reports to sick call and the extremely small and unsystematic differences between groups indicate that noise exposure did not affect this aspect of non-auditory behavior.

TABLE 5.6

Adjusted Mean Frequency of Report to Sick Call, Analyzed According to Each of the Criteria of Hazardous Noise Exposure.

CRITERION	MOST-EXPOSED	N	LEAST-EXPOSED	N
Auditory Threshold Shift	1.5	10	1.2	59
Estimate of Noise Exposure	1.0	37	1.4	23
Squadron Assignment	1.3	45	1.1	115

THE CECIL FIELD INVESTIGATION: PART III
GROUP PAPER-AND-PENCIL TESTS

Group paper-and-pencil tests were given in March 1957 on the second trip to Cecil Field. It was not possible to administer these tests during the first trip, since they had not been printed at that time. The results of these tests, then, could provide only a cross-sectional comparison. These results are more meaningful, nevertheless, than the results obtained in the preliminary investigations, since the "most-exposed" group used in the present study had much more noise exposure in terms of intensity than any of the groups used in previous cross-sectional comparisons.

A description of the nine factored aptitude tests is given in Appendix 5.4. Seven of the tests provided measures of complex intellectual functions. The other two tests (aiming and motor speed) provided measures of motor skill. All of the tests were speed tests.

Subjects

The group paper-and-pencil tests were given to 49 enlisted men from 12 squadrons at Cecil Field. The planes used by the 12 squadrons included propeller-driven aircraft, and jets with and without afterburners.

Procedure

A history of previous noise exposure was obtained by a short interview with each man, during which the questionnaire shown in Appendix 5.5 was completed. From this questionnaire the noise exposure for each subject was estimated, as in Part I. The subjects were divided into four groups, with only the results of Groups 1 and 4 being used in the data analysis presented here. Group 1, the "least-exposed" group, reported no noise exposure, or exposure to propeller-driven aircraft only. Group 4 the "most-exposed" group, reported a large amount of afterburner exposure to the F3H-2N Demon (The F3H-2N, as noted earlier, equals the F4D as a noise generator).

Results

Seven of the tests measured complex intellectual functions, and, as such, would be positively correlated with general intelligence level. Navy General Classification Test (GCT) scores were used as a measure of the intelligence level of the two groups. The average intelligence level of the "most-exposed" group (mean = 38) was considerably lower than that of the "least-exposed" group (mean = 53). In order to correct for this, analysis of covairance was once again used for the comparison of group performance. In this instance, the groups were statistically matched in terms of GCT scores, and the means of the factored aptitude test scores were adjusted accordingly. The adjusted mean scores for each of the tests are shown in Table 5.7. The "most-exposed" group gave the poorest performance on eight of the nine tests, but in only one case was the difference between groups statistically significant (at the 5 percent level of confidence).

There seems to be a somewhat greater indication of noise-induced decrements in performance for this group of tests than for the previously discussed tests. It should be remembered, however, that this analysis involved a cross-sectional comparison rather than a test-retest comparison, with a consequent loss of control of individual differences.

GENERAL DISCUSSION

The study of non-auditory effects was handicapped by the lack of a single, precise criterion of hazardous noise exposure, and by the relatively small number of subjects that were tested. The six-month period of exposure used for the assessment of test-retest performance and for the

TABLE 5.7

Adjusted Mean Scores on Factored Aptitude Tests, With the "Most-Exposed" and "Least-Exposed" Groups Statistically Matched in Terms of Intelligence Level. A High Score Indicates Good Performance for all Tests.

TEST*	ESTIMATE OF NOISE EXPOSURE			
	MOST-EXPOSED	N	LEAST EXPOSED	N
Aiming	63.7	8	70.4	8
Number Facility	21.5	9	26.2	8
Speed of Closure	13.0	9	17.5	8
Speed of Symbol Discrimination**	17.7	9	26.7	8
Deduction	15.3	8	15.4	8
Associative Memory	5.6	9	8.6	8
Induction	9.5	9	10.0	8
Visualization	10.2	9	8.7	8
Motor Speed	10.0	9	11.4	8

* Tests are denoted by the aptitude factors which they purportedly measure. The actual names of the tests are given in Appendix 5.4.

** For this test the difference between means was significant at the 5 per cent level of confidence.

frequency of reports to sick call was probably too short to provide an unequivocal demonstration of the presence or absence of cumulative decrements of behavioral efficiency. Therefore, it is not surprising that no more than a slight trend toward an over-all depression of the performance of noise-exposed personnel emerged from this study.

We can, however, conclude that six months of exposure to the noisiest planes in operational use by the Navy in 1956 resulted in no striking deteriorations in the behaviors tested. There is as yet no clear evidence of cumulative changes in non-auditory performance resulting from exposure to the high-intensity noise of jet aircraft.

The possibility of the occurrence of noise-induced changes cannot, however, be dismissed on the basis of the results of this study. Several of the inadequacies of the present study have already been mentioned. A number of the features of the test results themselves should also be considered. The auditory test results, as discussed in Chapter 4, indicate that the six-month period of noise exposure did not result in a statistically demonstrable change in auditory thresholds for the noise-exposed subjects as a whole. In such a case, we would certainly not expect large changes in non-auditory test performance. As was the case for the auditory measures, however, we cannot dismiss the possibility of noise-induced changes. On 49 out of the total of 66 comparisons made between "most-exposed" and "least-exposed" groups, the "most-exposed" group exhibited poorer performance. An increase in either the duration or the intensity of noise exposure might well make this a much more pronounced trend.

One of the stated aims of this study was not accomplished. This was the indication of crucial areas of performance for future investigators. Neither the presence nor the absence of noise-induced effects was demonstrated for any area of non-auditory performance. If anything, then, the scope of future investigations should be broadened to include areas of performance which were not tested in this study.

SUMMARY

The aims of this investigation were (1) to determine whether present levels of jet noise constitute a real threat to the well-being of exposed individuals in the sense of produceing persistent changes in non-auditory performance, and (2) to lay the groundwork for future investigators by identifying those areas of performance in which there is some indication that noise-induced changes are occurring.

Subjects exposed to the highest noise levels did not exhibit a substantial amount of deterioration in any of the areas of performance that we tested. Therefore, we can state that present noise levels do not constitute a serious threat for exposed personnel in terms of large changes in performance on our test battery. It should be made clear, however, that we can make no predictions about the effects either of higher noise levels of longer periods of exposure. Our conclusions apply only to a period of six months exposure to planes as noisy as the F4D.

APPENDIX 5.1

NON-AUDITORY TESTS USED IN PRELIMINARY INVESTIGATIONS BUT NOT USED IN THE FINAL INVESTICATION AT NAS CECIL FIELD

The principal reasons for discarding the tests listed below were: (1) lack of time for test administration; and (2) overlap between functions measured by these tests and functions measured by tests used in the final battery. The type of performance measured by each test is given in parentheses after the name of the test.

1. Block Design Test (brain damage). Administration time too long. Replaced by Digit Symbol Test.

2. Halstead Critical Flicker Frequency (CFF) Test (central nervous functions). Administration time too long. Replaced by group CFF test.

3. Simple Reaction Time Test (speed of movement). Administration time too long. Replaced by group reaction time test.

4. Two-Choice Reaction Time Test (speed of complex reaction). Administration time too long. Difficulty in interpretation of results.

5. Four-Choice Reaction Time Test (speed of complex reaction). Same as 4.

6. Bennett Hand Tool Dexterity Test (gross dexterity). Administration time too long. Replaced by modified Crawford Tweezer Dexterity Test.

7. Stromberg Dexterity Test (gross dexterity). Same as 6.

8. Crawford Small Parts Dexterity Test (fine dexterity). Same as 6.

9. Minnesota Rate of Manipulation Test (gross dexterity). Same as 6.

10. Sandpaper Test (tactual threshold). Difficulty in interpretation of results. Replaced by von Frey Hair Test.

11. Target Test (kinesthetic sensitivity). Difficulty in interpretation of results.

12. Purdue Hand Precision Test (complex eye-hand coordination). Overlapped with measures of dexterity, reaction time, and hand steadiness.

13. Elgin Test Reaction Scale (motivation). Insufficient time available for the required subjective evaluation.

14. Grayson Brief Screening Test for Organic Brain Damage (brain damage). Highly correlated with intelligence. Replaced by Digit Symbol Test.

15. Psychosomatic Inventory (neuro-psychiatric symptoms). Overlapped with Taylor Anxiety, Cornell Index, and Saslow Screening Inventory.

16. Face-Hand Test (brain damage). Poor subject reaction to test. No errors made by any subjects tested.

17. Henmon-Nelson Intelligence Test (general intelligence). Very highly correlated with Navy General Classification Test Score.

18. Single-Stylus Tapping Test (speed of repetitive movement). Replaced by group tapping test.

19. Double-Stylus Tapping Test (speed of complex repetitive movement). Same as 18.

20. Time Estimation Test (attention span). Results largely a function of "system" used by subject.

21-27. Measures of response to the stresses of delayed speech feedback; high-intensity pure tone, free association, and a modification of the Stroop Test. The response measures used were forearm muscle potential, fore-

head muscle potential, blink rate, heart rate, respiration rate, skin resistance, and finger movement. Some of the stress tests were used during the initial testing phase of the final study. Complete test-retest procedures could not be carried out because of lack of time for equipment maintenance between scheduled subjects.

APPENDIX 5.2

TEST-RETEST MEASURES USED AT NAS CECIL FIELD

The type of performance measured by each test is given in parentheses after the name of the test. A reference for each test is given in parentheses following the test description.

LARGE-SAMPLE TESTS

1. Critical Flicker Frequency (CFF) (central nervous system functioning). Test for determination of the frequency at which a flickering light is perceived as a steady light. Given as a ten-man group test in the trailer laboratory. Subject was required to release a telegraph key as soon as he perceived flicker, where the frequency of flicker was being decreased at a steady rate. Five threshold measures were obtained, with the final score being the median threshold in flickers per second. (Doehring, D. G., Ward, W. D., and Hixson, W. C., The development and standardization of a group test for critical flicker frequency. Joint Project NM 13 01 99 Subtask 1, Report No. 4, Pensacola, Florida: Central Institute for the Deaf and Naval School of Aviation Medicine, 1956.)

2. Simple Reaction Time (speed of voluntary movement). Test for speed of reaction to a visual signal. Given as a ten-man group test in the trailer laboratory. Response measure was the time between presentation of a visual signal and depression of a telegraph key by the subject. Ten trails were given, with the final score being the median reaction time of trials 6 through 10 in milliseconds.

(Teichner, W. H., Recent studies of simple reaction time. Psychol. Bull., 51: 128-149, 1954.)

3. Maximum Tapping Speed (speed of repetitive voluntary movement). Given as a ten-man group test in the trailer laboratory. Subject was required to tap a telegraph key as rapidly as possible for the total duration of a visual signal. Two five-second practice trials and one ten-second test trail were given. Score was the number of taps during a three-second interval on the test trial when tapping speed was maximal.

(King, H. E., and Clausen, J., Speed of Tapping. In Gerard, R. W., Ed.) Methods in Medical Research, Vol. 3, Chicago: Yearbook Publishers, 1950.)

4. and 5. Fine Hand Steadiness and Gross Hand Steadiness (muscular tension). Subject was required to hold a stylus having a tip 0.54 inches in diameter in a small hole, with arm extended. For fine hand steadiness the hole was .140 inch in diameter, and for gross hand steadiness the hole was .172 inch in diameter. One ten-second practice trial with the large hole was given, followed by ten-second test trials with the large hole and the small hole respectively. Score was number of stylus contacts on a ten-second test trial. The two measures were treated separately because a low correlation was found between the two measures in preliminary investigations.

(Hussman, T. A., Review of the literature on measurements of steadiness and body sway as related to fatigue. Maryland Univ., Contract DA 49-007-md-222, Technical Rept. No. 1.)

6. Steadiness of Standing (equilibrium). Subject wore a mortar-board cap on the top of which a piece of paper was attached. A writing pen extended from above and made contact with the paper, allowing a graphic recording of the amount of sway during a one-minute test period. Score was the maximum front-to-back sway plus the maximum side-to-side sway in 0.1 inches.

(Miles, W.R., Static equilibrium. In Gerard, R. W. (Ed.), Methods in Medical Research, Vol. 3, Chicago: Yearbook Publishers, 1953.)

SMALL-SAMPLE TESTS (all of these tests were given individually)

1. Tactual Threshold (tactual sensitivity). A nylon bristle of variable length was used to make contact with the skin on a hairless portion of the inner wrist surface. Score was the longest length of bristle (in millimeters) at which the subject reported feeling the stimulus.

(Woodworth, R. S., Experimental Psychology. New York: Henry Holt, 1938.)

2. Knox Cube Test (memory span). Standard administration and scoring procedure (from Grace Arthur Scale) except that all subjects were given all trials. Score was total number of errors on ten trials.

(Arthur, G., A Point Scale of Performance Tests, Vol. 1, New York: The Commonwealth Fund, 1930.)

3. Dexterity Test (fine dexterity). A modification of the tweezer portion of the Crawford Small Parts Dexterity Test. Subject used tweezers to place small pins on a board and to cover each pin with a cylindrical collar. Score was total number of pin-collar placements in a two-minute test trial, after a short practice trial had been given.

(Crawford, J. E., and Crawford, Dorothea M., Instruction Manual, Crawford Small Parts Dexterity Test, New York: Psychological Corporation, 1954.)

