WADC TECHNICAL REPORT 57-702

GUIDE FOR THE ANALYSIS AND SOLUTION OF AIR BASE NOISE PROBLEMS

A. C. PIETRASANTA
K. N. STEVENS

AND

THE STAFF OF BOLT BERANEK AND NEWMAN INC.

NOVEMBER 1961

Contract No. AF 33(616)-3685
Project No. 7210
Task No. 71711

BIOMEDICAL LABORATORY
AEROSPACE MEDICAL LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

1300 - August 1962 - 43-1896 & 1897

FOREWORD

This report was prepared by the firm of Bolt Beranek and Newman Inc. under Contract AF 33 (616)-3685 for the Aerospace Medical Laboratory, Aeronautical Systems Division, under Project 7210, "Human Response to Vibratory Energy," Task 71711, "Integration of Information on the Effects of Acoustic Energy and Its Control." Technical supervision of the preparation of this report was the responsibility of Lt. Lothar O. Hoeft and Dr. Henning von Gierke, Bioacoustics Branch, Biomedical Laboratory, Aerospace Medical Laboratory. The authors are grateful to Dr. von Gierke, Lt. Hoeft, and Mr. K. Eldred (formerly of Wright Air Development Center*) for their many helpful comments and suggestions, and to J. Rogers of Bolt Beranek and Newman Inc. for his editorial assistance.

*Wright Air Development Center has been redesignated Aeronautical Systems Division.

ABSTRACT

This guide presents detailed engineering procedures for analyzing and solving air base noise problems caused by jet operations. These problems are classified according to five "activity areas": (a) on- and off-base housing, (b) offices and work areas, (c) group meeting, study, and rest and relaxation areas, (d) hospitals, and important communication areas. For each of these areas, analysis procedures are described in detail, and several illustrative examples of the application of these procedures are discussed. The procedures are simplified so that personnel with little or no engineering training can readily apply them to solve air base noise problems. Also, these procedures have been developed so that all noise problems can be solved on paper. No direct measurements of air base noise are required. The guide is intended to be useful to anyone concerned with air base noise problems. It provides engineering guidance for the solution of a variety of problems, including planning new bases, modifying existing bases, and planning future modifications which may become necessary with newer aircraft.

PUBLICATION REVIEW

Jos M Quashnock

JOS. M. QUASHNOCK
Colonel, USAF, MC
Chief, Biomedical Laboratory
Aerospace Medical Laboratory

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

SECTION I

INTRODUCTION

There are over 150 major active Air Force bases in the United States. The majority of these bases have noise problems. Enough "know-how" and experience exists today to determine the necessary measures that may be taken to reduce or perhaps eliminate many of these noise problems. The purpose of this Guide is to present practical engineering techniques and procedures which may be used to analyze and solve air base noise problems resulting from jet operations.

Many problems other than those created by aircraft noise must, of course, be solved by air base planners. It is not the purpose of this Guide, however, to treat any problems except those resulting directly from aircraft noise.

This Guide is written primarily for air base planners and installations officers, but it will also be useful to anyone concerned with air base noise problems and their solution. Information is presented that will provide detailed engineering guidance for a variety of problems, including laying out the master plan of a new air base, redoing the master plan of an existing air base, siting new buildings, relocating maintenance run-up areas, extending a runway, building a new runway, modifying time schedules of either takeoff or maintenance run-up operations, altering flight paths, and evaluating the effect of the introduction of newer aircraft*.

The material presented in this Guide is an outgrowth of a detailed program of study carried out for the past several years by and under the direction of the Bio-Acoustics Branch of the Aero Medical Laboratory, Wright Air Development Center. Comprehensive noise surveys have been carried out at several Air Force bases. Much fundamental information has been collected on the noise produced by all types of jet aircraft operating on the ground and in flight. From these data engineering procedures have been developed for predicting the noise output of jet aircraft operating over a wide range of engine conditions.

The problem of the effect of jet noise on people who live on and near air bases, or who work in air base offices and try to communicate with one another in person or by telephone, has also been studied extensively. In addition, actual noise problems at various air bases have been analyzed, and noise control recommendations have been made.

* One problem that is not covered in this Guide is that of exposure of personnel to high intensity jet noise. This subject is covered in detail in References 1 and 2.

From these fundamental data as well as the experience gained in solving actual air base noise problems during this program of study, the engineering procedures presented in this report have been developed. These procedures are applicable to the analysis and solution of noise problems at any air base.

The engineering procedures required to analyze and solve air base noise problems are set forth in this Guide in the simplest terms possible. One does not have to be an acoustical engineer or a "noise expert" to understand and use them. The procedures are presented in such a manner that all noise problems can be solved by a "paper analysis".

No direct measurements of air base noise are required. A satisfactory evaluation of the noise environment on or around an air base requires that the noise be measured continuously at various locations and over a long period of time, from several hours to several days, to obtain a complete description of the noise. Such an evaluation is generally impractical; a satisfactory engineering estimate of the noise conditions can be made by means of the procedures presented in this Guide.

Air base noise problems are not solved easily. An air base can be considered as an extremely complex noise source composed of a number of individual noise sources. These include various types of jet aircraft taking off on several different runways and running up at one or more run-up locations with possible different angular orientations. For example, four different types of aircraft taking off on any one of four runways constitute sixteen different noise sources. The people in a nearby community or those living or working on an air base are exposed to noise in some degree from all of the various operations involving jet aircraft. Therefore, each of the noise-producing operations must be considered in analyzing a particular problem.

Important also is the fact that noise problems at any one air base may be interrelated. For instance, noise from jet run-up operations may produce unacceptable noise levels in the control tower on the base. This problem can be solved by improving the wall structure of the control tower. However, further analysis shows that the same run-up operations are producing an unacceptable noise level in nearby office buildings. Consequently, the decision is made to move the run-up operations to a different location. Control tower personnel and base office workers are now no longer bothered by the jet noise, but complaints begin to come in from an off-base community now exposed to unacceptable noise levels produced by the run-up operations at the new site. This example illustrates the need for considering the interrelation of noise problems at any one air base. More important, however, it emphasizes a point which cannot be made too strongly: a working knowledge of all of the material presented in this Guide is essential before beginning the study of any air base noise problem.

Another precaution is that the solution to a noise problem at one air base may not apply to the same type of noise problem at another air base. Noise problems must be evaluated and analyzed for each air base separately. There are no simple answers. At one base a community noise problem may be caused by takeoff operations alone; at another base it may be due to both takeoffs and run-ups, or perhaps even to run-ups alone. At one base office noise problems caused by jet noise may be solved by the use of run-up noise suppressors, but the same problem on another base may be solved more simply and economically by the relocation of the run-up area, or even by the angular reorientation of aircraft within the run-up area.

A number of possible solutions are suggested for noise problems considered in this Guide. The best solution to a particular noise problem on a given base must of course be determined by conditions peculiar to that base and in light of changing factors such as time and personnel available, funds available, materials and/or space available, etc. There are in general no solutions to air base noise problems that apply equally well to all air bases. If there were, there would be no need for this Guide.

SECTION II

GENERAL DISCUSSION OF AIR BASE NOISE PROBLEMS

Before detailed analysis techniques are presented, it is appropriate to discuss some of the fundamentals regarding noise produced by air base operations and the effects of this noise. How is the noise produced? What influences the propagation of noise from one place to another? When the noise gets to a particular place, whom does it affect, and to what degree? When does a noise problem exist? How serious is it?

Any noise problem, air base or otherwise, can be divided simply into three component parts:

Noise is produced by a noise source and travels over a propagation path to a receiver. For example, noise from a jet aircraft taking off (noise source) travels through the air (path) and through the wall (path) of a base headquarters, masking an urgent long-distance telephone message to the Base Commander (receiver).

The acoustical engineer considers each of these three elements in the analysis of a noise problem. He first determines how much noise the source or sources makes. Next, he finds out how the propagation path affects the amount of noise reaching the receiver. Finally, he determines whether the noise at the receiver is equal to, less than, or greater than, the noise exposure that would be considered acceptable for a particular type of receiver under a certain set of conditions. If the noise levels are greater than acceptable levels, that is, if they exceed the criterion, then a noise problem exists, and the next step is to find some way to reduce the noise levels -- noise control.

Because an air base is a composite noise "source" that consists of a number of separate noise sources, each varying with time, and since the sound propagates over a number of different paths depending upon where the source is located or how it is moving, the noise to which a receiver is exposed usually fluctuates markedly. Therefore, the description of the noise exposure must involve time as well as intensity or level.

The fundamentals of noise sources, propagation paths, and receivers on or near air bases are discussed below in Subsections A, B and C. Subsection D below explains in general the graphic method of representing jet noise through use of a series of noise contours. Finally, Subsection E presents a number of noise control methods used on air bases.

A. Noise Source

1. Amount of noise. The noise produced by a jet aircraft depends roughly on the thrust of its engines. The greater the thrust, the greater the noise output. For example, an F-102 fighter operating at military power with its 10,000 lb thrust engine produces appreciably more noise than a T-33 trainer with its 5,000 lb thrust engine. Further, any aircraft whose engines are equipped with afterburners will produce much more noise when the afterburners are on than when the engines are operating at military power.

The amount of noise produced by the many kinds of jet aircraft operating at various engine settings including afterburner is fairly well established[3,4]. On the basis of many measurements of the noise produced by aircraft operating on the ground at various engine settings, relationships have been developed between the noise output and the engine operating conditions (see Appendices A and B). The measured data as well as the relationships that have been developed form part of the basis for the engineering procedures presented in this Guide.

2. Frequency of noise. The total amount of noise produced by a jet aircraft is not enough to specify all of its noise characteristics. Frequency characteristics of the noise are also important. The "roar" of a diesel truck, for instance, is characteristic of a low frequency noise, whereas the whine of an idling jet is characterized by strong high frequency components. The noise from jet engines and aircraft includes frequency components over the entire audible range. People are much more sensitive to noise in the middle and high frequency ranges than to low frequency noise.

From what is known about the reaction of people to various kinds of noises, one can weight the frequency spectrum of jet noise and specify a single number that is reasonably adequate for many types of engineering analysis. This single number is called the

AIRCRAFT NOISE LEVEL (ANL)

The ANL describes basically the noise produced by a jet aircraft, taking into account both the overall level and the spectrum of the noise (see Appendix C).

3. Directional characteristics of noise. Like many other noise sources, the jet aircraft does not radiate sound uniformly in all directions. Jet noise is said to be directional, and the directional nature of the noise field around a jet aircraft is an extremely important factor in the analysis of air base noise problems.

A typical directivity pattern of noise from a jet aircraft is shown in Fig 1.