4. Digit-Symbol Test (brain damage). A sub-test of the Wechsler-Bellevue Adult Intelligence Scale. Standard administration and scoring procedures were used. Form I was used for the initial test and Form II was used for the retest. Score was total number of correct responses.

(Wechsler, D., The Measurement of Adult Intelligence. Baltimore: Williams and Wilkins, 1944.)

5. Taylor Anxiety Scale (manifest anxiety). Test form used only the fifty anxiety items from the Minnesota Multiphasic Personality Inventory, with items simplified as recommended by Taylor, Standard administration and scoring procedures used, with the final score being the total number of symptomatic responses.

(Taylor, J. A., A personality scale of manifest anxiety. J. Abn. Soc. Psychol., 48; 285-290, 1953.)

6. Saslow Screening Inventory (manifest psychiatric symptomology). Simplified version for non-college populations. Administration and scoring procedures recommended by Saslow were used. Score was total number of symptoms listed by subject.

(Saslow, G., Counts, R. M., and DuBois, P. H., Evaluation of a new psychiatric screening test. Psychosom. Med., 13: 242-253, 1951.)

7. Cornell Index, Form N2 (neuropsychiatric symptomology). Standard administration and scoring procedures were used. Score was total number of symptomatic responses.

(Barry, J. R., and Raynor, G. H., Psychiatric Screening of Flying Personnel: Research on the Cornell Index. USAF Project No. 21-0202-007. Report No. 2, 1953).

8. Visual Acuity. Ortho-Rater test for visual acuity. Standard administration and scoring procedures used. Score was the sum of "near" and "far" acuity measures, where subject used both eyes.

(Tiffin, J., Industrial Psychology. New York: Prentice-Hall, 1947)

9. Phoria (eye-muscle weakness). Ortho-Rater test. Score calculated in terms of amount of deviation from normal, using a sum of "near" and "far" measures for both lateral and vertical phoria.

10. Depth Perception (visual depth perception). Ortho-Rater test. Standard administration procedure. Score was total number of correct responses on nine trials.

APPENDIX 5.3

NOISE-EXPOSURE QUESTIONNAIRE USED FOR TEST-RETEST MEASURES AND SICK CALL MEASURES

CECIL FIELD FOLLOW-UP

RUN NO. _____

Name _____ Rate _____ Squadron _____
(Last, initials)

Job: (circle appropriate class)

MECHANIC ORDNANCE STRUCTURES ELECTRICAL GENERAL LINE

Time since exposure; How long has it been since you were last:

Within 50 feet of afterburner? _____
Within 30 feet of jet (afterburner not firing)? _____

Since the last hearing test, have you had a ringing in your ears that lasted half an hour or more? YES NO If so, was this after gunfire or noise?
GUNFIRE NOISE BOTH

Since the last hearing test, have you had trouble hearing ordinary conversation after exposure to noise? YES NO If so, how long did it last?

_____

AFTERBURNER EXPOSURE

Since the last hearing test, how many times have you been working within 50 feet of a plane while the afterburner was firing (try to estimate the number of planes as closely as possible)? _____ planes

About what fraction of the time did you have ear protection? _____ %

What type of protection? MUFFS PLUGS BOTH OTHER _____

NON-AFTERBURNER EXPOSURE

In an average work-week, about how many hours do you spend within 30 feet of jets (idling to 100%; afterburner not firing)? _____ hours

About what fraction of this time do you use ear protection _____ %

Type of protection: MUFFS PLUGS BOTH OTHER _____

How long ago did you start using this ear protection? _____ months ago.

ANY PARTICULAR INCIDENT THAT YOU THINK MAY HAVE DAMAGED YOUR HEARING SINCE THE LAST HEARING TEST?

_____

_____

APPENDIX 5.4

GROUP PAPER-AND-PENCIL TESTS GIVEN AT NAS CECIL FIELD

These tests were taken from A Kit of Selected Tests for Reference Aptitude and Achievement Factors (Educational Testing Service, Princeton, New Jersey, October 1954). The aptitude factor is given in parentheses after the name of each factor.

1. Dotting (aiming). Subject puts a dot entirely inside circles which are connected by lines. A 30-second practice trial and a 90-second test trial are given. Score is number of circles correctly dotted on test trial.

2. Addition Test (number facility). A speed test of the addition of sets of three 1- or 2-digit numbers. Score is the number correct in a three-minute trial.

3. Four-Letter Words (speed of closure). Subject circles all four-letter words found in 22 lines of continuous capital letters, Score is the number correctly circled in 2-1/2 minutes.

4. Letter "A" (speed of symbol discrimination). Subject's task is to check the four words containing the letter"a" in columns of 40 words each. Score is the number of words correctly checked in 2-1/2 minutes.

5. Reasoning (deduction). Subject's task is to indicate which inferences follow correctly from the premises of formal syllogisms. Score is number correct in 6 minutes.

6. Picture-Number (associative memory). Subjects memorizes associations between pictures and numbers on a practice trial of 3 minutes, and writes the appropriate number under each picture (20 pictures) on a test trial of 3 minutes. Score is number correct.

7. Letter Grouping (induction). Four sets of four letters each are presented. Subject's task is to find the rule which relates three of the sets to each other and mark the one which does not fit the rule. Score is number correctly marked in 3 minutes.

8. Paper Form Board (visualization). Each item presents a drawing of black pieces which can be put together to form a figure presented in outline form. Subject's task is to draw lines on the outline showing how the black pieces will fit together. Score is number correct in 5 minutes.

9. Writing X's (motor speed). Subject writes X's as fast as he can on or near dots, and is given a 30-second practice trial and a 90-second test trial. Score is number of X's written on test trial.

APPENDIX 5.5

NOISE-EXPOSURE QUESTIONNAIRE USED FOR GROUP PAPER-AND-PENCIL TESTS

GROUP TEST QUESTIONNAIRE

NAME _____ RATE _____ DATE _____
(Last, first, middle initial)

SERIAL NUMBER _____ AGE _____ SQUADRON _____

DO NOT FILL IN BELOW THIS LINE

TEMPORARY EXPOSURE: Time since exposed _____; Plane _____;

Power _____ Distance _____; Duration _____; Ear Protection ___

PREVIOUS EXPOSURE:	REGULAR JOB	DUTY SECTION
1. Plane		
Power		
Job		
Distance		
Duration		
Ear Protection		
2. Plane		
Power		
Job		
Distance		
Duration		
Ear Protection		
3. Plane		
Power		
Job		
Distance		
Duration		
Ear Protection		

CHAPTER 6

PSYCHIATRIC EVALUATIONS OF NON-AUDITORY EFFECTS OF HIGH-INTENSITY NOISE

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INTRODUCTION

In the BENOX Report, and in CHABA discussions based on that report, the suggestion was repeatedly made that the cumulative ill effects of noise exposure would most likely be found in the categories of chronic fatigue and reaction to total stress, or in the symptoms of covert injury to the central nervous system. This is of considerable interest to psychiatrists since the net effect of one or more of these stresses or injuries might be a personality change. The basis of these fears and speculations lay partly in a considerable number of anecdotal reports and partly in hypothethical speculation by both medical officers and laboratory scientists. The symptoms reported by individuals who had had habitual intermittent noise exposures included trouble in sleeping, increased irritability, and gradually diminishing libido.

One of the major objectives of the ANEHIN study was to determine whether such symptoms and complaints were in fact systomatically associated with exposure to high-intensity noise. Another objective was to carry out some of the long term studies that were specifically recommended in the BENOX Report. Three obvious tools for fulfilling these objectives were:

(1) neurological examinations,
(2) psychiatric interviews, and
(3) the use of physiological indicators of stress such as the neuro-humoral mechanisms involving the adrenal cortex.

In the early stages of the planning of the ANEHIN project two important, practical decisions were made which governed the size and scope of the neuro-psychiatric section of the project as well as the methods to be employed. These decisions were dictated by practical, realistic considerations of expense, the availability of naval and civilian personnel for this project, and the specific applicability of procedures to the situation at hand.

The first decision was that the psychiatrist for the ANEHIN Project should be a medical officer on active duty in the Navy. Such a medical officer would have a full concept of the functioning of the Navy and would be able to establish good rapport with the personnel with whom he had to deal. This requirement was met by the assignment of Lt. William I. Stryker, MC, USNR to the ANEHIN Project full-time and by the active cooperation of Capt. Philip B. Phillips, MC, USN.

The second decision was to conduct the psychiatric interviewing and the neurological examinations in the ship's sick bay and not in the mobile laboratory. This was done partly for practical reasons of space and convenience and partly to take full advantage of the medical status of Dr. Stryker and Dr. Phillips.

THE PSYCHIATRIC TEST METHOD

Methods Selected

A complete neurological examination at both the beginning and the end of the study periods was planned for all subjects. This was done on the assumption that the period of study would be six months, occurring during the cruise of an aircraft carrier in the Mediterranean. In practice, the full neurological examination was soon relegated to the status of a stand-by procedure to be employed only when special circumstances seemed to indicate its possible value in individual cases. This decision was primarily based on the well-known fact that a neurological examination is too gross a method to pick up small defects and the fact that the medical history usually provides necessary indications of early defects.

High priority was given to the development of a standardized form of pyschiatric interview. No ready research tools were available in this area, such as the physiological tests described below. Standardization of some sort was needed in order to make the results and impressions derived by different psychiatrists comparable for statistical purposes, and also to ensure that each psychiatrist would explore the same areas with each subject. A correlative second objective was the development of a scale or rating method that would assign a single number (or at worst a few numbers) to express the psychiatric status of each individual so that changes in status in a group might be statistically related to noise exposure.

The use of certain questionnaires, notably the Cornell Index, the Taylor Anxiety Scale, and the Saslow Screening Inventory, was shared with the psychological section of the ANEHIN Project. It was also planned that the statistical analysis of sick calls and accidents would be shared, although, due to limitations of psychiatric personnel, these analyses were made by the psychological section.

The methods finally employed by the neuropsychiatric group were:

(1) a routine psychiatric interview,
(2) A standardized medical questionnaire (Form 9, Appendix 6.3),
(3) A rating scale (Forms 4, 5, 6, 7, 8, Appendix 6.3), and
(4) the Cornell Index and the Taylor Anxiety Scale.

Methods Rejected

Several other procedures were considered carefully for inclusion but were rejected for one reason or another.

Electroencephalography of each subject before and after a period of noise exposure such as a six months tour of duty on a carrier, was rejected on account of the practical difficulty of obtaining satisfactory EEG's on large numbers of individuals at the beginning and end of a cruise. It was not considered feasible to carry out routine electroencephalography in the mobile laboratory so that the measurement, if made, would have to be done

in a shore-based facility. Electroencephalography was, however, designated as a "stand-by" procedure that would be employed in the final examination of any subjects who might be considered to have suffered significant adverse effects from exposure to high-intensity noise.

Physiological tests for evaluation of stress were explored in some detail, including the determination of 17-keto-steriods and cortico-steriods in the urine, creatin in the urine, urinary phosphates, uric acid, eosinophil counts, lymphocyte counts, and urinary potassium. A major objection to all but the last three of these tests was the requirement of 24 hour urine specimens. These would be practically impossible to collect successfully and process systematically aboard an operating aircraft carrier. Even if the 24 hour specimens could have been collected, some of the analyses would have been impossible with the facilities available in the medical department on shipboard and would have required that the specimens be refrigerated and flown to a central laboratory for final work-up. The eoxinophil count and the lymphocyte count seemed to be more practical. The latter was considered to be more valid, but more difficult to carry out successfully and would therefore require a trained technician. Except for certain differential staining, either or both could be performed easily with the usual facilities available in the sick bay of a large aircraft carrier. However, chiefly because of the shortage of personnel that could be assigned to the project these blood count tests were finally omitted. The omission was justified on theoretical grounds by evidence that similar physiological tests conducted in combat areas have shown little in the way of stress response except among personnel who were actually wounded or subjected to unusually severe stresses. The use of physiological tests of stress in the study of the effects of high-intensity noise was not discarded entirely, but was set aside until more delicate, but still practical, tests could be developed or until the noise stress should increase above its present apparent level.

Another rejected approach was the analysis by "peer ratings" and the inclusion of such items of individual behavior as eating habits, the use of free time, etc., to expand the over-all concept of ability to function. The suggestion that such methods would be appropriate to the ANEHIN study grew out of certain anecdotal reports, (Benox) including the suggestion of "personality changes." Such methods were not included, partly because of the expense in time and personnel required to make and analyze the many necessary observations, and partly because the analysis and interpretation of these types of data is not yet fully standardized.

On the basis of earlier experience on training cruises of the USS TICONDEROGA (October, 1955) and the USS FORRESTAL (January 1956), short-term neuropsychiatric studies were held to be unsuited to the ANEHIN problem. It was concluded that certain useful types of data might be obtained by cross-sectional studies of large, but selected, groups of subjects and also that other types of useful data would be obtained by longitudinal studies on smaller groups. It was soon obvious, however, that the amount of change that could be expected in any of our indices as the result of the

noise exposures encountered in naval operations during 1956 would be so small that any short-term study in the field would be of little value, particularly for such methods of observation as the neurological examination and the psychiatric interview.

THE DEVELOPMENT OF TECHNIQUES FOR ANALYZING PSYCHIATRIC OBSERVATIONS

One of the major problems at the present time in experimental psychiatry and psychosomatic medicine is how to obtain, systematize, codify, and effectively employ psychiatric observations that are to be related either to parameters of the environment (such as noise exposure) or to other changes at the physiological or behavioral level. The necessity for reliability of observations, both from one observer to another and in repeated trials on the same subject, is clearly recognized and has led to many efforts to standardize both the operational meaning of psychiatric terms and also the development of standardized psychiatric interviews. Our own first efforts were directed to standardization of the areas to be covered in the interviews and then to standardization of the particular questions to be asked.

Medical Questionnaire

One of our first steps was to develop a "medical questionnaire" which could be filled in by the subject while waiting his turn for the psychiatric interview (Form 2, Appendix 6.3). The use of this questionnaire with its "yes-or-no" answers gave a considerable amount of information, not all of which was strictly medical but all of which was pertinent to psychiatric evaluation. As the result of our experience with this questionnaire as it developed during three studies in the field, we feel that it is quite satisfactory in substantially its present form (Form 9, Appendix 6.3) and should prove useful in further studies of the effects of high-intensity noise. In a later phase of the ANEHIN study a Descriptive Summary was developed (see below page 165, and Form 3, Appendis 6.3). From the data obtained by this summary a group of 51 variables were defined and listed as shown on Forms 4, 5, and 6 in Appendix 6.3. These items were utilized in constructing the final form of the medical questionnaire and also in the development of the Psychiatric Rating Scale (Form 7, Appendix 6.3). This medical questionnaire was used as a means of standardizing the information gathered from individual subjects. In effect, it eliminated the necessity of giving the psychiatrists about 40 hours training in standardized interview techniques.

Interview Rating Form

An "interview rating form" was developed (Form 1, Appendix 6.3), to be filled out by the psychiatrist following each interview. The areas to be

covered in this rating form were:

(1) emotional stability,
(2) motivation,
(3) an assessment of the mental and emotional stresses to which each individual was subject, and
(4) indications of how effectively these stresses had been met by more or less effective "adjustment."

Finally, the psychistrist characterized each individual according to basic personality type.

As a result of practical experience with this interview rating scale on board the USS TICONDEROGA in 1955, the basic concepts involved were re-examined because of certain deficiencies that were noted in the interview rating form (Form 1 Appendix 6. 3). In each of the four areas covered (see list above) the variables were to be "rated" under three headings as maximum, moderate, or minimum. In the practical situation, great difficulty was encountered in judging how a given factor should be rated. In addition, it was felt that the most important indicators of personality change were probably being missed since not enough of the interviewee's subjective impressions and symptoms were obtained by this method.

Descriptive Summary

The Descriptive Summary (Table 6. 3, and Form 3, Appendix 6. 3) was next devised as a temporary form to be used as a tool for further development of our rating technique. It was developed with a three-fold purpose in mind:

(1) to give systematic information on which a rating could be based,
(2) to eliminate, insofar as possible, the subjective impressions of the psychiatrist.
(3) to explore the number of factors necessary to define adequately stresses, liabilities, assets, and the emotional stability of the population group being studied.

The Descriptive Summary was divided, not according to psychiatric concepts such as emotional stability and motivation, but according to areas of major concern in the life of an individual, namely: home, women, sex, religion, sound (noise), Navy, shipboard, job, and discipline.

The area entitled "sound" was obviously introduced because of the special interests of the ANEHIN Project. The four possible attitudes toward it were listed as:

(1) not disturbing
(2) distrubing
(3) uncomfortable
(4) tolerable nuisance

It was the psychiatrist's duty to determine the attitude of the subject toward each of the major areas of concern given above and estimate its strength on a restricted scale.

A number of potentially major manifestations of conflict or maladjustment were final items in the psychiatrist's descriptive summary: anxiety

psychosomatic symptoms, irritability, poor work efficiency, day dreaming, insomnia, falling asleep on the job, lack of confidence, and anorexia. The information obtained was not used to reach final definitive ratings but rather to define the criteria by which a still better rating scale could be developed.

Standardized Psychiatric Interview

The next step was the development of a standardized psychiatric interview. Thirty minutes proved to be necessary for a satisfactory interview of this sort, including opportunity for the psychiatrist to make sure that the subject had understood the meaning of the various questions on the medical questionnaire. This was accomplished partly by spot check repetition of particular question, by scanning the answers to the questionnaire, and by probing in more detail in the areas where answers were unusual or seemed to indicate conflict or maladjustment. When available, the subject's answers on the Cornell Index, the Taylor Anxiety Scale, and/or the Saslow Screening Inventory were also utilized as guides. The psychiatrist, at the end of the 30 minute interview, made such additional comments on the summary sheet as seemed pertinent and noted his general subjective impressions. The original medical questionnaire (Form 2, Appendix 6.3) as checked by the subjects did not adequately cover the items that were considered necessary for subsequent analysis and rating, and it was not until the data obtained from the use of the Descriptive Summary (Form 3, Appendix 6.3) were analyzed that the final, comprehensive questionnaire (Form 9, Appendix 6.3) was developed.

The Psychiatric Rating Scale

1. General.

The development of a psychiatric rating scale that would condense the information obtained from the questionnaire and the interview into a single number proved to be, as was expected, a difficult task. The task is still incomplete. Little progress was made during the final year of the project because the services of Dr. Stryker were no longer available to the ANEHIN Project, and, for the same reason (although planned for) no attempt was made in the final studies at Cecil Field to test the reliability of the psychiatric ratings and the validity of the scale, or to gain further experience in the practical use of these methods.

2. Development of the Scale.

A rating scale is needed to permit statistical comparisons among groups which have suffered different amounts of noise exposure, and for detecting changes in status before and after a long-term period of noise exposures. Our original concept was to make these comparisons in terms of the degree of "adjustment" of these individuals. The term "well adjusted" was intended to designate a state of well being or "normality" in relation to the particular group as opposed to a state of undue anxiety, conflict, or

"deterioration," such as might be produced by exposure to stress. In medical practice an experienced psychiatrist makes a considered judgment based on past clinical experience regarding the adjustment or mental well-being of an individual, and bases practical decisions and recommendations on this judgment. A major objective in our development of a definitive rating scale has been to make explicit and to standardize the processes that are used by psychiatrists in making their everyday judgments.

We believe that a psychiatrist's clinical judgment is based, in the first place, on the presence or absence of certain items in an individual's medical history and in his responses to questions. These items, which are the raw data, are organized in the mind of the psychiatrist in recognizable constellations, some of which are favorable in the over-all assessment, and others are unfavorable. Finally, a balance is struck among the various constellations that have been identified. At least three steps are involved in this process of forming a final judgment. One is the qualitative grouping of items into constellations; another is the quantitative estimate of the strength of each constellation; and the third is the combination of these values, some positive and some negative, on the basis of past clinical experience and knowledge of the "norm" of a particular group or segment of society.

The basic items are the answers checked in the medical questionnaire by the subject. (One of the important shortcomings of the first field studies on the TICONDEROGA and on the FORRESTAL was that frequently the subjects did not answer all the questions, and it was therefore impossible to complete the subsequent procedures and employ the standardized rating scale. The omission of a single item would necessarily disqualify that particular subject from inclusion in the final statistical comparisons.) The items are grouped into four constellations, as shown in forms 4, 5, 6, 8, Appendis 6.3 namely:

(1) motivation
(2) emotional stability
(3) stress
(4) liabilities

It is our hypothesis that these groups of factors interact in the following manner: Strong positive motivation toward the job and toward the navy indicates a "good adjustment" and are favorable indicators, yet lack of only one or the other does not necessarily indicate "poor adjustment." Emotional stability is also a favorable indicator. Evidence for emotional stability is the number and strength of conflicts over problems of religion, sex, authority, self-estimate and the absence of expressed manifestations of anxiety, depression, or psychosomatic symptoms, (Form 4, Appendix 6.3). Balanced against this are liability factors (Form 5, Appendix 6.3) or indicators of "poor adjustment," such as history or repeated disciplinary action, failure to complete education, frequent changes of jobs, dislike for or inability to adjust to shipboard, job, or navy. Further, balanced against both the estimate of emotional stability and liabilities, are the stresses to which each man is subjected prior to and during his navy career and irrespective of that career or particular job. In essence, tha man who has been and still

is subject to multiple home, family, or marital stresses has many liabilities; if he had made a "good adjustment," he is rated higher than a man who has few home, family, or marital stresses, and yet has made no better adjustment. The rating on the stress scale is therefore the opposite of the rating on the liability and emotional stability scales.

The kind of balancing that is implied above, in which the presence of stress counts in favor of a man rather than against him is well recognized at the intuitive level when we say, "Who wouldn't be a bit tense and jittery with troubles like that on his mind," or "He must be a really stable and well-adjusted fellow to carry on as well as he does after getting such bad news from home."

Description of the Scale

The original data for each of the four categories were items derived from the early use of the short medical questionnaire (Form 2, Appendix 6.3). Specifically, motivation was inferred directly from the estimates made by the subject in the two areas of navy and job. The quantitative rating value of various combinations of attitude toward job and toward naval service was made according to an arbitrary, yet considered, assignment of values shown in forms 7 and 8 Appendix 6.3. The scale runs from 1, which indicates no motivation, (even to the general life situations), to 6, which was the value assigned when the subject liked his job and was highly motivated to naval service.

The range of credit points for emotional stability was also from a minimum of 1 to a maximum of 6. The items indicating emotional conflict in the areas mentioned above were identified by reference to the specific questions in the medical questionnaire that cover the factors listed on Form 4, Appendix 6.3. Full, positive credit was given when no items indicative of conflict were found. If there was one item indicating conflict the credit value was 5, for two items it was 4, etc. For five or more items the minimum scale value of 1 was assigned.

The items which delineate personality liabilities were also derived from the answers to certain questions in the medical questionnaire. One such item, or none at all, merited the maximum scale value of 3. Two or three unfavorable items were given a value of 2, while the minimum scale value of 1 was given if there were four or more items.

The evaluation of stress was derived in the same manner with reference to the medical questionnaire (Form 9, Appendix 6.3) and the Rating scale (Form 6 and 7, Appendix 6.3). The maximum "credit" that was given for these factors was 3. This credit was given if there were four or more indicators of stress. Two or three indicators merited a credit of 2 on the scale; one indicator, or none at all, received the minimum credit of 1.

When the scale values were thus assigned in the four categories the numbers were added to give the final rating. The maximum (most favorable) rating was 18; the minimum was 4. A maximum rating would be interpreted

as follows: "highly motivated to his job and to the Navy, with not more than one liability factor in his history, no significant indicators of conflict or anxiety (emotional stability scale) and all this in spite of an unusual amount of past or present stress."

The stress of noise or other shipboard stress might weaken a man's motivation toward his job and/or the Navy. It might increase the indications of conflict or symptoms of anxiety or tension, or precipitate some new disciplinary action. These changes would lower a man's rating. Also the easing of a pre-existing domestic stress without any corresponding improvement in motivation or relief of anxiety would result in a slight lowering of a man's rating.

The scale was used in the form described above in the June, 1956 study on board the USS TICONDEROGA. Obviously, the method is still somewhat tentative. It requires validation as well as a careful study of its reliability. Neither has been accomplished, largely because the psychiatrist primarily involved in development and administration of this rating method was not available to the ANEHIN project during its last year of operation.

THE PSYCHIATRIC STUDY ABOARD THE TICONDEROGA

A definitive psychiatric study was carried out aboard the USS TICONDEROGA in June of 1956. Captain Philip B. Phillips, MC USN and Lt. William I. Stryker, MC USNR, joined the USS TICONDEROGA in Istanbul, Turkey, at a time when the TICONDEROGA had been operating in the Mediterranean for a period of seven and one-half months. During this period approximately 1500 catapult "shots had occurred involving F9F-6, F2H, FJ3, and AJ aircraft.

With the assistance of the yeoman in the flight operations office, a group of 70 men were selected according to the following criteria:

(1) Navy General Classification Test scores above 30 ("GCT": a test of general intelligence).

(2) Presence aboard the TICONDEROGA for at least 75 percent of the cruise.

(3) The majority of the men to be flight deck personnel. (However, not all had to be men with maximum exposure to noise, that is personnel working in close proximity to the forward catapults.)

(4) A small "control" group, to be men who work below deck and have low, little, or no exposure to noise.

The jobs of the 70 men were analyzed with respect to noise exposure and classified as follows:

(1) Very high noise-exposure: 13 men either working directly on the catapult, or plane pushers who worked between the forward catapults.

(2) High noise-exposure: 18 men with the gas crews, working forward

of the island structure and to the port and starboard of the two forward catapults.

(3) Moderate noise-exposure: 13 men who worked at or aft of the island cheifly as members of the arresting gear crew or as plane pushers.

(4) Low noise-exposure: 21 men who worked in the catapult-control room, arresting gear room, ammunition storage rooms, and bomb rooms.

(5) Unknown noise exposure: 4 men who worked on the hangar deck level where noise exposure was often quite great during maintenance run-ups of jet engines, but where it proved almost impossible to estimate the severity and duration of noise-exposure. (This group was not included in the final analysis because of this unknown noise exposure.)

Interviewing began three or four days after the TICONDEROGA had put into port following the Mediterranean cruise and a week after the last flight operations. Since the objective was to evaluate possible long-term effects, this schedule was fortunate as it allowed time for the dissipation of any possible temporary effects of noise exposure.