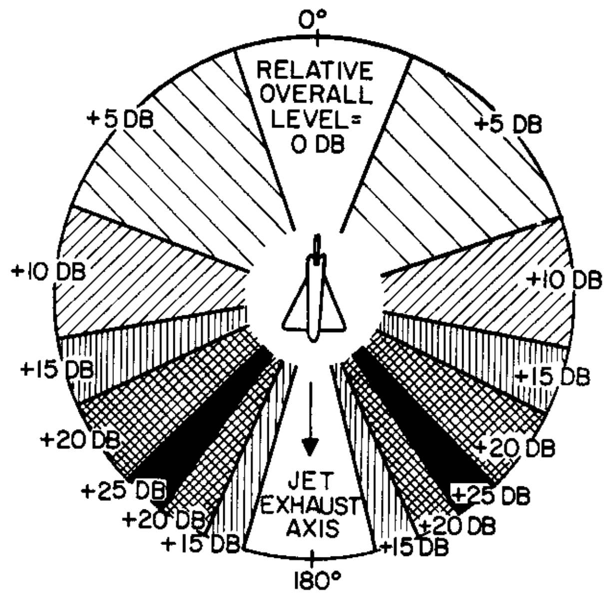


FIG. I DIRECTIVITY OF JET NOISE FIELD - FULL POWER.

A study of this chart reveals at least three important points:

a) The noise is not a maximum along the jet exhaust axis; actually, the jet noise is at a minimum along the axis.

b) The maximum noise is radiated at an angle of approximately 40° from the jet exhaust axis.

c) The jet noise field is extremely directional; at a fixed distance the noise level varies by as much as 25 decibels (equal to a ratio of 300 to 1 in noise power).

The fact that the noise level at a fixed distance from a jet aircraft can vary up to 25 decibels (db), depending on angular location only, is extremely important to bear in mind. Many noise problems can be solved by simply turning the jet aircraft.

B. Propagation Path

The second element of a noise problem, the path, is generally defined as anything that intervenes between the noise source and the receiver and affects the propagation of sound between the two. Generally, the path is simply air. It may be a wall, a window, or a noise suppressor.

Propagation of sound through the air is influenced by many factors. As sound travels away from a source it spreads and thereby decreases in intensity. This effect of distance is an important consideration in the analysis of any air base noise problem.

The consideration of obstacles in the propagation path is also of great importance. These obstacles take the form of buildings and/or parts of buildings (walls, windows, etc.), hills or abrupt height changes in terrain, noise suppressors, or anything that partially blocks the sound or reflects it out of its original path. The effects of such obstacles are considered in detail in later Sections (IV, V, VI).

Other factors which affect sound propagation are air absorption -- which varies with temperature and humidity and with the frequency of the noise; ground cover and type of ground surface; wind velocity and direction. These factors are difficult to anticipate correctly for all air bases. For purposes of this Guide, the following assumptions have been made:

a) Temperature and humidity are average or are not excessively high or low for long periods of time.

b) Ground cover is limited to low-cut grasses and sparse, low foliage; ground surface is hard-packed, concrete, or asphalt covered.

c) Weather conditions are not unusual.

C. Receiver

A receiver is anyone or anything that is affected by noise -- in this case, jet noise. People are receivers because they hear the noise and experience some reaction to it. There are also other kinds of receivers. These include animals, buildings, aircraft structures, and electronic equipment, to mention only a few. This Guide will be restricted to a consideration of people only as receivers.

Jet noise affects people in many ways. It may cause fear, annoyance, or interfere with sleep and relaxation in the home. In offices and work areas, as well as in the home, it may interfere with speech communication such as telephoning, conferencing, or normal everyday conversation. If the jet noise is intense enough, it may cause loss of hearing, generally temporary, but sometimes permanent. (This latter effect of jet noise is usually only experienced very near jet aircraft running-up on the ground and is not a consideration of this Guide.*)

---

* See footnote on page 1.

The manner in which a particular fluctuating noise affects people at or near an air base depends on the activities of the people. What are the various kinds of activities associated with air base operations? In answer to this question it has been found convenient to group the various "activity areas" that might be affected by air base noise into the following categories:

Housing Areas (On- or Off-Base)

Offices and Work Areas

Important Communication Areas

Hospitals

Group Meeting, Study, Rest and Relaxation Areas

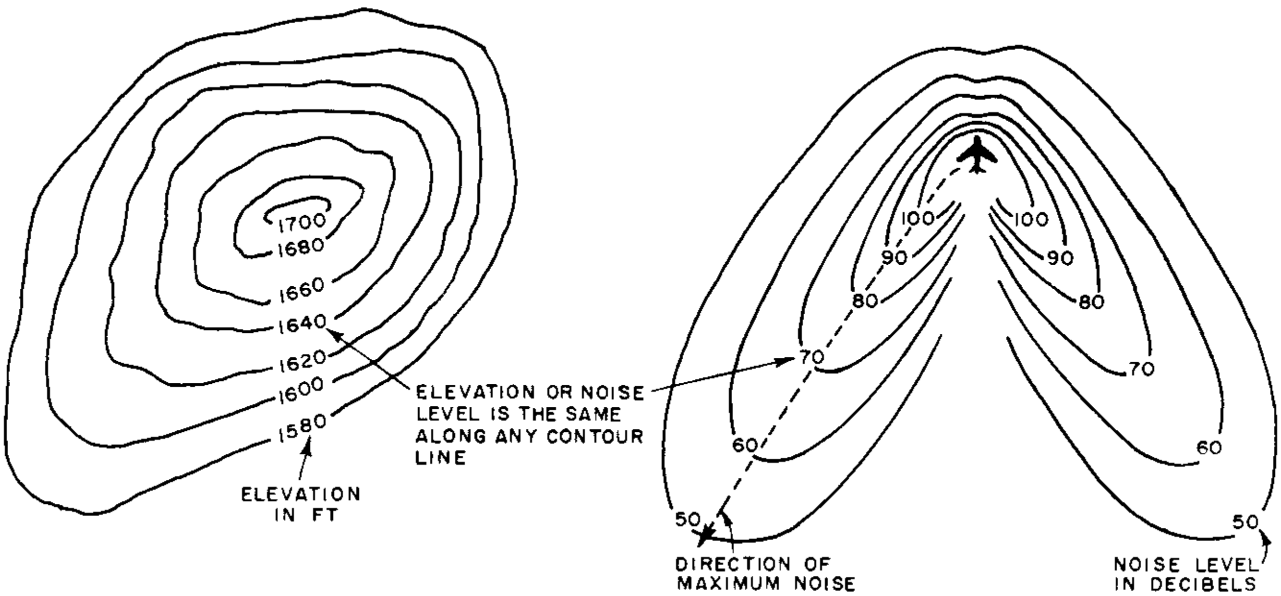
For each of these areas one can specify criteria or acceptable noise levels[2]. The various kinds of criteria are discussed individually in Section IV which is subdivided according to the activity area breakdown above.

The Aircraft Noise Level (ANL) measured in a particular space at an air base arising from air base operations usually fluctuates markedly with time. In such a situation it may be necessary to determine the maximum ANL or perhaps the average ANL in order to assess the effect of noise on activities within the space. The term "noise exposure" is regularly used to describe the fluctuating noise to which a particular person or group of people is exposed.

D. Noise Contours

This Guide describes how to determine the maximum or average ANL for jet aircraft of different types, either running up or taking off. The various ANL values are displayed as a series of noise contours (similar to land contours used by surveyors -- see Fig 2). The noise contours have been carefully constructed on the basis of measurements of the noise produced by jet aircraft operating on the ground or in flight. They can be used to determine the noise exposure at any location on or near an air base by simply applying proper correction numbers for a particular air base. In other words, the noise exposure at any point is determined by considering the noise produced by jet aircraft together with the operational schedule of the air base. The basic procedure is illustrated in Fig 3.

From a knowledge of the base operations, i.e., takeoffs, run-ups, runway utilization, type of aircraft, etc., plus the use of the ANL, maximum ANL, or average ANL contours which are provided in Section III, one can construct a composite set of contours as shown at the bottom of Fig 3 which describe the noise exposure at any point on and around the air base.



LAND CONTOURS

GIVE ELEVATION AT ANY POINT

SHOW VARIATION OF ELEVATION WITH DISTANCE

GIVE ONE A "PICTURE" OF THE SHAPE OF THE LAND

NOISE CONTOURS

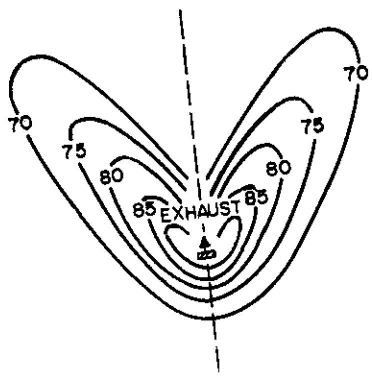
GIVE NOISE LEVEL AT ANY POINT

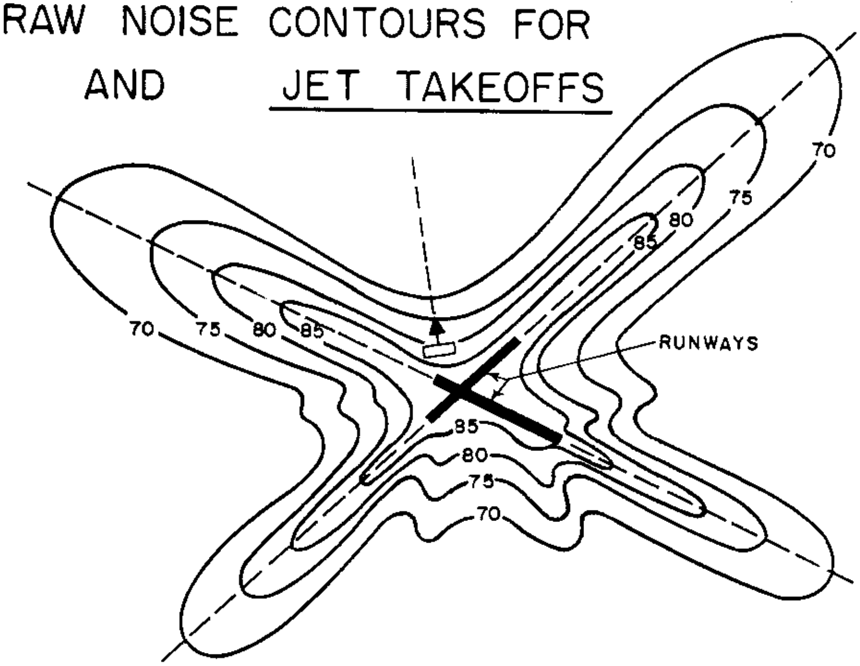
SHOW VARIATION OF NOISE LEVEL WITH DISTANCE

GIVE ONE A "PICTURE" OF THE NOISE FIELD

FIG. 2 SIMILARITY BETWEEN NOISE CONTOURS AND LAND CONTOURS.