Each man was scheduled for a one-half hour period with either Dr. Phillips or Dr. Stryker. Upon arriving, each man filled out the medical questionnaire. He was then interviewed for 15 minutes. Items on the questionnaire were carefully checked and additional comments and general subjective impressions were added by the psychiatrists. The period of 15 minutes allotted for the interview proved to be quite adequate for this purpose.

The data were analyzed as described in the foregoing section and a final rating scale value was computed for each man.

The analysis of data of this type usually involves the use of a cutting score. A cutting score of 12 was established (although not validated) by previous comparisons of the earlier rating forms with the Saslow Screening Inventory, which has a well-established cutting score. Scores of 13 or above designated the more "adjusted" group and 12 or below the less "adjusted" group.

TABLE 6.1

Mean Psychiatric Ratings Of Subjects Grouped According to Estimate of Noise Exposure

NOISE EXPOSURE	NO OF SUBJECTS	MEAN PSYCHIATRIC RATING
Very High	13	12.6
High	18	12.9
Moderate	21	13.4
Low	14	13.7

TABLE 6.2

Distribution of Psychiatric Ratings, With an Indication of the Number of Subjects in Each Exposure Group Who Received a Given Rating.

PSYCHIATRIC RATING	NOISE EXPOSURE			
	VERY HIGH	HIGH	MODERATE	LOW
9			2	
10		3	3	
11	5	1	2	2
12	4	2	1	2
13		4	6	
14		4	5	5
15	3	4	1	4
16	1		1	1
% above 12	32.5	66.7	61.9	71.4

Table 6.1 shows that the mean scores of each group differed little, but Table 6.2, where the distribution of scores is given in relation to the cutting score, suggests a significant difference between groups. There thus appears to be a relation between the rating scores and the noise exposure that would be consistent with the hypothesis that high noise exposure had caused a deterioration of motivation or an increase in anxiety or tension.

Correlation of Psychiatric Rating Scores with Noise Exposure

As will be seen in Table 6.3, the correlations of the psychiatric rating scale to the Taylor Anxiety Inventory and the Cornell Index while not high (.34 in both cases) are significant at the 1% level of confidence. The Taylor and Cornell tests, on the other hand, are highly correlated at .84, which is also significant at the 1% level. This similarity in scores indicates that the Taylor and Cornell tests are both evaluating the same modality. Our conclusion is that the low correlation between the psychiatric rating scale and the Taylor-Cornell tests indicates that the latter tests are not evaluating the same modality measured by the psychiatric rating scale, although some common factors are probably present.

TABLE 6.3

Rank-Difference Correlations
(N - 62)

ITEM	PSYCHIATRIC	TAYLOR	CORNELL
Psychiatric Rating	-	.34**	.34**
Taylor Anxiety Scale		-	.84**
Cornell Index			-

** Significant at the 1 per cent level of confidence

A review of the psychiatrists' evaluations and comments showed that many of the subjects gave anecdotal reports similar to those noted in the BENOX Report. The most common complaints were increased irritability, tenseness, insomnia, and occasionally fear because of the inability to communicate with other men in the presence of the noise. However, with the exception of the difficulty of communication, most of the men stated that they did not feel that their trouble was due to the noise. They felt much more strongly that their trouble was due to the general dangers of the job and to their concern about the delay in returning to the United States. The men who, on the questionnaires and in interviews, expressed a dislike toward shipboard duty, gave the separation from home, wife, and family as their primary reason for such a feeling.

It is quite possible, therefore, that the relationship between rating scores and noise exposure depends on the parallel between the danger involved in the job and the noise exposure associated with the job.

The Relation of Rating Scores to Dangers of the Job

The general dangers of the jobs and the worries of personnel about returning home were therefore examined more systematically. The USS TICONDEROGA was kept in the Mediterranean approximately three months beyond its scheduled return to the United States because the relief ship had developed difficulties that required its putting back into drydock. This delay had a rather marked demoralizing effect upon most of the crew members.

On this particular cruise, all members of the flight deck crew were made keenly aware of the dangers of their jobs as a result of a number of flight deck accidents. In the most serious one, a large group of flight deck personnel were struck and several men were killed by an airplane which had jumped the Davis barriers. In the other accidents a number of pilots were killed.

The degree of danger experienced in flight deck jobs decreases (as does the exposure to high intensity noise) as one gets further away from the areas of aircraft operations. In reference to the test groups shown in Table 6.2, the 'very high noise-exposure' group (which includes catapult men and the plane pushers working around the catapult) is in a potenitally more dangerous position than the 'high noise-exposure' group which is aft of the catapults. The 'moderate noise-exposure' group is also in a relatively dangerous position. This group maintains and operates the arresting gear and must be on deck in close proximity to the landing aircraft. There is always the threat of a cable snapping or rockets dropping from a landing aircraft. Personnel of this group frequently must disengage the tail hook from the landing cable. On the other hand, the 'low-noise-exposure' group is stationed below the flight deck and is in the least dangerous as well as the least noisy job. The relation between rating scores and the probable danger associated with the job is therefore at least as high as, and perhaps higher than, the relation between the rating scores and noise exposure.

The conclusions given above are borne out by statements by the subjects

TABLE 6.4

Percentage of Subjects in Each Noise-Exposure Group Who Expressed Negative Reactions to Their Job, to Jet Noise, and to Shipboard Duty

NOISE EXPOSURE	EXPRESS ANXIETY ABOUT JOB	STATE JET NOISE DISTURBING	DISLIKE SHIPBOARD DUTY
Very High	92.3	53.8	69.2
High	61.1	55.5	55.5
Moderate	71.4	61.9	76.1
Low	21.4	35.7	42.9

themselves. (Table 6.4). Among the men working in the most dangerous jobs involving very high noise exposures 92.3% expressed anxiety about their jobs. The percentage of expressions of anxiety is a little lower but about equal for men receiving the high and the moderate noise exposures. The percentage is a little higher for the men receiving the moderate noise exposures; in the psychiatrists' opinions they actually have a slightly more dangerous job. Among the men who work on the safest jobs just below the flight deck only 21.4% expressed any anxiety about their jobs.

The statements of the men as to whether jet noise was disturbing (although not employed as an item in calculating the rating score) is perhaps a little surprising. Only 7 out of 13 men (53.8%) receiving the very high noise exposure reported that the jet noise was disturbing to them. A somewhat larger percentage of the groups receiving high and moderate noise exposure expressed this opinion, while among those receiving the low noise exposure 5 out of 14 men (35.7%) stated that the jet noise was disturbing.

The Psychiatrists' Impressions.

The over-all subjective impression developed aboard ship during the study by the two psychiatrists was that the anxiety level among the men working on the flight deck was considerably greater than that encountered among a similar group of men interviewed aboard the same ship in October 1955, approximately eight months earlier. (Unfortunately the overlap between the earlier group studied and the final group is too small and the differences in the methods of interview employed are too large to allow any significant comparison of scores for the same individuals before and after the 7 1/2 months cruise.) The psychiatrists believe, quite apart from any evidence provided by tabulation of data, that the basic reasons for the increased anxiety lay in the awareness of the inherent dangers of the jobs and the fact that the ship was overdue for return to the states. A man's rating score and his consequent assignment to a better or less "well adjusted" category seemed to be more directly related to the multiple home, family, marital, religious, and sexual conflicts and, in certain cases, to conflicts between the subject and his senior petty officer, chiefs, and division officers

rather than to any direct and obvious effect of working in high-intensity noise. Some men did state that the noise was extremely disturbing, but both psychiatrists agree that jet noise is not, in their opinion, presently a cause of significant deterioration of personality. Whatever the neuropsychiatric effects of high noise exposure may be they are subtle and difficult to extract. The present series of carefully planned and carefully conducted interviews did not reveal any easy or obvious correlations with noise exposure, nor do they give any cause for alarm.

RECOMMENDATIONS FOR FURTHER STUDY

Further refinement of the techniques of neuropsychiatric examination is desirable in order to permit early detection of any "deterioration" or other ill effects from noise exposure or forms of stress. The standardized interview rating form developed during the first half of the ANEHIN Project represents a step in this direction, but it requires further improvement and, particularly, studies of its reliability and validity.

Although the present study did not give positive evidence of ill effects from the noise exposures that were encountered by flight deck personnel on board the USS TICONDEROGA in 1955-1956, studies of this sort should be repeated from time to time in the future as noise exposures increase. In the meantime, ships' medical officers should be alert for indications of increased stress associated with high noise exposure. Such indications may be increased sick-bay calls, increased accident rate, vague indications of tension, anxiety, or fatigue, or the stress may be revealed by direct questioning in relation to special complaints or symptoms.

Any future investigation of cumulative neuropsychiatric effects of noise exposure should include comparison studies made before and after a period of several months of habitual exposure of a group of men to high-intensity noise. Control groups which have less noise exposure but which are subject to the same command and which are matched with the experimental group in regard to intelligence level, age, marital status, and general background must also be studied. If possible, the control group should also be balanced with respect to other stresses such as dangers inherent in their jobs.

Noise exposure should be more precisely defined and more precisely measured in any future study. If possible, it should be expressed in physical terms and not merely in terms of the jobs and the items of equipment that generate noise.

If either audiometric, psychological, physiological, or psychiatric techniques should indicate at some future time that noise-exposed personnel are suffering ill effects from their noise exposure, consideration should be given to the use of methods that were not employed in the present study, namely, the complete neurological examination, the electroencephalogram, and physiological (neuro-humoral) indicators of reactions to stress. These measures need not be employed, however, until there is clearer indication

than in 1957 of definite cumulative ill effects, other than hearing loss, from noise exposure.

APPENDIX 6.1

BIBLIOGRAPHY

BIBLIOGRAPHY

Eosinophil Count

1. Best, W. R., et al., Studies on adrenocortical eosinopenia; a clinical and statistical evaluation of four-hour eosinophil response tests. J. Clin, Invest., 31: 733-742, 1952.

2. Domanski, T. J., and Muttal, J. B., The physiologic recognition of strain associated with flying. J. Av. Med. 24: 441-445, 1953.

3. Donato, R. A., and Strumia, M. M., An exact method for the chamber count of eosinophils in capillary blood and its application to the study of the diurnal cycle. Blood, 7: 1020-1029. 1952.

4. Dreyfuss, F., and Feldman, S., Eosinopenia induced by emotional stress. Acta Med. Scand., 144: 107-113, 1952.

5. Fisher, B., and Fisher, E. R., Observations on the eosinophil count in man: a proposed test of adrenal cortincal function. Amer. J. of the Med. Sciences, 221: 121-132, 1951

6. Gofton, J. P., Graham, B. F., McGrath, S. D., and Cleghorn, R. A., Evaluation of changes in eosinophil levels in studies of adrenocortical function and stress. J. Av. Med., 24: 123-126, 1953.

7. Howard, J. M., et al., Studies of adrenal function in combat and wounded soldiers, a study in the Korean Theater. Ann. of Surg., 141: 314-320, 1955.

8. Speirs, R. S., Assay of ACTH activitv based on the eosinopenic response in normal and hypophysectomized mice. Endocr., 52: 300-310, 1953.

9. Wake, R. F., Graham, B. F., McGrath, S. D., A study of the eosinophil response to exercise of man. J. Av. Med., 24: 127-130, 1953.

Lymphocyte Count

1. Dougherty, T. F., and Frank, J. A., Quantitative and qualitative responses of blood lymphocytes to stress stimuli. J. of Lab. and Clin. Med., 42: 530-537, 1953.

2. Frank, J. A., and Dougherty, T. F., Assessment of stress in human subjects by means of quantitative and qualitative changes of blood lymphocytes. J. of Lab. and Clin. Med., 42: 538-549, 1953.

3. Hills, A. G., Forsham, P. H., and Finch, C. A., Changes in circulating leucocytes induced by the administration of pituitary ACTH in man. Blood, 3: 755-768, 1948.

4. Nelson, D. H., Sandberg, A. A., Palmer, J. G., and Tyler, F. H., Blood levels of 17-hydroxycorticosteroids following the administration of adrenal steroids and their relation to levels of ciruclating leucocytes. J Clin, Invest., 31: 843-849, 1952.

K Determination in Urine

1. Cooke, R. E., Segar, W. E., Cheek, D. B., Coville, F. E., and Darrow, D. E., Extrarenal correction of alkalosis associated with K deficiency, J. Clin. Invest., 31: 798-805, 1952.

2. Davis, J. O., and Howell, D. S., Comparative effects of ACTH, cortisone, and DCA on renal function: electrolyte excretion and water exchange in normal dogs. Endocrin. 52: 245-255, 1953.

3. Hoagland, H., Pincus, G., Elmadjian, F., et al., Study of adrenocortical physiology in normal and schizophrenic man. Arch. Neuro. and Psychiat., 69: 470-485, 1953.

4. Hoagland, H., Stress and the adrenal cortex with special reference to potassium metabolism. Psychosom. Med., 12: 142-148, 1950.

5. _____, The nature of adrenal stress response in schizophrenic man. J. of Nerv. and Ment. Dis., 111: 434-439, 1950.

6. Roberts, K. E., and Pitts, R. F., Effects of cortisone and DOCA on the renal tubular reabsorption of phosphate and the excretion of titratable acid and potassium in dogs. Endocrin., 52: 324-330, 1952.

7. Sprague, R. G., Power, M. H., and Mason, H. L., Physiologic effects of cortisone and ACTH in man. J. A. M. A., 144: 1341-1347, 1950.

Neurological Studies, Face-Hand Test

1. Bender, M. B., The pehnomena of sensory displacement. Arch. Neur. and Psychiat., 65: 607-621, 1951.

2. Bender, M. B., Fink, M., and Green, M., Patterns in perception on simulataneous test of face and hand. Arch. Neur. and Psychiat., 66: 355-362, 1951.

3. Fink, M., Green, M., and Bender, M., Perception of simultaneous

tactile stimuli by mentally defective subjects. J. of Nerv. and Ment. Disorders, 117: 43-49, 1953.

4. Green, M. A., and Fink, M., Standardization of the Face-hand test. Neurology, 4: 211-217, 1954.

Psychiatric Interviewing

1. Aita, J. A., Efficacy of the brief clinical interview method in predicting adjustments. Arch. of Neur. and Psychiat., 61: 170-176, 1949.

2. Bass, B. M., The leaderless group discussion, Psychol, Bull., 51: 465-492, 1954.

3. Hunt, W. A., Wittson, C., and Hunt, E. B., Military performance of a group of marginal neuropsychiatric cases. Amer. J. Psychiat., 109: 168-171, 1952.

4. Hunt, W. A., and Wittson, C., Some sources of error in the neuropsychiatric statistics of World War II, J. Clin. Psychol., 5: 211-217, 1949

5. Raines, G. N., and Rohrer, J. H., The operational matrix of psychiatric practice: consistency and variability in interview impressions of different psychiatrists. Amer. J. Psychiat., 111: 721-733, 1955.

6. Reid, J. R., and Finesinger, J. E., The role of definitions in psychiatry. Amer. J. Psychiat., 109: 413-420, 1952.

7. Reitzel, E. C., Miller, V. L., and Knox, G. W., Neuropsychiatric screening of a million men. Nav. Med. Bull., 48, 555-565, 1948.

8. Wittson, C. L., Harris, H. I., and Hunt, W. A., Detection of neuropsychiatric infit. Nav. Med. Bull., 40: 340-346, 1942.

9. _____, Three years of naval selection: a retrospect. War Med., 7: 218-221, 1945.

10. _____, The predictive value of brief psychiatric interview. Amer. J. Psychiat., 107: 582-585, 1951.

APPENDIX 6.2

NEUROLOGICAL EXAM

NEUROLOGICAL EXAM

Name _____ Service Number _____

General

Intact / Absent 0

Tremor
- Gross _____
- Fine _____
- Other _____

Obvious Gross Abnormality

Gait _____

Special

Deep Tendon Reflexes (Rate 1-4, 0 Absent)

	Left	Right
Biceps		
Triceps		
Knee Jerk		
Achilles		
Abdominal		
Cremaseteric		

Pathological Reflexes

Babinski		
Gordon		
Oppenhiemer		
Chaddock		
Hoffman		

Cranial Nerves

I Olfactory — Sweet _____ Pungent _____

II Optic — Visual Field
- Left eye: Horizontal __ Vertical __
- Right eye: Horizontal __ Vertical __

III Occulomotor

IV Trochlear

VI Abducens — External Occular Muscles: Intact ___ Impaired ___
- Pupils: Equal ___ React to: Light _____ Accommodation __
- Nystagmus _____
- Strobimus _____

V Trigeminal — Motor
- Masseter: Left _____ Right _____
- Temporal: Left _____ Right _____
- Ptergoids: Left _____ Right _____

Sensory (Face) _____

VII Facial

Motor

Smile _____ Show Teeth _____ Frown _____

Sensory

Ant. 2/3 of Tongue _____

VIII Auditory

Tested by Dr. Ward.

IX Glossopharyngeal

Gag Reflex _____ Deviation of Uvula ___

Sensory

Post. 1/3 of tongue

X Vagus

Swallow _____

Cough _____

Gag _____

XI Accessory

Shrug Shoulders _____

Turn Head _____

XII Hypoglossal

Deviation of tongue on protrusion

Left _____

Right _____

Mid-line _____

Sensory

Vibratory _____

Dull _____ Sharp _____

Hot _____ Cold _____

Cerebellar

Rebound _____

Past pointing _____

Position sense _____

Supination and pronation _____

Posterior Column

Rhomberg _____

Thalamic

Writing on Hands _____

Perception of object in hand _____

APPENDIX 6.3

PSYCHIATRIC FORMS

INTERVIEW RATING FORM

(Form 1)

Name _____ Service No. _____

RATING

Emotional Stability _____ Motivation _____ Stress _____

Personality Type _____ Interviewer _____

EMOTIONAL STABILITY
Score
Weight No.

6. _____1. Extremely unlikely to develop severe emotional illness.
5. _____2. Unlikely to develop severe emotional illness.
4. _____3. Is basically emotionally stable but may develop emotional illness
3. _____4. Is somewhat emotionally unstable with good control
2. _____5. Is somewhat emotionally unstable with poor control (e. g. potentail casualty)
1. _____6. Is already unstable.

MOTIVATION
Score
Weight No.

6. _____1. Likes job and is highly motivated to Naval Service. (3-3)
5. _____2. Likes job but is passive to Naval Service. (3-2)
4. _____3. Likes job but is poorly motivated to Naval Service. (3-1)
5. _____4. Would like different job better but is highly motivated to Naval Service. (2-3)
4. _____5. Would like different job better and is passive to Naval Service. (2-2)
3. _____6. Would like different job better and is poorly motivated to Naval Service. (2-1)
4. _____7. Dislikes job but is highly motivated to Naval Service. (1-3)
3. _____8. Dislikes job and is passive about Naval Service. (1-2)
2. _____9. Dislikes job and is poorly motivated to Naval Service. (1-1)
1. _____10. No motivation; even in general life situation. (1)

STRESS SCALE
Score
Weight No.

6. _____1. Max Stress (3)

DESCRIPTIVE SCALE
Basic Personality Type

Max Assets 1. Anxiety _____
(3) Min Liabilities

STRESS SCALE (cont'd)

5. _____ 2. Max Stress (3)

4. _____ 3. Max Stress (3)

5. _____ 4. Mod Stress (2)

4. _____ 5. Mod Stress (2)

3. _____ 6. Mod Stress (2)

4. _____ 7. Min Stress (1)

3. _____ 8. Min Stress (1)

2. _____ 9. Min Stress (1)

1. _____ 10. Already a Casualty.

Max Assets 2. Hysteria _____
(2) Mod Liabilities

Max Assets 3. Obsessive _____
(1) Max Liabilities

Max Assets 4. Psychopathic _____
(3) Min Liabilities

Max Assets 5. Cyclothymic _____
(2) Mod Liabilities

Max Assets 6. Schizoid _____
(1) Max Liabilities

Max Assets 7. Paranoid _____
(3) Min Liabilities

Max Assets 8. Other _____
(2) Mod Liabilities

Max Assets
(1) Max Liabilities

DESCRIPTIVE SUMMARY (Include when applicable change from previous interview)

MEDICAL QUESTIONNAIRE

(Form 2)

Name _____ Service No. _____ Rank/Rate _____

Time in Navy _____ Married _____ How many years _____ Single _____

Divorced _____ Wife _____ How many Children _____

(Answer "yes" or "no" or fill in the blank.)

1. Have you ever had severe or prolonged headaches? yes no
   if yes: a. Recur frequently? yes no
   b. Ever on one side only? yes no
2. Do you ever have buzzing or roaring in your ears? yes no
3. Do you ever have dizzy spells? yes no
   if yes: a. Frequently? yes no
   b. Bad enough to make you stop work? yes no
4. Have you ever had a period of temporary blindness or had your vision become blurred for a short time? yes no
5. Do you ever see double? yes no
6. Have you ever fainted or blacked out? yes no
7. Have you ever been knocked out? yes no
   if yes: a. Were you unconscious more than 1 to 2 minutes? yes no
8. Have you ever had shakes or tremors? yes no
9. Do you have to watch your feet to know where to place them? yes no
10. Have you ever had a fit or convulsion? yes no
11. Have your hands ever been numb or had a tingling sensation in them? yes no
12. Have you ever had a nervous breakdown? yes no
13. Have you ever been in a mental hospital? yes no
14. Have you ever been arrested? yes no
15. Have you ever been convicted of any charge? yes no
    If traffic violations - How many _____
16. How many jobs have you had in the past 10 years? _____
17. How far did you go in school? _____ _____
18. How do you feel you get along with your shipmates? Good __ Fair __ Poor _____
19. How do you feel you get along with your superiors? Good ___ Fair ___ Poor _____
20. Did you object to this questionnaire or any question in it? yes no
    What question(s) if any, No.(s) _____
21. Are both your parents living? yes no
    If no - Check one who has died: Father _____
    Mother _____

22. Have your parents ever been:
    a. Separated _____
    b. Divorced _____
    c. Remarried _____
    d. None of these _____

23. Who was the most important adult in your life up to 10 years of age?
_____

24. Who was the favorite child in your family? _____

25. How many brothers and sisters do you have? _____
    a. Brothers _____
    b. Sisters _____

26. Has anyone in your family ever had a history of:
    a. Nervous breakdown _____
    b. Insanity _____
    c. Suicide _____
    d. Drunkenness _____
    e. D. T.'s _____
    f. Fits or convulsions _____

27. What were your favorite subjects in school? _____

28. Did you get along well with your teachers or was there one or two who rubbed you the wrong way? _____

29. Have you ever had Venereal Disease? yes no

30. Do you smoke? yes no
    If yes: a. How much per day? _____

31. Do you drink? yes no
    If yes: Are you a light ____ moderate ____ or heavy ____ drinker?

32. Have you ever had a Mast or Court Martial? yes no
    If yes: a. Masts _____
    b. Summary _____
    c. Special _____
    d. What was the charge? _____
    e. How did things turn out? _____

33. Do you consider yourself a nervous person or a worrier? yes no
_____

34. Do any of your friends or family feel that you worry too much or are a nervous person? yes no
_____

DESCRIPTIVE SUMMARY

(Form 3)

Areas Involved

Name _____

1. Home Rigid Relaxed

Mother	Like	Dislike	Hostility	Anxiety	Competition
Father	Like	Dislike	Hostility	Anxiety	Competition
Siblings	Like	Dislike	Hostility	Anxiety	Competition

2. Women

Wife	No Problems	Pregnant	Major Problems	Divorced
Girl	No Problems	Pregnant	Major Problems	Divorced
Fiancee	No Problems	Pregnant	Major Problems	Divorced

3. Sexual

No experience Conflict Fear of Masturbation Guilt

4. Religion

None Regular Conflict Guilt

5. Sound

Disturbing Not Disturbing Uncomfortable Tolerable Nuisance
Does not wear ear protection _____ Does _____ Kind _____
Feeling toward ear protectors _____

6. Navy

Career Don't like Serving time

Gets along well with Superiors _____ Doesn't get along _____

7. Shipboard Like Dislike
Does sound affect this choice? _____

8. Job Like Dislike
Does sound have anything to do with this? _____

Would like different job better _____

9. Discipline

Courts _____ Masts _____ Civilian _____

Major Manifestations

Tension	Day Dreaming
Anxiety	Insomnia
Psychosomatic Symptom Type	Falling Asleep on Job
Irritability	Lack of Confidence
Poor Work Efficiency	Anorexia

Overall Rating

(5) 1. Superior
(4) 2. Good
(3) 3. Average
(2) 4. Borderline
(1) 5. Poor

EMOTIONAL STABILITY SCALE

(Form 4)

Any factor counts 1 point

Sexual Conflict
- (1) Morals vs desire for experience
- (2) Guilt over sexual experience
- (3) Guilt over extra marital sexual experience

Conflict with Authority Figures (Mental or Overt)
- (1) Direct Superiors
- (2) Mother
- (3) Father
- (4) Both parents
- (5) Wife
- (6) Shipmates

Religious Conflicts
- (1) Conflict with Parental teachings
- (2) Conflict with Religious Principles
- (3) Considers self overly religious
- (4) Irregular church attendance with guilt or conflict

Conflicts within Self
- (1) Considers self a worrier
- (2) Feels others consider him a worrier
- (3) Expressed lack of confidence
- (4) Poor expression of goals in life
- (5) Considers self a worrier with little or no reason

Expressed Manifestations
- (1) Anxiety under stress
- (2) Constant anxiety and tension
- (3) Depression

Observed Manifestations

Over two psychosomatic symptoms checked

LIABILITIES SCALE

(Form 5)

Any factor counts 1 Point

Disciplinary Problems

(1) Masts
(2) Courts
(3) Over 2 civilian arrests
(4) Over 5 civilian arrests

History of Mental Illness in Family

Dislikes Shipboard

Dislikes job

Dislikes Navy

Educational Assets (Liability if less than 11 years)

Grades	7	8	9	10	11	12	13	14
No. Subj. Comp.	3	3	3	9	7	13	1	1

Mode - 12th grade
Median - 10.8 grades -

More than 4 jobs in past 10 years

STRESS SCALE

(Form 6)

Any factor counts 1 Point

Stresses within the home

(1) One parent an excessive drinker
(2) Both parents excessive drinkers

Broken Homes (Divorced or Separation)

(1) Both parents dead
(2) One parent dead with remarriage
(3) One parent dead without remarriage

Home Guidance as Stated by Subject

(1) Good Guidance
(2) Little or no guidance
(3) None

Financial Stress

Of definite disturbing proportions to subject

Marital Stress

Of definite disturbing proportions to subject

RATING SCALE

(Form 7)

STRESS RATING		SCALE RATING
0 1	Minimum stress	1
2 3	Moderate stress	2
4 or over	Maximum stress	3

LIABILITIES RATING		SCALE VALUE
0 1	Minimum Liabilities	3
2 3	Moderate Liabilities	2
4 or over	Maximum Liabilities	1

EMOTIONAL STABILITY Points	SCALE VALUE
0	6
1	5
2	4
3	3
4	2
5 or over	1

MOTIVATION RATING Points - Job	SCALE VALUE
3	3
2	2
1	1

MOTIVATION TO NAVAL SERVICE	SCALE VALUE
3	3
2	2
1	1

MOTIVATION SCALE

(Form 8)

JOB	POINTS
Likes job	3
Would like a different job	2
Dislikes job	1

MOTIVATION TO NAVAL SERVICE	
Highly Motivated	3
Passive	2
Poorly Motivated	1

MEDICAL QUESTIONNAIRE

(Form 9)

Name _____ Service No. _____ Rank/Rate ___

Time in Navy _____ Married _____ How many years ____ Single __

Divorced _____ Wife Living _____ How many children _____ __

(Answer "yes" or "no" or fill in the blank.)