BASED ON A STUDY OF OPERATIONAL DATA
ONE CAN DRAW NOISE CONTOURS FOR
JET RUN-UPS AND JET TAKEOFFS





AND THEM COMBINE THEM TO OBTAIN COMPOSITE CONTOURS FOR
ALL JET OPERATIONS

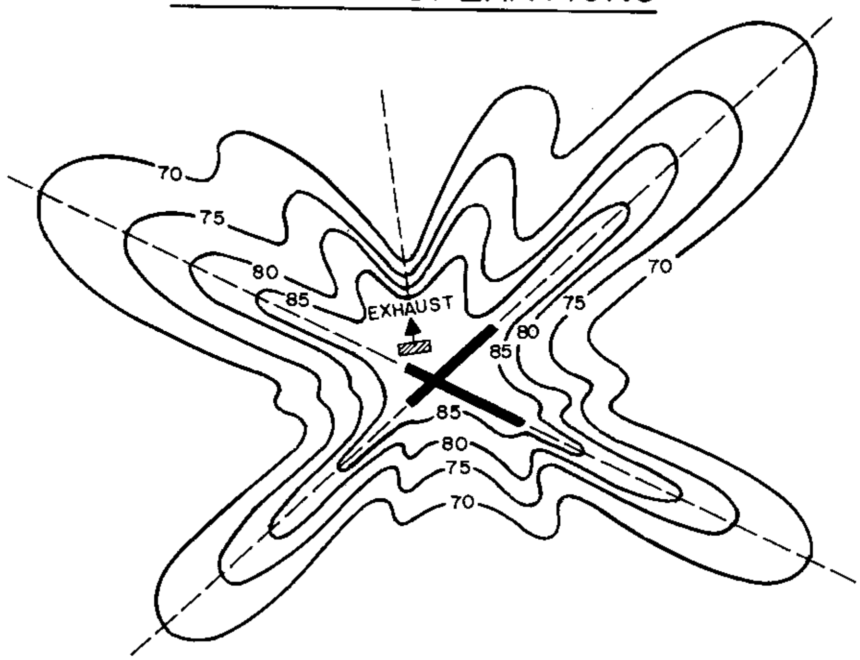


FIG. 3 ILLUSTRATION OF THE USE OF NOISE CONTOURS.

The shape of these composite contours, as will be shown in later sections, is influenced by a number of factors including the location and orientation of the runways, the shape of the flight paths for each of the runways, the location of the run-up areas, the orientation of aircraft in these run-up areas, etc. All of the various noise producing operations have been essentially lumped together and their total noise output is described by these contours. Thus, the final contours are representative of the air base as a total noise source.

(If the air base as a total noise source radiated sound equally in all directions, the composite contours would simply be circles. This condition almost never occurs. The contours shown in Fig 3 are typical of the type of contours representing the noise output of an air base. They are generally irregular in shape and are characteristic only of the base for which they are drawn.)

Once the composite noise contours have been constructed, the next step is to compare the noise exposure at the receiver with the appropriate criterion for the noise problem at hand. If the criterion is not exceeded, then a noise problem does not exist. If, however, the noise exposure is found to be too high, then a noise problem does exist. The approach at this point is then one of trying to adjust the noise exposure to meet the criterion. This adjustment is accomplished either by some action on the noise source or by some modification of the intervening propagation path. Section IV gives specific examples of such adjustments.

E. Noise Control

The required amount of noise reduction can be achieved in several ways, depending on the conditions that exist. First, one must decide by examining the contours whether takeoff or run-up operations are the most important contributors to the noise exposure in the community. If the main offender is the noise from takeoff operations, then one solution involves altering flight paths to direct aircraft away from the community.

On the other hand, if the noise exposure in the community results primarily from run-up operations, other measures will be taken. Aircraft may be reoriented during run-ups to make maximum use of their directional characteristics, the run-up area may be moved to another part of the base, or run-up noise suppressors may be utilized.

As the above example suggests, the engineering techniques presented in this Guide permit the determination of the amount of noise reduction that is required to solve a particular noise problem. They also show which of the two main types of operations, takeoffs or run-ups, are causing the problem. In addition -- and this is an important point -- the magnitude of the contribution from each of these operations can be determined.

The importance of this point is illustrated by the following example: Suppose that an analysis indicated that the ANL should be reduced by 20 decibels and that run-ups are the controlling noise source. The decision is made to buy a number of run-up noise suppressors that will bring about a 20 db reduction in ANL. The expense of these run-up suppressors is not entirely warranted. A more detailed study of the problem reveals that, although the run-ups are the controlling factor, a reduction in run-up noise of only 10 db will result in a condition where the ANL's produced by the run-ups and the takeoffs are essentially equal. Therefore, any additional reduction in the run-up noise beyond 10 db would be unnecessary, unless something is done about noise from the takeoff operations.

The above is only an example of the various kinds of air base noise problems that can be studied by use of the procedures described in this Guide. Some of the many ways in which the Guide may be useful are listed below:

1) Evaluation of an existing community noise problem.

2) Evaluation of an existing office or work area noise problem.

3) Siting of on-base housing and other air base buildings.

4) Planning and layout of an air base.

5) Layout of spaces within a building.

6) Relocation of run-up areas.

7) Evaluation of the need for run-up suppressors.

8) Modification of flight operations.

9) Evaluation of the effect of lengthening, closing down, or building runways.

10) Evaluation of the introduction of newer jet aircraft.

SECTION III

BASIC INFORMATION REQUIRED FOR CONSTRUCTION OF NOISE CONTOURS

Three kinds of basic information are required for the analysis of air base noise problems. One has to do with the noise output of jet aircraft under various conditions of run-up and takeoff - "noise data". Another describes the air base operations in some detail - "operational data". The third type of information specifies the kinds of activity that go on in the various working spaces on the air base or specifies the nature of the on- or off-base communities that are exposed to noise.

The basic noise data required for the analysis of any air base noise problem are presented in Subsections A, B, and C below in the form of tables, graphs, and contour plots. However, these noise data are useless without a knowledge of the run-up and takeoff operations at the particular air base in question. Therefore, Subsection D below describes the particular operational data that are required before one can carry out an analysis. A suggested form for tabulating this information is also given. Procedures for combining noise data and operational data, together with information concerning the receivers of the noise, are discussed in Section IV.

A. Noise Output of Jet Aircraft

The noise output of jet aircraft varies with the type of jet engines in the aircraft, the number of engines, and the power setting of the engines. All USAF operational jet aircraft have been arranged in four different groups according to their noise output at military power or with afterburner. These groups of aircraft with their associated operating conditions are given in Table I*.

---

* Turbojet engines can be operated on open jet test stands at air bases and, consequently, constitute noise sources that are as important as run-ups of jet aircraft. Therefore, relative noise output values for turbojet engines are also listed in Table I. Noisewise they can be considered the same as run-ups, and all information presented in this Guide relative to aircraft run-ups applies equally as well to jet engine run-ups.

TABLE I

RELATIVE NOISE OUTPUT OF USAF
OPERATIONAL AIRCRAFT OPERATING WITH ALL ENGINES* AT MILITARY
POWER (MIL) OR WITH AFTERBURNER (A/B)

GROUP	I	II	III	IV
RELATIVE NOISE OUTPUT IN DECIBELS	0 db	+5 db	+10 db	+15 db
AIRCRAFT	T33 F80 R/F84F F84E,G F86A,E,F F86D(MIL) F89(MIL) F94A,B F94C(MIL) B47(1Eng)** B57(1Eng)**	F86D,K(A/B) F86H F89(A/B) F94C(A/B) F100(MIL) F101(MIL) F102(MIL) F104(MIL) B45 B47 B52(1Eng)** B57 B58 (MIL-1Eng)** B66 B66(1Eng)** KC135(1Eng)**	F100(A/B) F101(A/B) F102(A/B) F104(A/B) F106(MIL) B52 B58(MIL) B58 (A/B-1Eng)** KC135	B58(A/B) F106(A/B)
ENGINES	J33(MIL) J35(MIL) J47(MIL) J48(MIL) J65(MIL)	J35(A/B) J47(A/B) J48(A/B) J57(MIL) J73(MIL) J79(MIL)	J57(A/B) J75(MIL) J79(A/B)	J75(A/B)
EQUIVALENT NUMBER OF GROUP I AIRCRAFT	1	3	10	30

*Except as noted.

**For use in run-up analysis only.

Group I aircraft have been assigned a relative noise output of 0 db. The noise output of the aircraft in Groups II, III, and IV are given relative to the noise output of Group I, and are + 5 db, + 10 db and + 15 db, respectively. For instance, an F101 operating with afterburner (A/B) falls into Group III, and has a noise output 10 db greater than an F86D operating at military power (Group I). One also notes that it produces five db more noise than the F94C operating with its afterburner (Group II).

Only relative values of the noise output of the various aircraft are given in Table I since it is more convenient to relate their noise output to that of one group of aircraft, in this case, Group I aircraft. For this reason an additional quantity is given at the bottom of Table I - "the equivalent number of Group I aircraft". For Group I aircraft the value is 1, for Groups II, III and IV, the values are 3, 10 and 30, respectively. Hence, one Group III aircraft is equivalent in noise output to ten Group I aircraft. Also, a Group II aircraft, for example, produces as much noise as three Group I aircraft operating simultaneously.

In certain noise problems, particularly those involving run-ups, one must also consider the noise output of jet aircraft operating at engine settings below military power. In Table II the relative noise output of USAF aircraft operating below military power is given. The region between 96% and 100% rpm

TABLE II

RELATIVE NOISE OUTPUT OF USAF AIRCRAFT OPERATING BELOW MILITARY POWER

Per Cent rpm	Relative Noise Output	Equivalent Number of Aircraft at Military Power
96-100	0 db	1
88-96	-5 db	0.3
80-88	-10 db	0.1

is noted as 0 db on the relative scale of noise output. Between 88% and 96% rpm the average noise output is 5 db less than at military power, and between 80% and 88% rpm the average noise output is 10 db less. Relative values are given for engine operation above 80% rpm only, because it has been found that in most air base noise problems the noise produced at lower power settings is not sufficient to alter the effects of noise produced by engine operation at the higher power settings.

In some noise problems involving run-ups below military power it is convenient to use another relative quantity - "the equivalent number of aircraft at military power". These relative values are given in the lower line of Table II. For 96% to 100% rpm the equivalent number of aircraft operating at military power is, obviously, 1. Between 88% and 96% rpm it is 0.3 and from 80% to 88% rpm it is 0.1. For example, the noise produced by three aircraft operating at 90% rpm, for instance, is equivalent to that of one aircraft operating between 96% and 100% rpm.

In summary, Table I gives the noise output of the various USAF operational aircraft referenced to the noise output of aircraft in Group I. Table II gives the noise output of USAF operational aircraft operating below military power referenced to the noise output of the same aircraft at military power.

B. Noise Contours for Simple Run-up Operations

1. Description of Contours. Figure 4 presents contours which describe the noise field around a jet aircraft during run-up operations. (The contours are presented for two scales, 1 in. = 2 miles in Fig 4A, and 1 in. = 1000 ft in Fig 4B.) The numbers on the contours represent ANL's that would be produced by a Group I aircraft. For aircraft in the other three groups, Groups II, III, and IV, the shapes of the contours remain the same, but the numbers on the contours must be increased by 5 db, 10 db, and 15 db, respectively. In other words, the values on the contours are simply scaled upward to account for the increased noise output of aircraft other than those in Group I. For a particular aircraft the corrections to be applied are those at the head of the columns in Table I, labeled "relative noise output in decibels".

The run-up noise contours of Fig 4 can also be used for engine operation below military power. The numbers on the contours must be scaled downward accordingly. The correction numbers for a particular engine setting are those given in the second column of Table II. For a Group I aircraft operating between 80% and 88% rpm, for instance, the numbers on the run-up contours should all be reduced by 10 db.