1. Have you ever had severe or prolonged headaches? ..... yes no
   If yes: a. Recur frequently? ..... yes no
   b. Ever on one side only? ..... yes no
2. Do you ever have buzzing or roaring in your ears? ..... yes no
3. Do you ever have dizzy spells? ..... yes no
   If yes: a. Frequently ..... yes no
   b. Bad enough to make you stop work? ..... yes no
4. Have you ever had a period of temporary blindness or had your vision become blurred for a short time? ..... yes no
5. Do you ever see double? ..... yes no
6. Have you ever fainted or blacked out? ..... yes no
7. Have you ever been knocked out? ..... yes no
   If yes: Were you unconscious more than 1 to 2 minutes .. yes no
8. Have you ever had shakes or tremors? ..... yes no
9. Have you ever had a fit or convulsion? ..... yes no
10. Have your hands ever been numb or had a tingling sensation in them? ..... yes no
11. Have you ever had a nervous breakdown? ..... yes no
12. Have you ever been in a mental hospital? ..... yes no
13. Have you ever been arrested? ..... yes no
14. Have you ever been convicted of any charge? ..... yes no
    If traffic violations - How Many _____
15. How many jobs have you had in the past 10 years? _____
16. How far did you go in school? _____
17. How do you feel you get along with your shipmates? Good _____ Fair ____ Poor ____
18. How do you feel you get along with your superiors? Good _____ Fair ____ Poor ____
19. Are both your parents living? ..... yes no
    If no - check the one who has died:
    Father _____
    Mother _____
20. Have your parents ever been:
    a. Separated _____
    b. Divorced _____
    c. Remarried _____
    d. None of these _____

21. If parents divorced or one has died and one remarried: How do you feel you get along with your step parent?

Better than real parent _____
Worse than real parent _____
About the same _____

22. Who was the most important adult in your life up to 10 years of age?

_____ _____ _____

23. Who was the favorite child in your family? _____
24. How many brothers and sisters do you have? _____
    a. Brothers _____
    b. Sisters _____
25. Has any one in your family ever had a history of:
    a. Nervous breakdown _____
    b. Insanity _____
    c. Suicide _____
    d. Drunkenness _____
    e. Fits or convulsions _____
26. Have either of your parents been excessive drinkers at any time? ..... yes no
    If yes: Father _____
    Mother _____
    Both _____
27. Are there any financial problems at home that cause you worry or concern? ..... yes no
28. Do you feel your parents were _____ too easy _____ too hard reasonable _____ in their discipline and guidance when you lived at home?
29. Do you have any disagreements with your parents at the present time? ..... yes no
30. Are you married? ..... yes no
    If yes - Answer a., b., c..
    a. Do you have any problems with your wife that worry you? ..... yes no
       What
    b. Are there any financial problems that worry you? ..... yes no
    c. Have you ever been divorced or separated? ...yes no
31. Do you like shipboard duty? ..... yes no
32. Would you like shore duty better? ..... yes no
33. Do you like your present job? ..... yes no
34. Would you like a different job better? ..... yes no
35. Do you like the Navy? ..... yes no
36. Plan to make it a career? ..... yes no
37. No career -- just serving time ..... yes no
38. Does your present job involve any danger to you? ..... yes no
39. Do any of the duties assigned to you seem dangerous? ..... yes no

40. Have you experienced any "close calls" in the performance of your duties? ..... yes no
41. Do you consider yourself a nervous person or a worrier? ..... yes no
42. Do any of your friends or family feel that you worry too much or are a nervous person? ..... yes no
43. Do you ever feel you are not able to do the job assigned to you? ..... yes no
44. What do you plan for your life work? _____
45. What religion are you? _____
46. Do you attend church regularly? ..... yes no
    a. If not -- Do you feel guilty? ..... yes no
    b. Would your parents approve? ..... yes no
47. Have you ever thought you were too religious? ..... yes no
48. Have you had any sexual experience? ..... yes no
    a. Do you feel guilty about this? ..... yes no
    b. Does this conflict with any of your beliefs? .... yes no
    c. Would your parents approve? ..... yes no
49. Did you get along well in school? ..... yes no
50. Did you fail any grades? ..... yes no
    What ones? _____
51. Have you ever had Venereal Disease? ..... yes no
52. Do you smoke? ..... yes no
    If yes: How much per day?
53. Do you drink? ..... yes no
    If yes: Are you a light ____ moderate ____ or heavy ____ drinker
54. Have you ever had a Mast or Court Martial? ..... yes no
    a. Masts _____
    b. Summary _____
    c. Special _____
    d. What was the charge? _____
    e. How did things turn out? _____
55. Do you feel uneasy when in a 'tight spot'? ..... yes no
56. Do you ever get any of the following when in a 'tight spot' or under tension?
    a. Headache _____
    b. Dizziness _____
    c. Shakes _____
    d. Tightness in your stomach _____
    e. Sweaty hands _____
    f. Trouble getting your breath _____
57. Is the jet noise disturbing to you? ..... yes no
58. Do any of the following happen when you are near the jets?
    a. Ears hurt _____
    b. Head hurts _____
    c. Dizziness _____
    d. Trouble thinking _____
    e. Can't walk straight _____

59. Do any of the following happen after a day of operations?

a. Trouble getting to sleep at night _____

b. Lose temper easily _____

c. Appetite poor _____

d. Feel jittery _____

60. Have you ever worn ear protection? ..... yes no

What kind _____

Do you wear any kind at present? ..... yes no

What kind _____

How do you like the type ear protection you have worn or are now wearing? _____

61. Did you object to this questionnaire or any question in it? ..... yes no

What question(s) if any, No.(s) _____

CHAPTER 7

CRITIQUE OF FIELD STUDIES

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INTRODUCTION

The ideal approach to the problem of relating noise exposure to changes in auditory and non-auditory performance of exposed personnel would be to expose subjects to known amounts of noise in a well-controlled laboratory situation. Our objective, however, was to investigate the possibility of persistent changes in performance, and we would obviously not wish to produce such changes in volunteer subjects. Instead, we decided to test those men whose jobs required them to be routinely exposed to high-intensity noise generated by jet aircraft, since it was an increasing concern about the well-being and operating efficiency of just these men that was the prime motivating factor for the ANEHIN study. These factors dictated the choice of a field type study.

TYPES OF FIELD STUDIES

There are a number of kinds of studies which can be conducted in the field. Three of these were thought promising enough to be considered as the method of choice for the ANEHIN project.

Cross-sectional studies

In this type the performance of noise-exposed personnel would be compared with that of non-exposed personnel. Here, only one test would be given to the men in each group. Preliminary trials of this method indicated it was not satisfactory for the purposes of the ANEHIN study since it did not give good control of differences between individuals. However, it was used in several cases where retests were not possible.

"Before-and-After" studies

In this type young men would be tested at the time of induction before they were exposed to high-intensity noise, and again at the time of discharge after several years of exposure to noise. Although promising, this type was rejected because of the length of time required to derive the comparative information. However, this method is recommended for future studies of the ANEHIN type.

"Test-Retest" studies

These would be similar to the before-and-after studies, except that retesting would be done at fixed intervals of six months to one year. The performance of men having severe exposures would be compared with that of men having no exposure during the period between tests.

This method was used for studies conducted aboard the USS FORRESTAL (auditory tests only) and at NAS Cecil Field (auditory and non-auditory tests).

Subject to the limitations discussed later, it was found that a test program of this type could be conducted successfully in the field.

GENERAL COMMENTS ON OPERATIONS

For audiometry and for three of the psychological tests, administration to groups of ten men at a time proved to be particularly effective. We believe it will be an equally effective procedure for many other tests. It is advantageous because a small group of men can usually be spared from a squadron or duty section for a short period without disrupting the operating schedules, and group testing is a much faster way of collecting data than individual testing.

Excellent cooperation was obtained both from the men tested and from the officers or petty officers who enforced the testing schedules. Almost all of the subjects took the tests seriously, and there was only one complaint that men were kept from the performance of essential duties. This high level of cooperation appears to be the result of (1) the fairly high official priority given to the project, and (2) the genuine concern of officers and men about the possible hazards of jet noise exposure. At each testing location our first contacts were made through the dispensary or carrier sick bay, and the establishment of our field testing program was greatly facilitated by the support provided by the officers and men of these medical departments. Cooperation of this kind must be obtained if future testing programs are to be successful.

LIMITATIONS TO FIELD STUDIES

Even with the best of cooperation, there are drawbacks to any field-testing situation. Some limitations were known at the outset, some anticipated difficulties never materialized, and some difficulties were found only by experience. The most serious of these limitations are discussed below.

Lack of Stimulus Control

A major drawback is the lack of control of the amount of noise exposure. One must take exposure as it occurs and attempt to measure it. Only a gross estimate of the total exposure can be made because of such variable factors as the intermittency of the noise, the high gradients of intensity near the aircraft, and the fact that the men move about in the noise field. Although "typical" exposures may eventually be determined by special apparatus (see Chapter 3), a considerable zone of uncertainty will still surround any statement about the exposure of a particular man.

A further complication in determining the effective auditory stimulus is the uncertainty introduced by the use of ear protection. There is, of course, no problem when the men use no protection. But if they profess

frequent use of ear plugs, one can only guess how well the ear plugs fit.

Extraneous Factors

A related difficulty is that extraneous factors affecting the subject's responses were and always will be more prevalent in field studies. At best, this necessitates more elaborate controls; at the worst, a good deal of data may have to be discarded. For example, the men tested aboard the FORRESTAL were also exposed to gunfire during the course of the three-month study (see Chapter 4). If marked hearing losses had occurred, we could not have been sure that they were due to aircraft noise.

Although the short-duration aftereffects of noise are of some interest, they were extraneous factors in the present context, since our professed emphasis was on long-term effects. A 40-hour rest from noise exposure which seems to be necessary for recovery from mild temporary hearing loss was not common at land bases and was very rare aboard ship. This is one of the most telling limitations of shipboard studies. Air operations may continue almost until the ship docks, at which time many of the men go on leave and are not available for testing.

Scheduling

Flight operations, being dependent upon weather, are not completely predictable, so that scheduling of testing must be done on a day-to-day or, occasionally, even an hour-to-hour basis. A planned program in the nature of an "experimental design" will seldom if ever be successfully completed in the field-study setting.

Portability Considerations

Certain tests that would have been desirable (for example, tests for reaction to stress requiring immediate biochemical analysis) needed either too much space or too much apparatus to be given aboard ship. A related problem is that tests requiring immobility were impossible on shipboard because of the ship's motion (e.g. steadiness of standing).

Attrition

The rate of attrition of men being studied is quite high, due to discharge and transfer. Although the composition of the ship's crew remains fairly intact throughout a formal cruise of as much as eight months, as in the case of the TICONDEROGA studies (see Chapter 6), we found that the turnover in squadron personnel at a Naval Air Station was about 40% over a period of seven months. It is doubtful, therefore, that in testing a single squadron, the test-retest interval could be longer than a year.

Logistics

The transportation and relocation of the mobile laboratory trailer proved to be a persistent source of difficulty. Special permits had to be obtained from each state traversed because of the trailer's great length. Since the trailer did not have its own tractor, the hauling had to be contracted for several weeks in advance. In addition, hitching the tractor to the trailer often required several hours because of the construction of the trailer dolly. To hitch the tractor it is first necessary to raise the trailer, using heavy duty jacks. The dolly (which is not an integral part of the trailer) is then removed and the tractor is attached. Care must be used in this operation since the trailer can be pushed off the jacks before the tractor is in the proper position. These drawbacks could be avoided by the permanent assignment of a tractor to the trailer or by the installation of hydraulic jacks on the front end of the trailer.

Space

Although the size of the trailer was unimportant at shore bases, there were complaints from the hangar-deck officers that it took up too much space aboard ship. We had originally hoped to take the trailer aboard a carrier for a six-month Mediterranean cruise, but were informed that all hangar-deck space was needed for essential equipment and supplies.

Assistants

The problem of obtaining permanent competent assistants was one that we were unable to solve. Although we were able to get excellent help on a temporary basis when needed, we strongly recommend that competent and conscientious men be permanently assigned to the trailer. In order to keep the turnover of such personnel to a minimum, it is further recommended that these assistants be civilians.

SUMMARY

We have demonstrated that field studies of the effects of aircraft noise are practicable, provided that the spirit of cooperation displayed by the officers and men during the ANEHIN project continues at its present level. One cannot usually draw as broad conclusions as one would like from field studies because of the lack of control over the noise exposures of the men and the number of extraneous factors affecting the behaviors being tested. However, it is possible to answer the question of whether or not men are suffering damage in that particular situation.

The rate of attrition of subjects will always be a limiting factor in studies restricted to a small number of men. Only a large-scale program involving testing throughout the Navy can overcome this difficulty.

Another general limitation is the requirement of portability, which restricts the number of tests that can be undertaken with the mobile

laboratory. In addition, there is difficulty in maintaining the planned test schedules.

The performance of studies aboard ship has several additional drawbacks. The ship's motion limits the tests that can be employed, and the trailer laboratory is an obstruction on the hangar deck. Only rarely is there a period without noise long enough to keep temporary effects (particularly temporary threshold shift) from obscuring any persistent effects.

Difficulties that were encountered, but which probably can be solved satisfactorily, include the logistics of transporting and relocating the trailer and the problem of obtaining adequate assistants for test administration and scoring.

CHAPTER 8

REVIEW OF ORGANIZATION AND PROCEDURES

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ANEHIN AS A MODEL "TROUBLE HUNT"

The stated objective of the ANEHIN project was to determine what, if any, cumulative effects were being produced on naval personnel by routine exposure to high-intensity noise. This was a difficult objective because only one such cumulative aftereffect, namely, impairment of hearing for high-frequency sounds, had been clearly identified in advance. A major part of the project therefore became a wide-spreading "trouble hunt," or search, for undesirable effects in any or all areas of general health of naval personnel and their ability to perform military duties.

This general search can serve as a model, not only for a possible later study of high-intensity noise when noise exposures become more severe than they are at the present time, but also for any other search for unknown but suspected cumulative effects. Such effects may be feared from any new or greatly increased stress that develops in the course of future military operational procedures that may be incidental to new weapons systems. Such stresses might include extremes of temperature, restriction of diet, of oxygen supply, of freedom of movement, of exposure to mechanical vibrations, etc., etc. Any of these, if sufficiently prolonged and severe, might produce cumulative aftereffects in addition to their more obvious immediate and acute effects. As in the ANEHIN study, some one organ system will probably be particularly vulnerable to the particular stress, but there will still be the possibility of indirect, unidentified but undesirable, cumulative aftereffects. The ANEHIN project can serve as a model for a search for such aftereffects; therefore, the organization of the ANEHIN project, the reasons for including and for excluding certain types of test and procedures and also the qualifications and backgrounds of the ANEHIN personnel will be reviewed once more. Certain suggestions for alternate organization and divisions of responsibility that might be considered in future similar projects are included.

This review will also serve to indicate where individual credit is due in the complex over-all project.

ANEHIN AS A FIELD STUDY

The ANEHIN project was planned as a field study for two reasons. The first was the fear that exposures to jet-engine noise in the unexplored range above 140 decibles might already be producing injurious cumulative aftereffects. If so, the project could serve as an immediate monitor to identify and remove afflicted personnel, and also to assess the effectiveness of such protective measures as would naturally be undertaken. The second reason was that it seemed impossible to bring into the laboratory both the noise exposures and the other stresses of actual military duty that might combine with noise exposure to produce anxiety, fatigue, or other aftereffects.

The personnel selected for study were the flight deck crews of aircraft

carriers and the maintenance personnel who service high-performance jet aircraft. They were chosen because they clearly received the most severe noise exposures that were being regularly encountered in the line of military duty.

In all, three field studies were successfully conducted, one on board the USS FORRESTAL, one on board the USS TICONDEROGA, and one at NAS Cecil Field, Florida.

ANEHIN'S SPECIFIC AREAS

Noise Exposure

Noise exposure was the specific environmental stress that led to the establishment of ANEHIN. An essential part of the project was therefore to measure the noise exposures of the personnel who were to be observed. It was recognized at the outset that available methods and instruments for the measurement of noise exposure were clearly inadequate for military situations characterized by relatively brief and perhaps infrequent exposures to noises of very high intensity. An early decision was made to develop, as part of the project, a method which could be used to measure and summate the actual noise exposures of particular individuals. The method for the measurement of noise exposure relies on a special device, the "noise cumulator." This device was successfully developed for this project, but not in time for use in the ANEHIN field studies. The equivocal results of the field studies can be attributed in large measure to lack of adequate information concerning the actual noise exposures. This point is made clear in Chapters 4 and 5.

Hearing Loss

Hearing was the specific function for which lasting impairment by severe noise exposure had already been established, particularly hearing for high-frequency sounds. Quantitative assessment of this impairment was an obvious requirement of the project. This led in turn to a requirement for a mobile laboratory in which hearing, and other functions also, could be tested in the field. An adequate acoustic environment for hearing tests is notoriously difficult to find on shipboard or near aviation test facilities. A trailer-mounted laboratory was therefore designed and constructed to meet the special needs of audiometry in the field.

Another requirment of field audiometry that could not be met effectively by available equipment was a method for testing a large number of ears rapidly but in sufficient detail and with sufficient precision. The large numbers were needed for adequate cross-section surveys and also for longitudinal before-and-after studies. The ANEHIN project therefore developed for this purpose a semiautomatic group audiometer that tests 10 subjects at a time by the "method of single descent." This audiometer was used

successfully in the mobile laboratory in all of the field studies, and has since been further improved by the addition of an automatic print-out device for quick display of the data.

ANEHIN'S GENERAL AREAS

Several other general areas were explored for indications of undesirable cumulative aftereffects of noise exposure. Any future "trouble hunt" will presumably wish to explore these same areas. Here much advance thought was given to the selection of particular tests and methods, and several additions and omissions were made on the basis of experience in the first field trials. Certain deliberate compromises were made because of the cost in time or equipment of some theoretically desirable methods. In other cases the limiting factor was the unavailability of adequately trained personnel, whether at the investigator or at the technician level.

As a matter of policy, only well-established tests and methods were adopted in these general areas. The development of new instruments and methods was reserved for the specific problems related to the special stress (noise) and a known injurious effect (impairment of hearing). In the general areas where effects were only feared or suspected, and where the number of possible effects or tests is almost unlimited, our policy was to select ready-made tests of known reliability and, at least, apparent validity. The selection was further guided by an effort (1) to sample broadly various organ systems and various types of function, performance and behavior, and (2) to observe realistic limits of expense and available personnel. The tests and procedures employed in addition to audiometry were chosen to detect possible changes in sensory and psychomotor performance, equilibrium, central nervous and complex intellectual functions, anxiety, and the incidence of sick calls and accidents.

Physiological Indicators of Stress

Several experts were consulted on general physiological responses to stress, notably the activity of the adrenal glands. They informed us that the pattern of certain changes in the excretion of ketosteroids and other substances in the urine and also of secondary changes in the number of certain types of blood cells is well established in response to severe bodily injury such as burns. The nature and severity of the stresses that produce clear, recognizable changes is, however, far more severe than anything produced by current noise exposures. Physiological changes do not occur reliably in response to "stress" at the psychiatric level or at the intermediate level of chronic fatigue; yet it is in just these later areas that we believe that cumulative aftereffects of the "stress" of repeated noise exposures are most likely to appear. The physiological indicators of stress are well adapted for study in an experimental situation but would present serious practical difficulties in the field. The physiological indicators were there-

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fore reluctantly omitted from the ANEHIN field studies.

Medical Indicators

A complete, routine neurological examination was originally included in the ANEHIN routine, partly because of a theoretical fear that high-intensity acoustic energy might act directly on and injure nervous tissue. After the first field study the neurological examination was omitted, partly because we realized that no significant changes could reasonably be expected during the short periods of actual field studies and partly because of lack of adeuqate medical personnel to perform the examinations at appropriate times.

We did examine the frequency and reasons for sick bay calls. In future studies such medical and physiological indices as gain or loss of weight could easily be added.

Psychological and Psycho-physiological Tests

A battery of tests was selected to sample the areas of sensory, psychomotor, and higher intellectual functions. It included a group of psychophysiological measures aimed to detect anxiety and tension. A set of group paper-and-pencil tests also explored anxiety, and in addition included some neuropsychiatric tests and a variety of factored aptitude tests. The final battery gave as great a variety as seemed possible in a shipboard situation, but the choice was limited both by the number of personnel available for administering the test and by problems of space in the mobile trailer laboratory. The group paper-and-pencil tests do not suffer from these limitations.

In future "trouble hunts" further simplification of the test battery may be possible if the selection is restricted, as it should be, to a small number of simple, reliable tests of established significance. Considerable technical skill and also additional personnel are now and probably always will be required, however, both for upkeep and for the efficient administration of certain items of the laboratory apparatus. Such tests are more efficiently administered under controlled experimental conditions than in the field.

Psychiatric Methods

The psychiatric interview was the major psychiatric method employed. The interview was, however, supplemented by questionnaires and by group paper-and-pencil tests. The objective of the interviews was to seek evidence of chronic fatigue, anxiety, loss of motivation, or other indications of increased stress.

In psychiatry the chief criterion has always been, and still is, the opinion of an experienced psychiatrist. The opinion must, however, be based on facts of observation or on statements obtained from the subject in interviews or by written answers to questionnaires. There is as yet little

standardization of psychiatric methods, and we therefore attempted to standardize at least the information to be elicited from the subjects. Requiring the psychiatrist to make a set of similar judgments and comparisons in all cases was an attempt to standardize the psychiatric evaluations. The objective was to minimize the amount of individual subjective interpretation required of the psychiatrists so that results could be compared from one examiner to another and from one time to another. A useful start was made in this direction but was interrupted, and the work is still imcomplete. The clinical impression of our psychiatrists, based on partially standardized interviews and questionnaires, remains our chief tool in this area, and it has yielded important and useful information. The strategic advantage of a doctor in navy uniform was demonstrated, but with the relative shortage of naval medical personnel it was not feasible for a doctor to be assigned to the project for its full duration. This situation warns of future difficulty if and when a resumption of this or similar studies is undertaken. As an alternative a civilian neuropsychiatrist or a clinical psychologist might be substituted. A clinical psychologist would be a logical member of the team in that many of the tests in the psychological battery are pencil-and-paper tests that could best be handled by such an investigator. This type of test does not require special laboratory facilities. In this area the organization of any new project might well depend on the type of personnel available and the situation in which the study would be carried out.

Observations of Group and Social Behavior

The observation of group and social behavior, as an additional method, was discussed at length early in the ANEHIN planning, particularly with Wilse B. Webb, Ph.D., of the staff of the Naval School of Aviation Medicine. Indicators such as eating and recreation habits and group behavior of various sorts may prove to be sensitive to the development of "stress," "anxiety," "chronic fatigue," etc., but the methods of observation and analysis are at this time cumbersome and imperfectly developed. The difficulty in a field study of isolating the possible effects of noise exposure from the many other stresses of military life would be very great. For these reasons, and the necessity of keeping the size of our scientific staff within practical limits, such methods were excluded from the ANEHIN battery although it was recognized that they might be feasible and profitable under conditions of a controlled experiment on severe noise exposures.

Statistical Methods

In field studies, and also in controlled experiments on human subjects, appropriate statistical methods must always be employed to obtain the maximum amount of useful information from such studies. The proper use of statistics begins with the selection of methods and the design of the experiments. Statistical considerations entered at all stages of the ANEHIN planning, in the collection of data and in the analysis of results. A final

step, the application of analysis of covariance to the results of the psychomotor and psychophysiological tests, was undertaken as the result of suggestion made by Lyle Jones, Ph. D. and R. C. Davis, Ph. D. at the October, 1957 meeting of the Committee on Hearing and Bio-Acoustics (CHABA).

ANEHIN AS AN INTERDISCIPLINARY PROJECT

This survey of the ANEHIN methods and activities has emphasized the variety of techniques that has been employed. The variety was required by the uncertainty of the exact nature of the non-auditory effects of noise that might appear. The study could not well have been carried out by any smaller of less varied group than was actually employed. This principle applies also to the future, it is not economical or effective to organize a wide-spreading "trouble hunt" on a small scale. If it is to be undertaken at all, it must be broadly planned and adequately supported.

INDIVIDUAL CREDITS

Three members of the ANEHIN Project were electrical and acoustical engineers. Robert Benson, PhD., designed the mobile trailer laboratory. He also suggested the form of analysis to be used in the noise cumulator and carried out some of the early planning. With Dr. Ward he started the studies that led to the use of the method of single descent in a semiautomatic group audiometer. Dr. Benson resigned from the ANEHIN project in October 1954. Jerome R. Cox, Sc. D., took over responsibility for the electro-acoustic aspects of the project. He carried out the major development and the field trials of the noise cumulator and also completed the group audiometer. He developed the automatic print-out feature of this instrument. With the help of Arthur A. Niemoeller, a graduate student in electrical engineering, he established the adequacy of available microphones in high-intensity noise fields.

W. Dixon Ward, a Ph. D. in Experimental Psychology, had special previous experience in psychoacoustics and a background in physics. He was responsible for all of the measurements of hearing in the ANEHIN project and the analysis of the auditory data. He collaborated with Drs. Benson and Cox in the development of the group audiometer and showed that the instrument is accurate enough for general use in other military and industrial monitoring situations.