Summary

The noise contours of Fig 4 are for Group I aircraft. For aircraft in other groups, increase the values on the contours by the decibel correction numbers in Table I. For aircraft operation below military power, decrease the contour values by the decibel correction numbers in Table II.

The noise contours of Fig 4 can be used, after determining the appropriate total correction numbers from Tables I and II, to describe the noise field around USAF operational aircraft operating from 80% rpm up through military power, and including afterburner. The resulting contours (in the form of an overlay) can be superimposed on a map of an air base having the same scale by positioning the center of the distance circles at the location of the jet exhaust opening of the aircraft, and by orienting the contours so that the jet exhaust of the aircraft is pointing in the direction shown on the contours. For aircraft operating at other locations, or with other angular orientations, the contours must be moved and repositioned accordingly. Procedures for combining individual sets of contours for different run-up locations and orientations are given in Section IV.

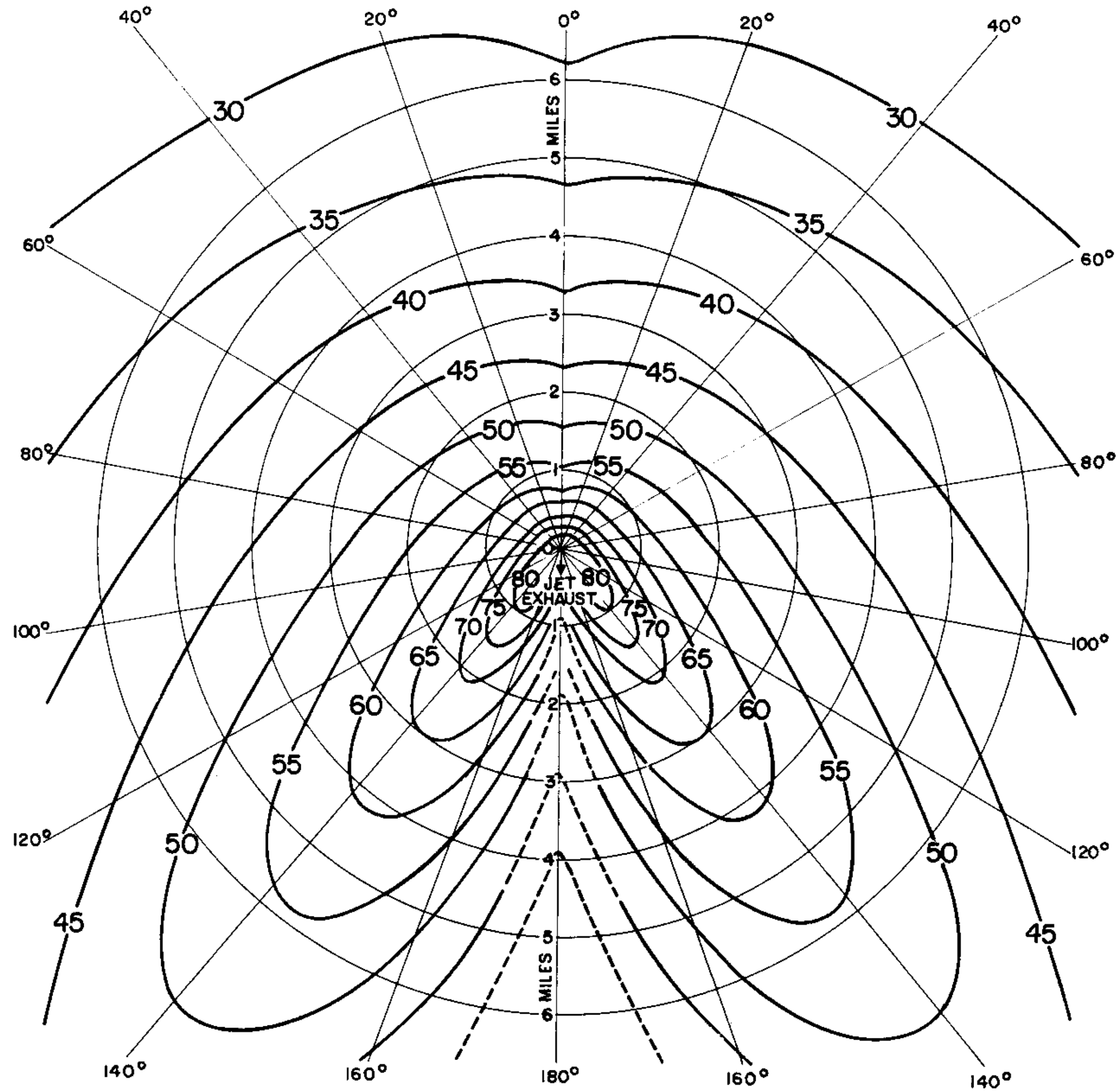
2. Extended run-up areas. In a maintenance run-up area where only one run-up position is employed, the use of the run-up contours is a simple operation. However, where an extended run-up area exists the question arises of whether this area can be considered as a single run-up area or whether it must be considered as a number of individual run-up positions. The answer depends on the size of the run-up area and the distance and angle to the receiver in question (a building, a group of buildings, or a housing area).

This situation is illustrated schematically in Fig 5, where several aircraft, all with the same orientation, are to be run-up along a row. If the overall length of the row of aircraft is L, and the distance from the approximate center of the row (O) to the point in question (X) is D, then all aircraft can be considered to be run-up at point O if:

Forward of the aircraft --- D/L is greater than 1/2

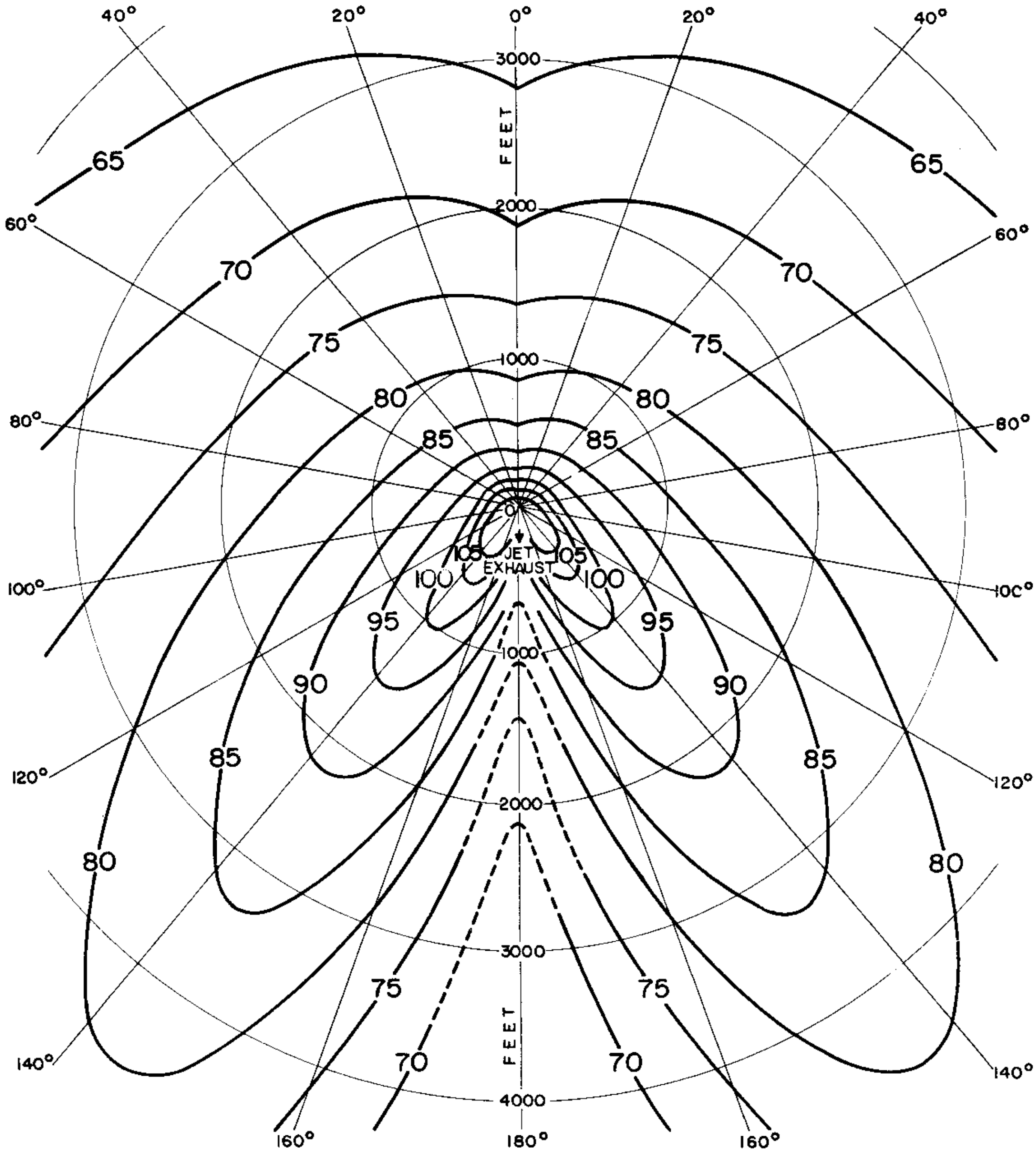
Aft of the aircraft --- D/L is greater than 3

If the above conditions are not satisfied, the run-ups must be considered individually and run-up contours must be moved from position to position and combined in order to determine the total noise output from run-up operations.



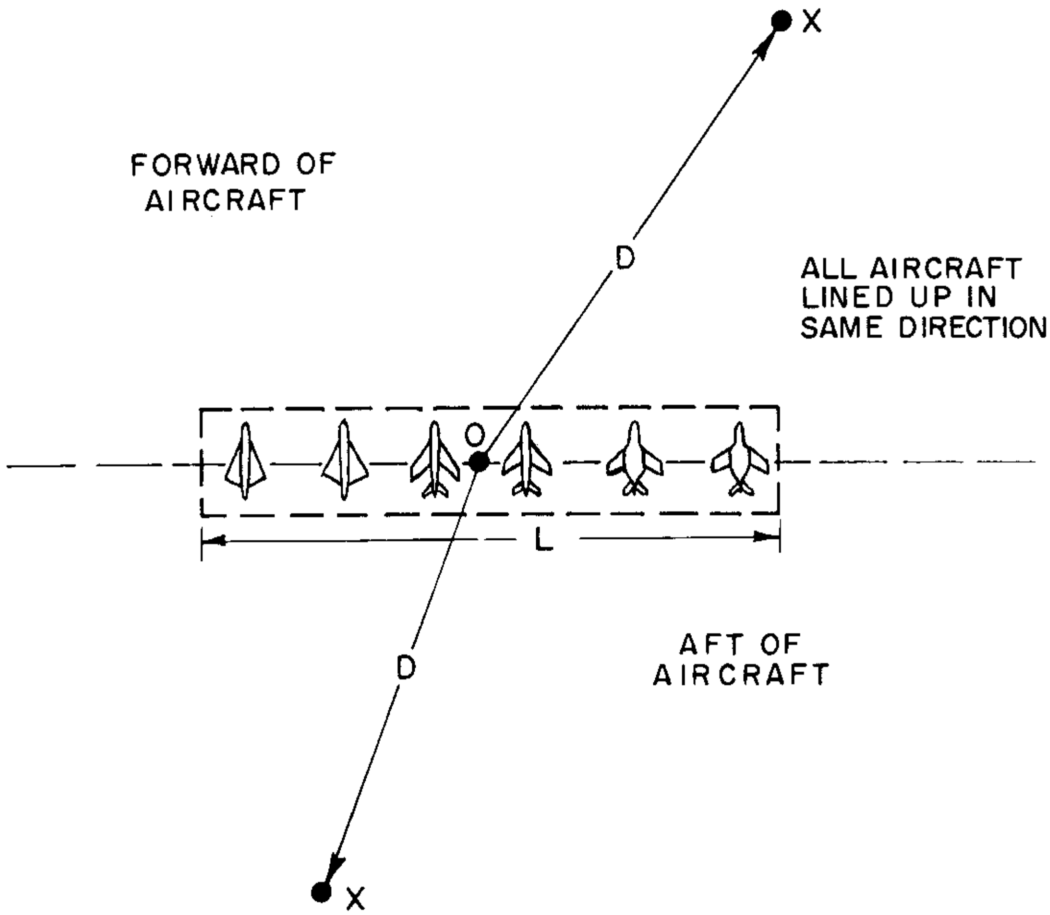
SCALE: 1 IN. = 2 MILES

FIG. 4A AIRCRAFT NOISE LEVEL CONTOURS FOR RUN-UPS OF GROUP I AIRCRAFT.



SCALE: 1 IN. = 1000 FT

FIG. 4B AIRCRAFT NOISE LEVEL CONTOURS FOR RUN-UPS OF GROUP I AIRCRAFT.



D = DISTANCE TO POINT IN QUESTION (X), EITHER FORWARD OR AFT OF AIRCRAFT

L = APPROXIMATE LENGTH OF RUN-UP AREA

O = CENTER OF RUN-UP AREA

IN AN EXTENDED RUN-UP AREA AS SHOWN, ALL AIRCRAFT CAN BE CONSIDERED TO BE RUN UP AT POINT O **IF**:

FORWARD OF THE AIRCRAFT D/L IS GREATER THAN 1/2	AFT OF THE AIRCRAFT D/L IS GREATER THAN 3

FIG. 5 TREATMENT OF EXTENDED RUN-UP AREAS

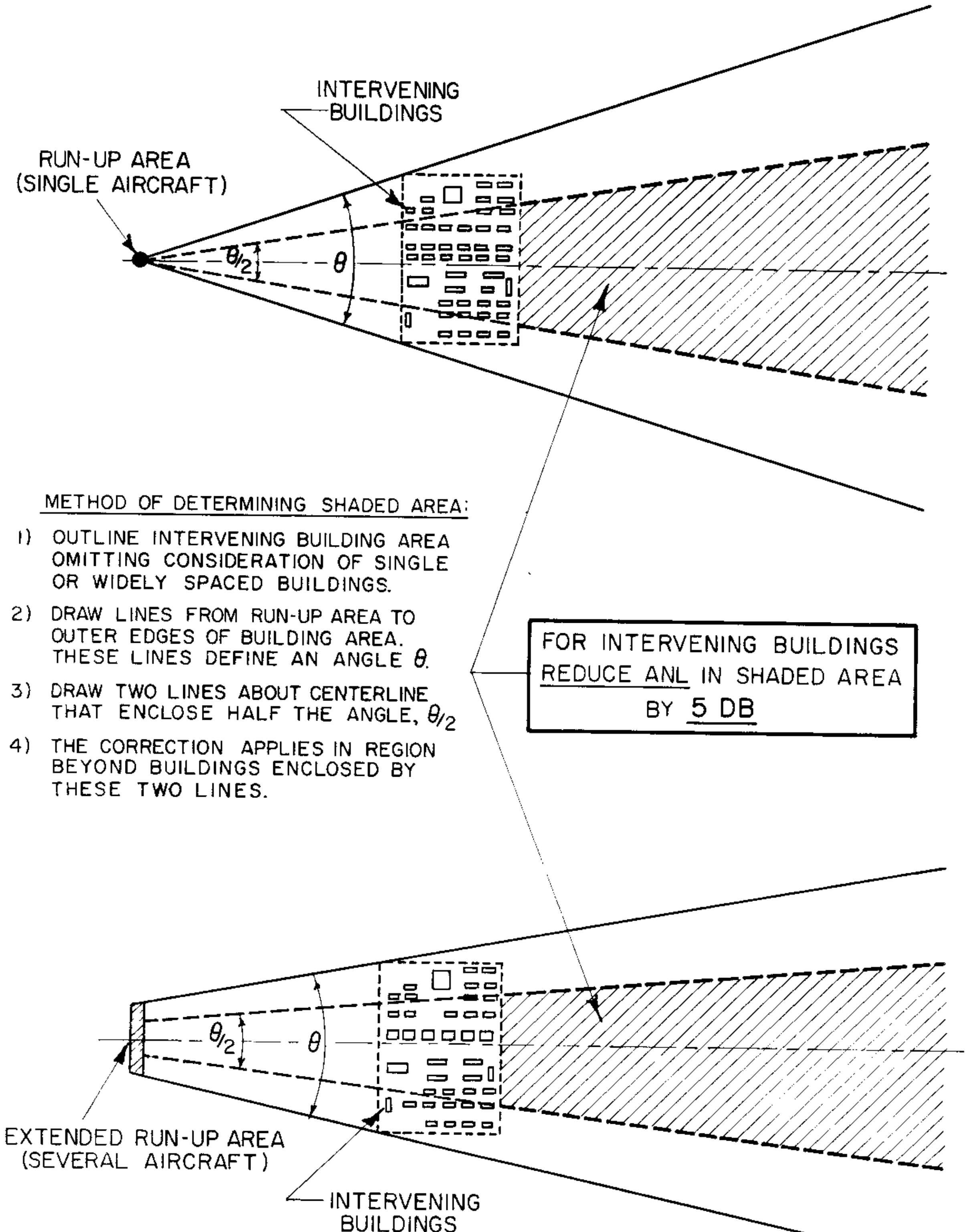


FIG. 6 ANL REDUCTION OF INTERVENING BUILDINGS.

In every problem involving run-up operations, the D/L ratio should be checked to determine whether or not the run-ups can be assumed to be located at one point, or, conversely, beyond what distance the run-up contours apply.

3. Effect of Intervening Buildings. Another factor that must be considered in the use of run-up contours is the shielding effect of groups of buildings. The contours of Fig 4 have been drawn assuming that the terrain in question is essentially flat and free of any obstructions, including hangars, buildings, etc. If structures exist between the run-up area and a particular receiver, the ANL's at that receiver will be less than those indicated on the contours. The amount by which the contour values should be reduced can be found by reference to Fig 6 on page 21.

C. Noise Contours for Simple Takeoff Operations

The noise produced on the ground by an aircraft taking off or flying overhead is somewhat different in character from that produced by a run-up operation. During the major part of a run-up operation, the engine is generally left at each of several power settings for a period of time and, consequently, the noise output of the aircraft while at one power setting remains essentially constant. On the other hand, as an aircraft passes overhead, the noise level on the ground rises to some maximum value and then decreases until the aircraft is no longer heard. These two characteristic time patterns for a run-up and a takeoff (or fly-over) are illustrated in Fig 7.

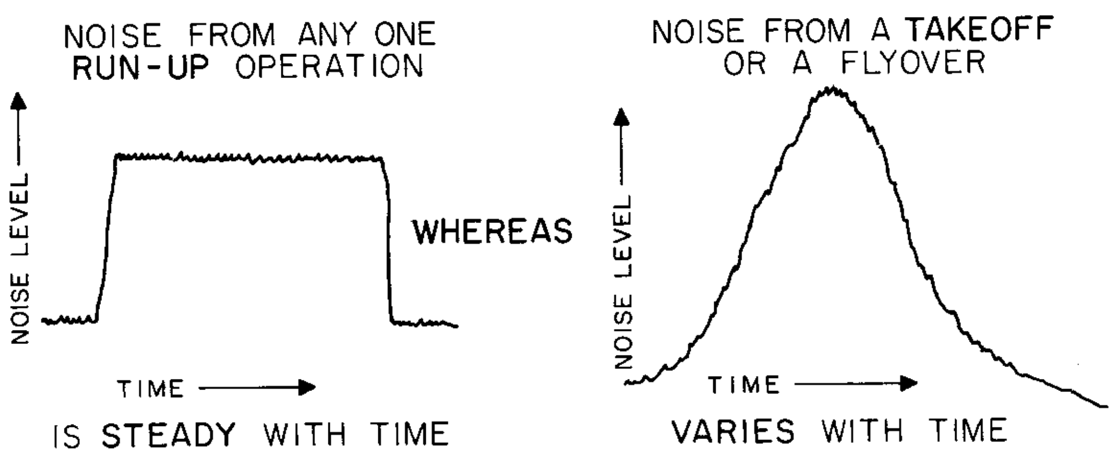


FIG.7 COMPARISON OF NOISE FROM RUN-UPS AND TAKEOFFS.

The effects of these two kinds of noise are somewhat different, and therefore each must be considered separately. For a run-up operation the ANL at any angle and distance from the jet noise source can be found directly from the run-up contours described above, provided that the values on the contours have been appropriately corrected for the type of aircraft and operation involved. The situation is somewhat more complicated for aircraft taking off. Two factors must be considered: one, the noise output of the type of aircraft in question (as given in Table I) and two, the fact that the aircraft is continuously changing altitude as it takes off which means that the noise on the ground is varying continuously with time.

These factors have been taken into account in the following ways:

1) Three different flight profiles have been assumed; these profiles will apply to takeoffs of all USAF operational aircraft. (see Fig 8)

2) For each of these three flight profiles noise contours for takeoff operations have been constructed in terms of the MAX ANL and the AVG ANL. (see Figs 9 and 10)

Therefore, for the range of takeoff profiles that one might encounter with present-day operational aircraft, contours are available which describe the maximum noise levels produced on the ground by an aircraft in flight (the MAX ANL contours), and which also take into account the time variation of the noise (AVG ANL contours).

The three profiles that have been assumed for use in this guide are shown in Fig 8, where altitude is plotted as a function of the distance from the beginning of the runway. Actually, three flight profile areas, rather than discrete flight profiles, have been designated. Although it would be more correct to use the actual flight profile in any particular instance, the amount of variability that normally exists due to pilot technique, nature of mission, location of base, and attendant atmospheric conditions, etc., rules out using actual flight profiles as impractical and unrealistic.