D. G. Doehring, also a Ph. D. in Experimental Psychology, with special experience in the study of motor functions, developed the ANEHIN battery of psychological and psychomotor tests. He administered these tests in the field studies and carried out the statistical analysis of the data. He also assisted in the analysis and preparation for publication of parts of the psychiatric studies.

William I. Stryker, M. D. , who had had training as a psychiatric interne, was assigned full time to the project for about one year, as a Lieutenant in the Naval Medical Corps. He made significant progress toward standardization of interviews and the development of a method of scoring certain psychiatric data. In the actual field studies aboard the USS FORRESTAL and USS TICONDEROGA great assistance was given by Capt. Philip B. Phillips, a board diplomate in psychiatry.

Hallowell Davis, M. D., a neurophysiologist with special interests in the auditory system, and Director of Research at Central Institute for the Deaf, was coordinator of the ANEHIN project. He drafted the more general chapters of this report. He was assited in drafting and editing by J. Richardson Usher, Ph. D., a technical writer.

Although the primary responsibility for each area lay with each senior investigator and each drafted the corresponding chapter or chapters of this report, all have read and criticized the other sections. We have also benefited from consultation and advice of our colleagues at the Naval School of Aviation Medicine. The final conclusions and recommendations represent a true consensus of the entire ANEHIN group.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS

The following over-all conclusions from the ANEHIN study are clear:

(1) As of March, 1957 there is no reasonable cause for immediate alarm concerning cumulative aftereffects of jet-engine noise exposures of naval personnel.

(2) It is unsafe to extrapolate from present noise exposures to the more severe exposures that must be anticipated in the future. The extent of the present margin of safety is not known, and continued vigilance is required.

(3) In the opinion of the ANEHIN group, at least two other undesired effects of high-intensity noise are, as of 1957, more serious threats to military operations than are its cumulative after effects. They are

(a) interference with communication and

(b) decrement in performance of personnel during actual exposure to high-intensity noise.

The following comments further summarize and evaluate the results and conclusions from the individual chapters.

The results not only show that there is no clear positive evidence of aftereffects from present noise exposure, but they also indicate that our research methods were sufficiently delicate to have almost certainly detected any such effects if they had been present to a significant extent. One basis for this confidence is that in two very different areas, the audiometric and the psychiatric, small positive effects were actually found, but they appeared on closer analysis to be due to causes other than exposure to jet-engine noise. Specifically, an increased incidence of high-frequency hearing loss among noise-exposed personnel seems probably to be due more to gunfire than to jet-engine noise, and an increase in anxiety and lowering of morale among flight deck personnel during a prolonged Mediterranean cruise were rather clearly associated with risk of bodily injury and with an unexpected prolongation of the cruise. With our psychological test battery we found a suggestion of a general trend among the most noise-exposed personnel toward a slight decrement of performance over the entire group of tests.

The amount of change is not significant in the statistical sense in any one area, but the consistency of the direction of small changes is suggestive. It points toward the probable adequacy and delicacy of the test battery and a possibly marginal situation in regard to production of aftereffects.

Certain instruments and methods developed as part of the ANEHIN project are suitable for more extended use for other purposes.

(1) A semiautomatic group audiometer, suitable for use in the mobile laboratory, was designed especially for rapid but accurate testing. This audiometer has been equipped with an Automatic Audiometric Data System (AADS) that will print the audiograms of the ten subjects as fast as the measurements are taken. The ten sets of numbers are tabulated on a

single sheet of paper. Audiograms for both ears of a group of ten men can be obtained in ten to fifteen minutes. The method ("method of single descent") has been validated in terms of standard clinical audiometry, and the instrument appears suitable for general use as a monitoring audiometer.

(2) The establishment of a suitable battery of psychomotor and psychological tests was a task of selection and of practical trial under the conditions imposed by the mobile laboratory and other practical restrictions. Our selection includes tests of vision, touch, equilibrium, motor coordination, central nervous functions, complex intellectual functions and emotional adjustment. New tests that may be developed elsewhere in the future should be considered for addition, but the present battery is reasonably brief yet variegated and its administration has proved practical in a mobile field laboratory. The battery is now available for further use either as a whole or in parts, as recommended below.

(3) A device known as the "Noise Cumulator" has been developed and a prototype was used successfully on board the USS FORRESTAL. It gives numerical measures of noise exposure in terms of total time of exposure to noise in specified frequency bands and above various pre-set intensity levels. The field use of the instrument involves obtaining tape recordings of the noise exposure of a man during the actual performance of his job in noise. He wears a frequency-modulated short-wave transmitter in a helmet. Analysis of the recordings is carried out when and where it may be convenient. The field unit, including microphone and transmitter, performs reliably and accurately in noise fields up to about 145 db. Considerable experimental work involving human subjects must still be done, however, to validate the measures obtained in terms of specified biological effects. Several different bases of analysis can be employed, depending on the choice of the method of rectification of the signal, the frequency bands, and the spacing of the intervals of intensity. Unfortunately, highly impulsive noise made up of discrete impulses, such as gunfire, is still beyond the scope of the instrument. But even without validation, which will be a long and difficult task, the Noise Cumulator is now suitable for a basic survey of the noise exposures associated with the operation of various aircraft and many other types of noisy equipment. Through routine noise studies of the operation of new equipment, any great increase in the noise exposure of personnel can be detected or forecast.

The ANEHIN project, with its interdisciplinary organization, can serve as a model in many ways for any "trouble hunt" that may be undertaken in the future with respect to possible but unidentified cumulative effects of any new stress or combination of stresses encountered in military operations. Certain unavoidable limitations of field studies are pointed out in Chapter 7. We believe that if another "trouble hunt" is undertaken it must be broadly planned and adequately supported.

GENERAL RECOMMENDATIONS

Monitoring of Personnel

For adequate protection of military personnel against the uncertain hazards of future increases in noise exposure, "Multiple Monitoring" should be instituted. Multiple monitoring means that routine spot-check tests, both auditory and non-auditory should be applied regularly to certain classes of personnel at strategic locations. Selected, simplified methods can be employed. The tests should be applied, in general, to the class of personnel known or judged to be exposed to the greatest risk, or, in the present case, to those undergoing the most severe and extended noise exposures. If the injury is clearly defined and measurable, as in presistent high-tone hearing loss, the monitoring can be reduced to a single test and can be applied as a regular routine to all exposed personnel. Where the effects are not yet identified, as with the postulated non-auditory effects, a variety of tests in the nature of periodic spot checks can be carried out, as, for example, with selected psychological and psychomotor tests, medical questionnaires and psychiatric interviews. The value of such sample testing of a small proportion of the entire group will be greatly enhanced if the selected tests are first administered to naval personnel as routine early in their training. The personnel tested should, of course, include many who are likely to be assigned to jobs that will involve severe noise exposures. Later, after a year or two, men can be retested and their changes in performance, if any, related to known or estimated noise exposure.

Monitoring of Noise Exposures

Monitoring of noise exposures by physcial methods should be instituted to detect any systematic increase in the noise exposures of personnel. The negative results of the present survey of auditory and non-auditory effects show that the operational noise exposures encountered in early 1957 are within a reasonable "tolerable range" or "criterion limits." At present the 1957 exposures are defined only in terms of months on a certain kind of job or military duty with certain types of high performance aircraft. But the noise cumulator is now ready, wherewith to translate that description to a statement of total number of seconds or minutes exposure per day (or week or month) to noise in each frequency band and above each of a series of intensity limits. In these terms the noise exposures from new equipment and with new operational procedures can be compared reasonably with the old. It will at least be known when the limits now established as tolerable begin to be exceeded by large amounts.

Renewal of the ANEHIN Project

If and when, but only if and when, a substantial increase in noise exposure occurs, due either to the introduction of noisier equipment or a

change in operational procedure, a new study of cumulative effects should be undertaken by methods similar to those in the present study.

Establish Valid Criteria of Noise Exposure

The Noise Cumulator should be used in an effort to validate a physcial method for estimating the biological hazard of noise exposures. A scale of exposure is needed that is related by more than guesswork to its auditory and non-auditory biological effects. The present margin of safety is unknown and should be determined.

A Controlled Experiment on Human Volunteers

Specifically, in order to determine valid criteria and the margin of safety we recommend a carefully planned, well controlled experiment on volunteer subjects. Noise exposures should be considerably but cautiously extended, under close medical supervision. The full battery of ANEHIN tests and perhaps others as well should be employed. Such a study was actually planned in some detail for the ANEHIN project for the year 1957, but could not be carried out because of the unavailability of adequate noise sources and of the additional personnel that would have been required. The experiment is still recommended from the scientific point of view, however, as the logical and highly desirable next step. The recommended experiment on noise exposure would complement the multiple monitor studies in the field. This combination of planned experiment plus monitoring is proposed as the long-term follow-up of the intensive ANEHIN field study that has just been completed. The field situation provides combinations of stresses that are not reproduced in experiments, but the field study has shown that, at 1957-levels and durations of noise exposure, not even the combined stresses are critical. A margin of sa ety of unknown amount exists with respect to increasing noise exposure. The only feasible way to assess and thus take full advantage of this margin of safety is by direct, deliberate increase of controlled noise exposure until limits of tolerance begin to disappear.

Summary of General Recommendations

The above general recommendations can be summarized as follows:

Elaborate field studies of cumulative auditory and non-auditory effects of high-intensity noise may be discontinued. Instead should be substituted:

(a) multiple monitoring of personnel for auditory and non-auditory effects;

(b) monitoring of noise exposures of new aircraft and new operational procedures; and,

(c) a controlled experimental study on human volunteers, designed to establish limits of tolerance and well founded criteria for noise exposures measured in physical terms.

SPECIFIC RECOMMENDATIONS

The ANEHIN group believes that the above general objectives could be achieved by the following specific steps:

(1) Institute shipboard studies, presumably during training cruises, of the noise exposures of actual naval operations. These studies should be conducted according to methods outlined in Chapter 3. Continue such studies as a monitor activity, because operational changes such as habitual use or non-use of afterburners at take-off may make critical differences in the noise exposure of deck personnel.

(2) Institute systematic monitoring of the noise output of new types of aircraft and the noise exposures to be expected in launching and maintaining such aircraft. Early information of this sort will reduce the necessity for further shipboard studies.

(3) Determine the method of using the noise cumulator that most closely predicts actual biological effects. Temporary changes in hearing may reasonably be used as such a biological effect until other effects of noise are clearly defined.

(4) Institute monitoring audiometry, as described in CHABA reports,[9.1] as a routine for all noise-exposed personnel. Routine monitoring audiometry need not be conducted on shipboard.

(5) Continue special auditory monitoring studies in situations that involve the severest noise exposures, as at NAS Cecil Field. In these situations annual neurological examinations should be included. Use such studies to evaluate the effectiveness under field conditions of ear protective devices such as plugs, muff, and helmets.

(6) Evaluate the ANEHIN group audiometer, which employs the method of single descent and an automatic data printing system, for general use in routine monitoring audiometry.

(7) Establish base-line normals for performance on selected physiological and psychomotor tests. Administer these tests as routine to a considerable number of naval personnel during training. Conduct sample retest studies from time to time when and where definite information as to noise exposure is available.

(8) Employ selected psychological tests systematically, on a monitoring basis, at installations such as NAS Cecil Field relatively severe noise exposures are common.

(9) Maintain full medical watchfulness, including spot-check psychiatric interviews, to detect possible cumulative effects of total stress. This watchfulness will become more important as noise exposures and other stresses and hazards increase. Noise exposure is only part of the general

9.1 "Monitoring Audiometry and the Medical Disposition of Cases of Hearing Loss." Final Report of Working Group 25, CHABA Report No. 6. Technical Report No. 11 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151 (01), NR, 140-069. See also the more explanatory version in Davis, H., Hoople, G.D., and Parrack, H.O. The medical principles of monitoring audiometry, Arch. of Indust. Health, 17: 10-20, 1958.

problem of stress, cumulative fatigue, decrement of performance, and possible permanent injury.

(10) Alert all naval medical officers to the importance of observing and reporting carefully all exceptional individual cases of accidental, very severe noise exposures. These cases should be brought from the level of anecdotes to that of carefully reported clinical cases. The noise exposure should be reported as fully as possible as well as relevant tests for possible injury to nervous system, lungs, intestinal tract, and other organs.

(11) Continue work on the standardization of the psychiatric interview and particularly on the development of a scale of motivation, anxiety, etc., on which personnel can be rated. Here it is not yet clear what aspect or features of a man's feelings and behavior are relevant, and, if more than one item is relevant, how the two should be combined and in what proportion. These problems involve very basic concepts in psychiatry and in the science of test-construction alike, and progress in this area would be of value not only for the noise problem but for many other problems of stress of other kinds.

(12) Intensify studies of the decrement of performance in the actual presence of very intense noise. For this purpose, a carefully controlled, well designed experiment with volunteer subjects is strongly recommended. The noise exposures should equal, in intensity, the most severe that may be habitually encountered in operations and the durations should be considerably but cautiously extended under careful medical monitoring. Noise made up of discrete impulses such as gunfire could be included to advantage. Studies should be made of performance on various manual, sensory, and mental tests during noise exposure. Also before-and-after studies should be made of hearing, of psychological performance, of medical and physiological indicators of stress and of emotional and psychiatric status. Even group and social behavior might be included. Such an experimental study might at one stroke greatly extend our concept of "probably tolerable noise exposure."