For each of these flight profiles noise contours in terms of the MAX ANL are given in Figs 9A, 9B and 9C (for flight profiles No. 1, No. 2, and No. 3, respectively). The numbers on the contours represent the MAX ANL's produced on the ground for a Group I aircraft whose flight profile lies in the appropriate profile area of Fig 8. For other than Group I aircraft, the values on the contours must be adjusted upward by use of

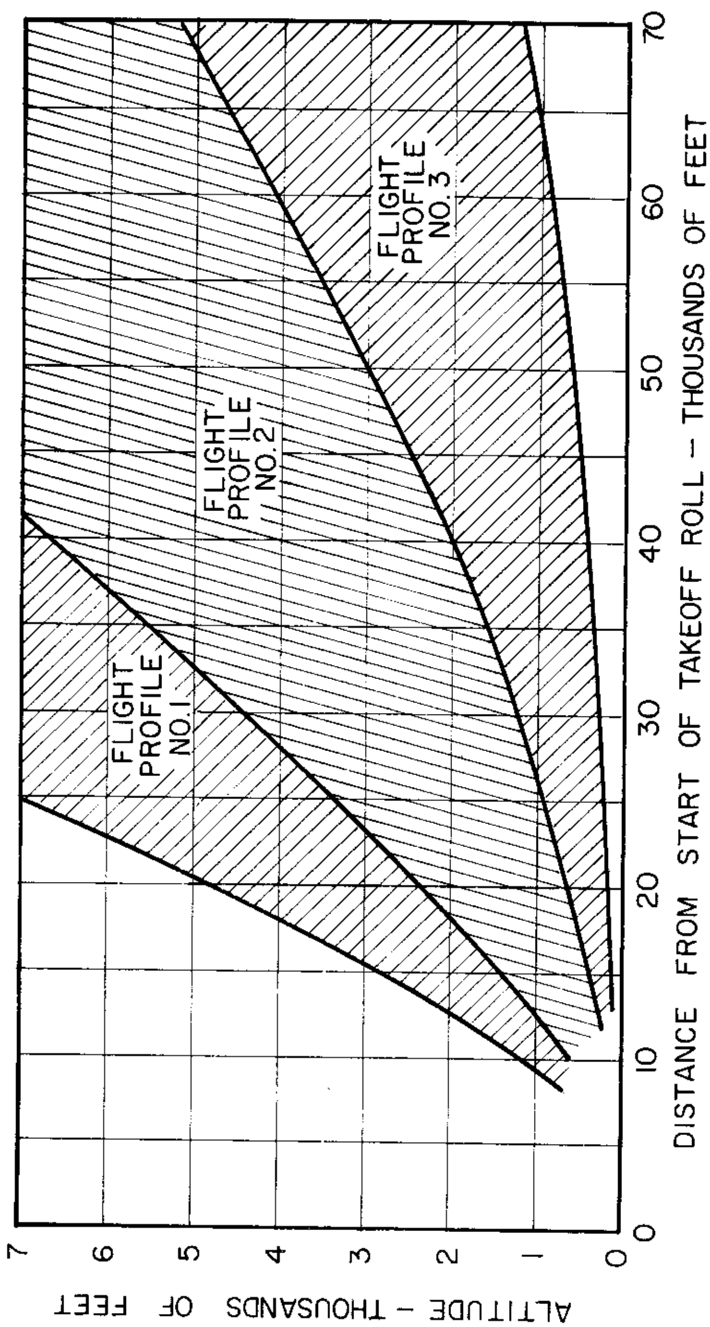


FIG. 8 FLIGHT PROFILES FOR USE IN ANALYSIS.

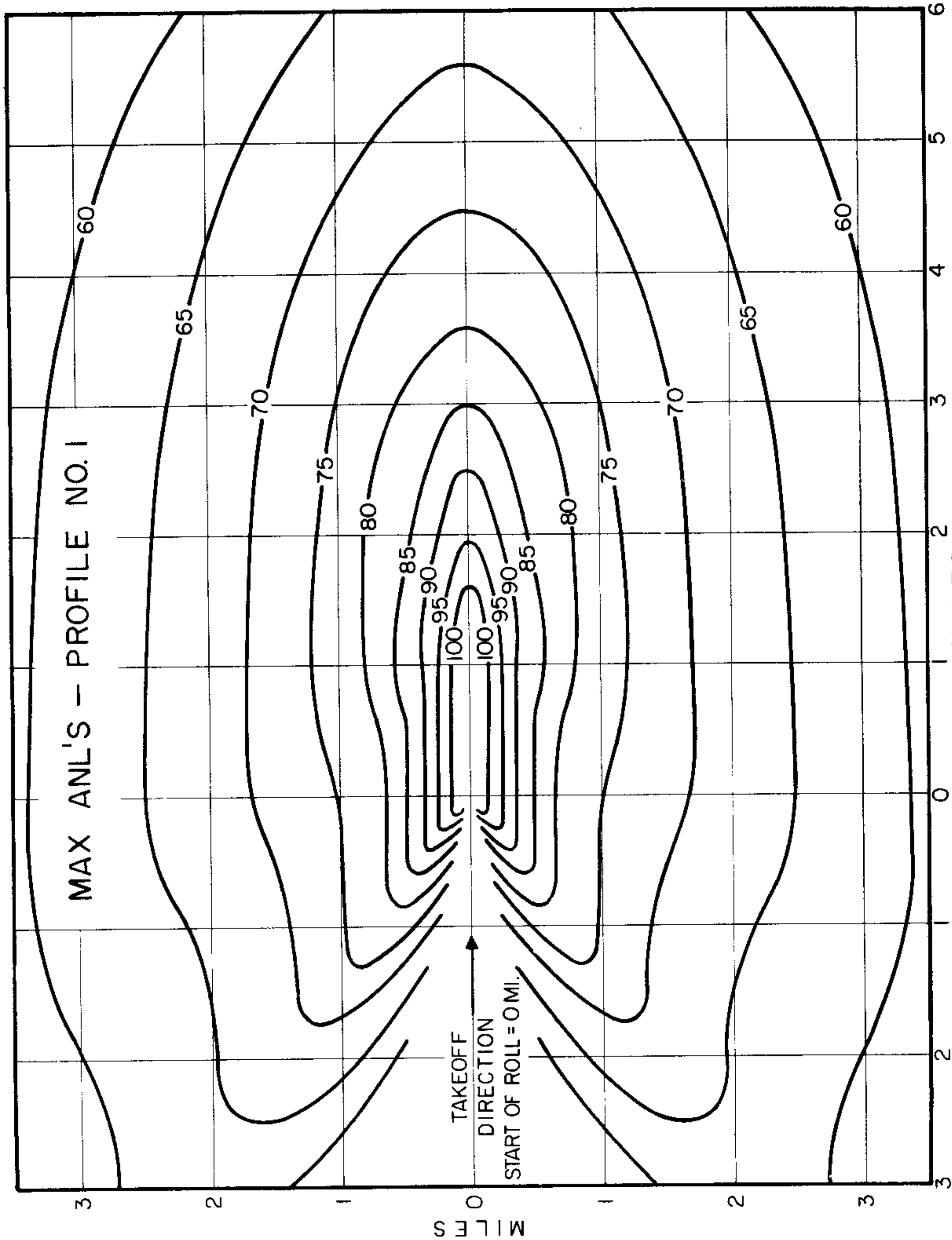


FIG. 9A CONTOURS OF MAXIMUM AIRCRAFT NOISE LEVELS (MAX ANL'S) FOR TAKEOFFS OF GROUP I AIRCRAFT – FLIGHT PROFILE NO. I

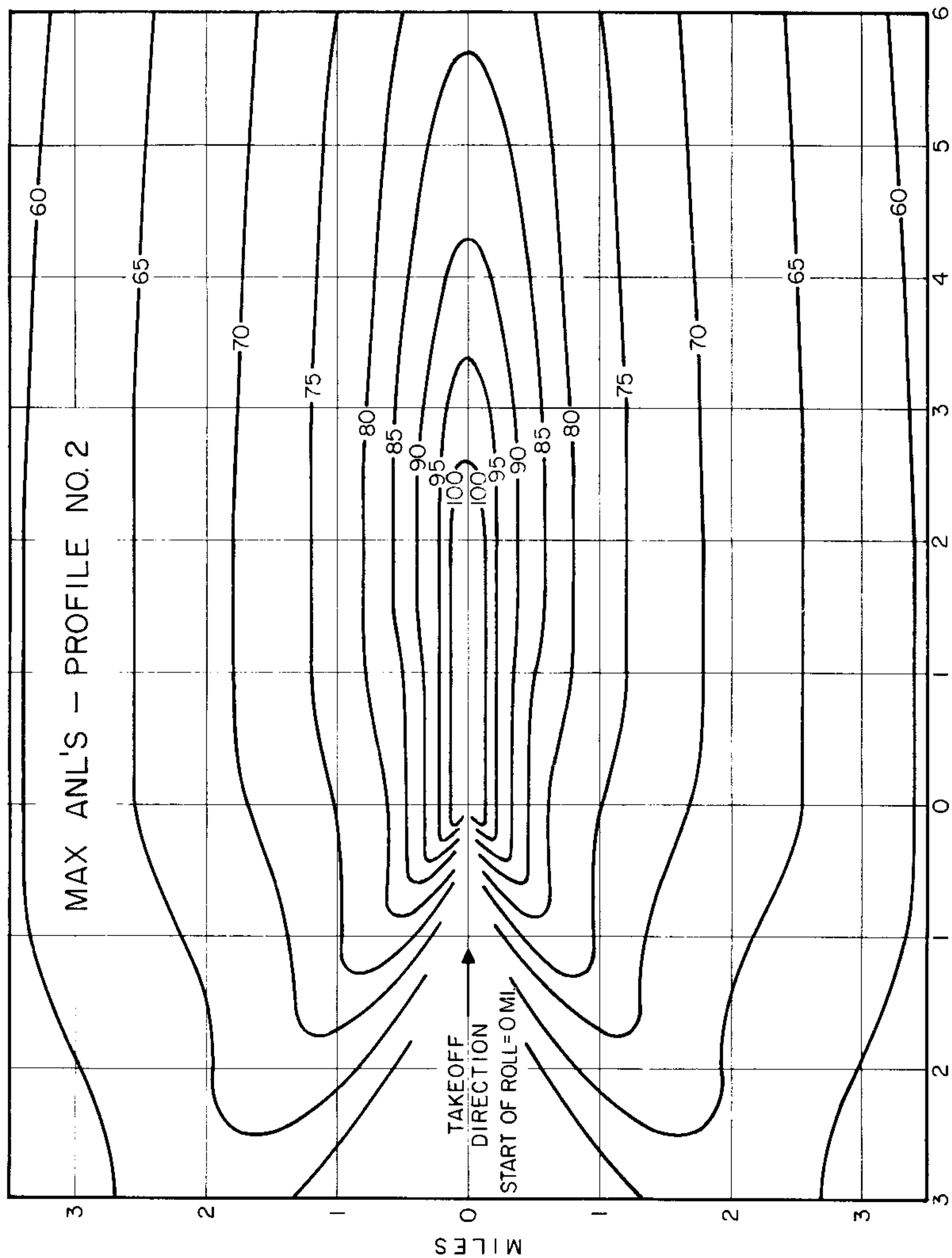


FIG. 9B CONTOURS OF MAXIMUM AIRCRAFT NOISE LEVELS (MAX ANL'S) FOR TAKEOFFS OF GROUP I AIRCRAFT — FLIGHT PROFILE NO. 2

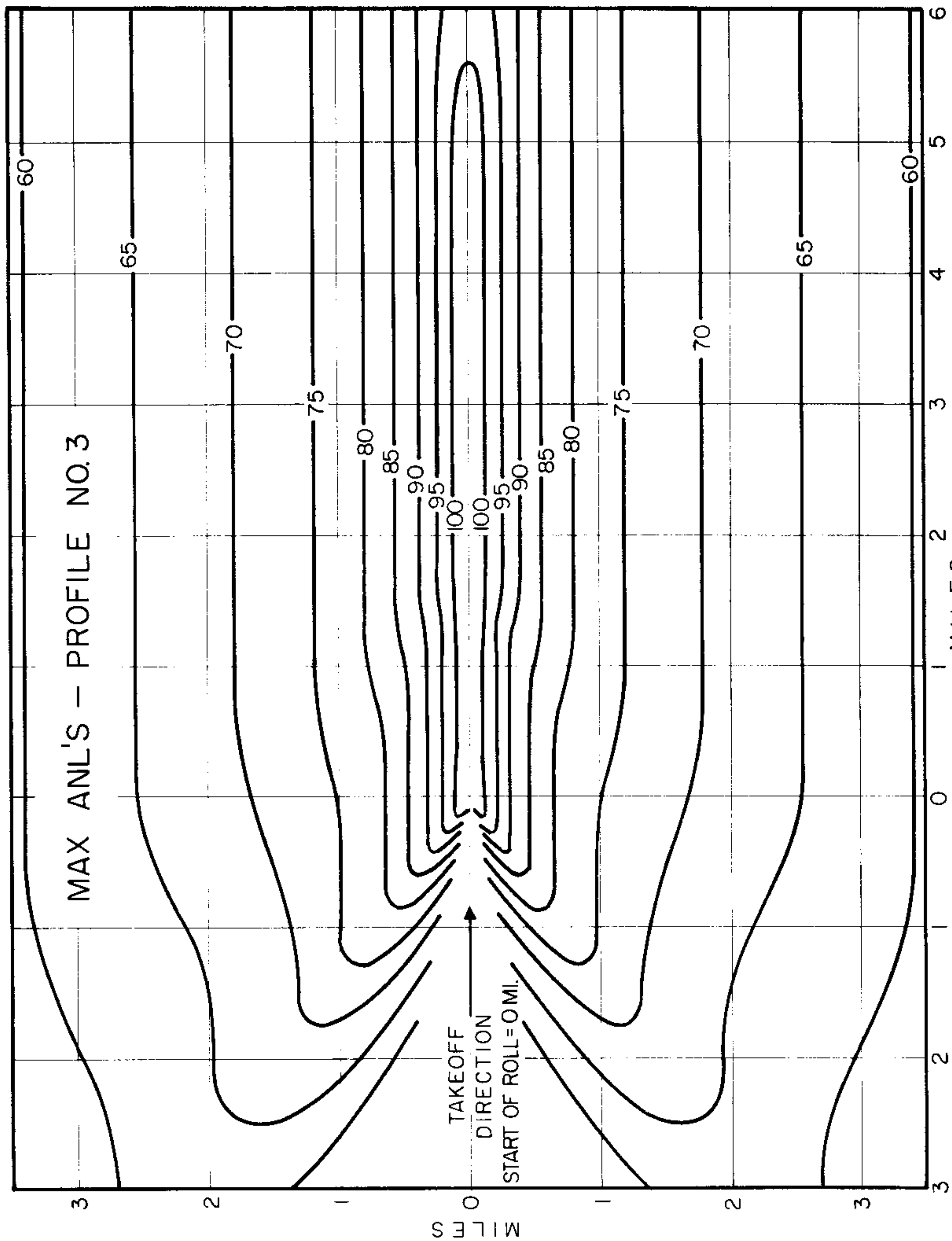


FIG. 9C CONTOURS OF MAXIMUM AIRCRAFT NOISE LEVELS (MAX ANL'S) FOR TAKEOFFS OF GROUP I AIRCRAFT — FLIGHT PROFILE NO. 3

the relative noise output "corrections" in db from Table I. In Fig 9, zero miles marks the beginning of the takeoff roll and all aircraft take off in the direction indicated.

Takeoff noise contours in terms of AVG ANL's are given in Figs 10A, 10B and 10C for flight profiles No. 1, No. 2, and No. 3, respectively, of Fig 8. The db values on the contours are representative of noise levels on the ground averaged over takeoff time and apply for Group I aircraft only. For aircraft in Groups II, III, or IV, the numbers on the contours must be increased by 5, 10 and 15 db, respectively. Since the AVG ANL contours take into account the duration of the noise as well as the amount of noise produced, these contours must somehow be referenced in time and, therefore, they have been drawn for <u>one takeoff per hour</u>. For more than one takeoff per hour corrections are applied to the contours in the manner discussed in Section IV-A.

The choice of MAX ANL or AVG ANL contours to describe the noise from takeoff operations will depend upon the particular problem at hand. The procedures described in Section IV indicate which contours are to be used. For either type of contours the choice of individual contours will depend on the flight profile of the aircraft involved. If information on the flight profile is available, then the choice is made relatively simple by use of Fig 8. If little or no data are available, then a best estimate must be made. In making this estimate it should be noted that profile No. 1 is usually only attained by the latest type of fighter aircraft operating with afterburners and attempting to climb out as rapidly as possible. Profile No. 2 probably applies to most of the present-day fighter aircraft, as well as light jet bombers. Flight Profile No. 3 should be used for the heavier aircraft such as B-47's and B-52's.

The takeoff noise contours of Figs 9 and 10 assume that aircraft take off on a <u>straight-out</u> path, that is, along a line that is an extension of the runway. However, in practice aircraft often make a turn after leaving the runway and hence follow a <u>curved flight path</u>. The takeoff noise contours must also follow the same path and therefore must be curved in some manner to correspond to the flight path.

This bending of the contours is illustrated in Fig 11 where a single contour line from a set of "straight-out" contours has been redrawn for the curved flight path shown. At corresponding distances along, and at perpendicular distances to the side of the flight path, the contour values are exactly the same. For example, in Fig 11 it is noted that point A, which is located at about the 9-mile point on the curved flight path is the same as point A for the "straight-out"

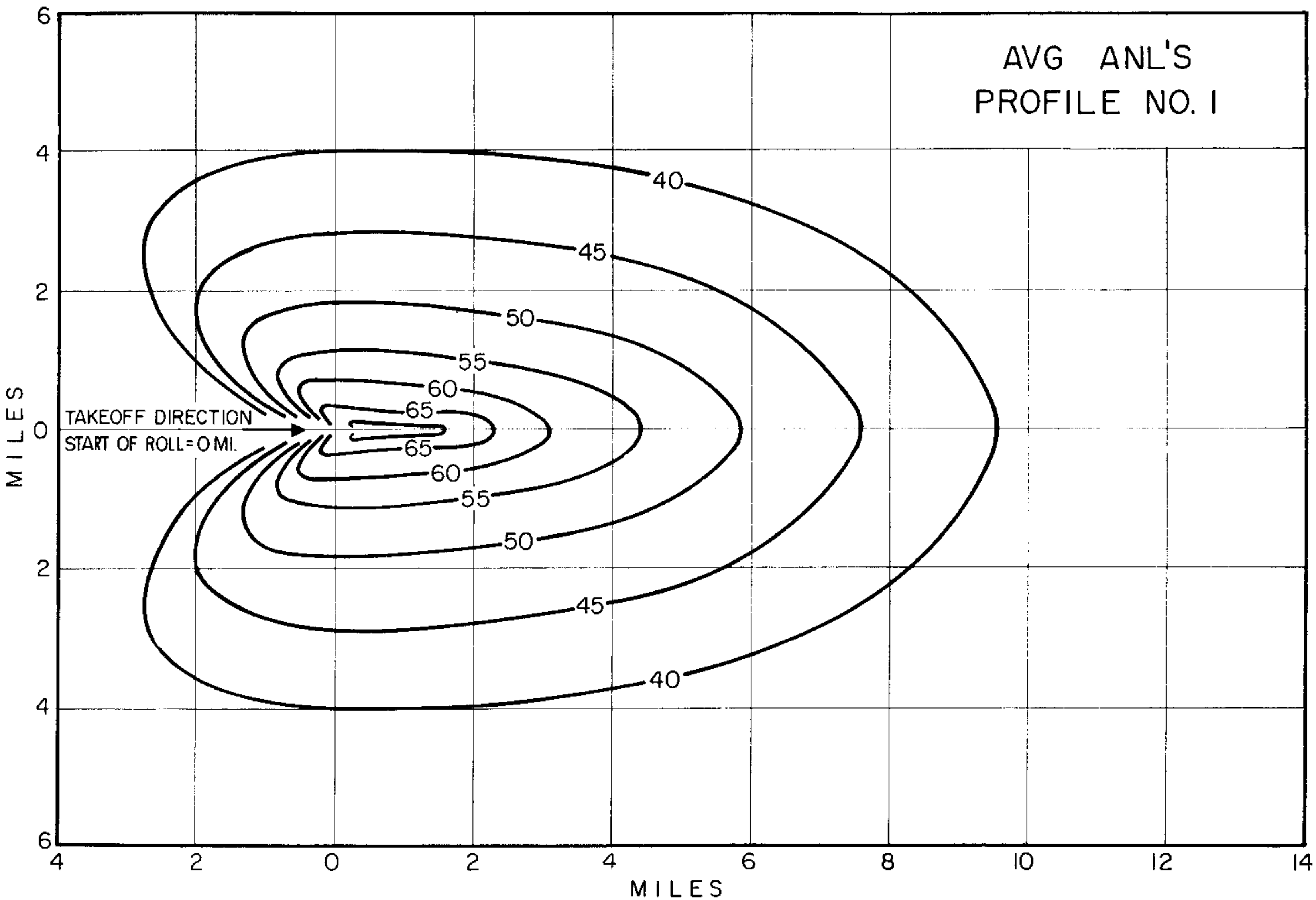


FIG. 10A CONTOURS OF AVERAGE AIRCRAFT NOISE LEVELS (AVG ANL'S) FOR GROUP I AIRCRAFT — FLIGHT PROFILE NO. I

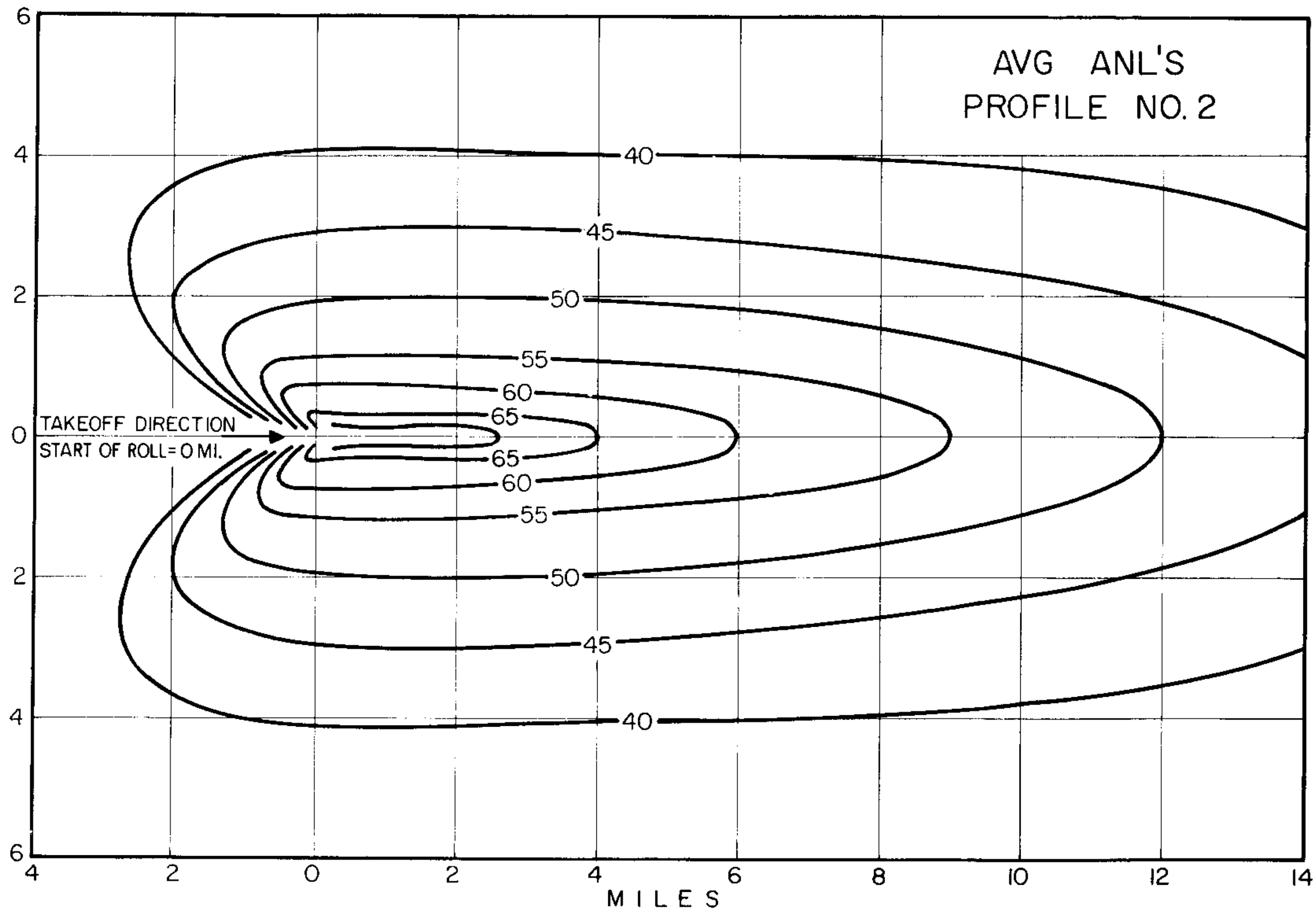


FIG. 10B CONTOURS OF AVERAGE AIRCRAFT NOISE LEVELS (AVG ANL'S) FOR GROUP I AIRCRAFT — FLIGHT PROFILE NO. 2

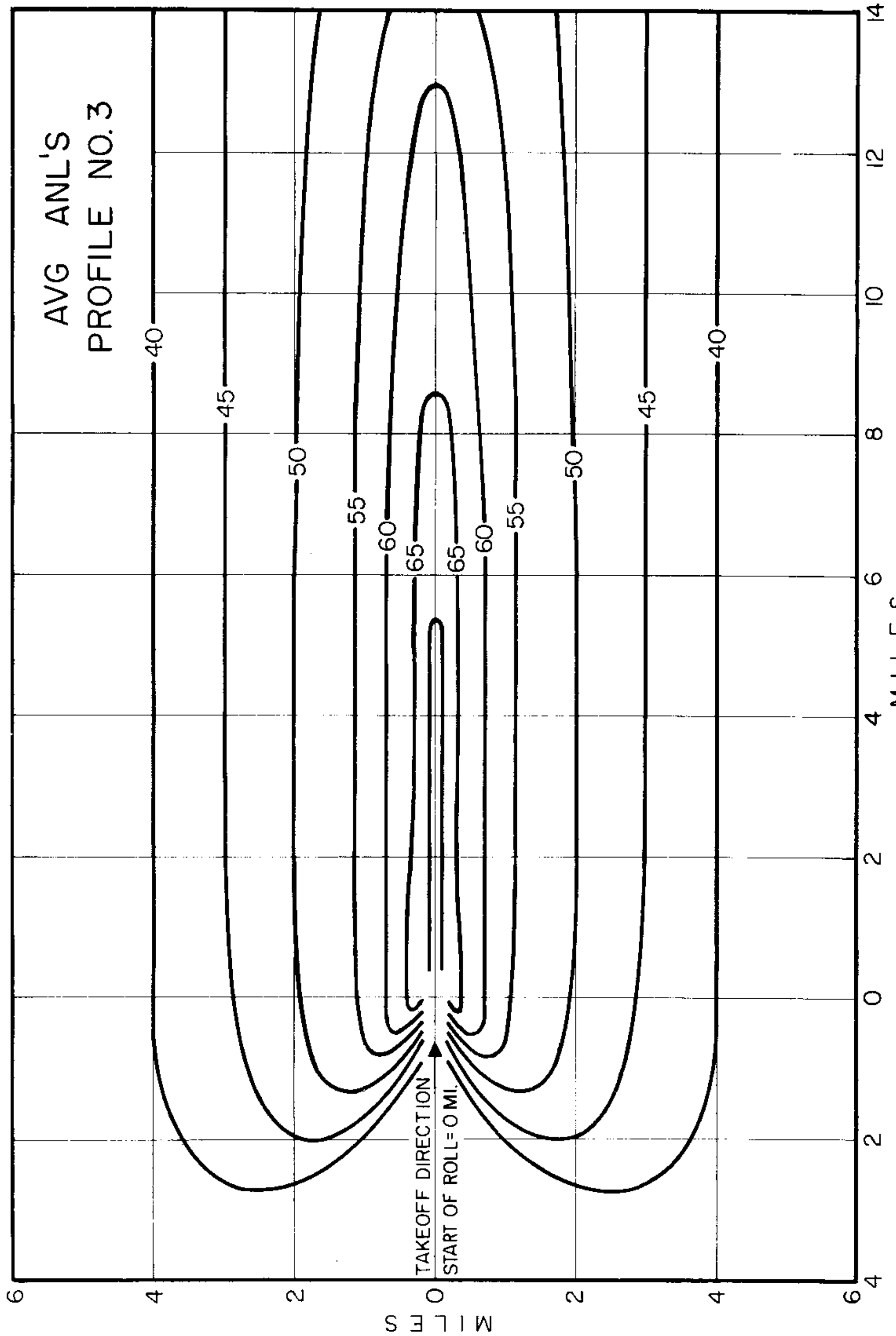


FIG. 10 C CONTOURS OF AVERAGE AIRCRAFT NOISE LEVELS (AVG ANL'S) FOR GROUP I AIRCRAFT — FLIGHT PROFILE NO. 3

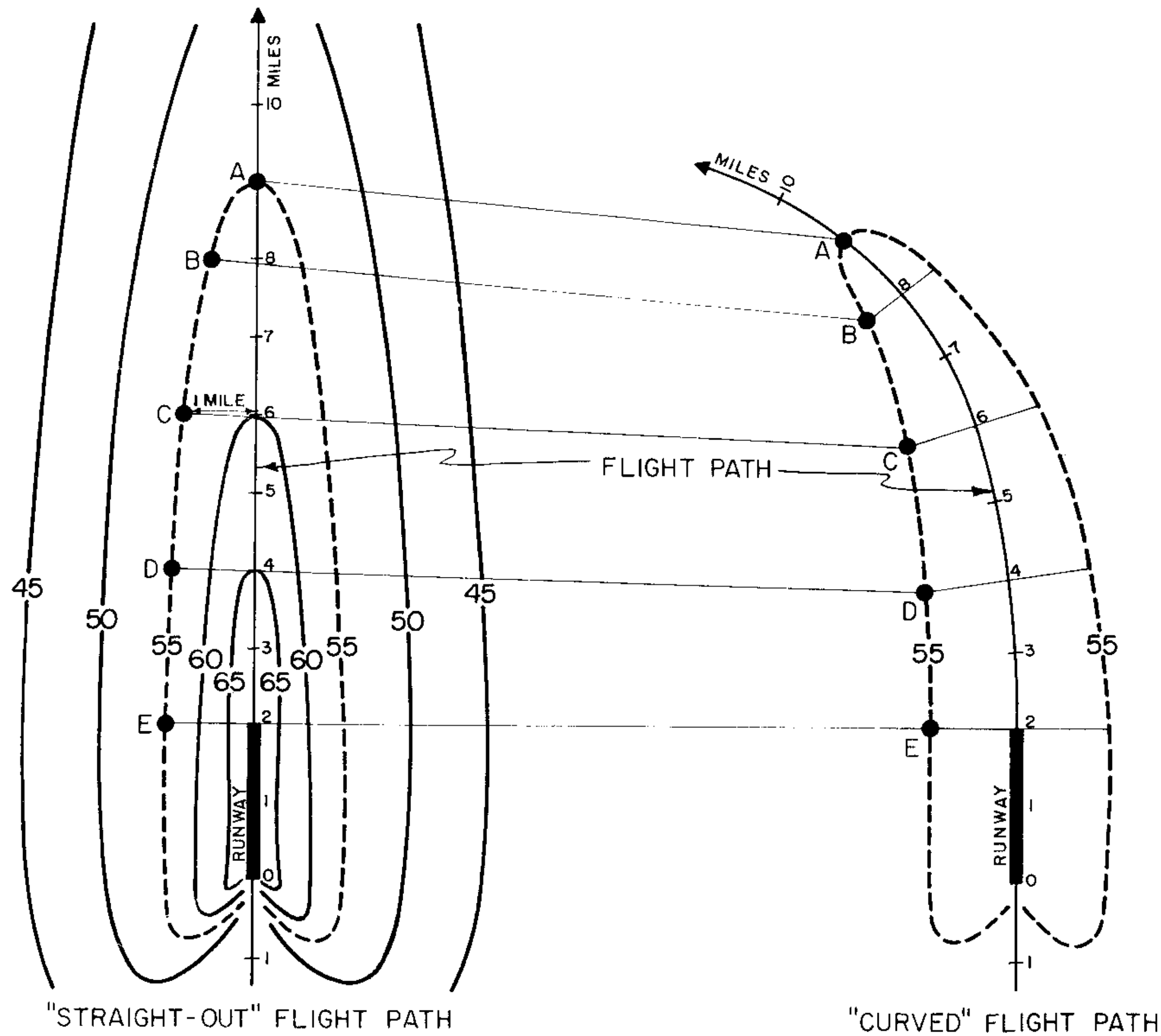


FIG. II ILLUSTRATION OF CONSTRUCTION OF CONTOURS FOR CURVED FLIGHT PATHS.

flight path which is also at 9 miles. Point C which is 6 miles out and 1 mile off to the side of the flight path for the straight-out path is also 6 miles out along the curved flight path and 1 mile to the side of, and along a line perpendicular to, the flight path. In a similar manner, points B, D, and E have been drawn. Only enough points should be calculated to enable one to sketch roughly the contour lines.

D. Operational Data

Before proceeding to analyze any air base noise problem one must obtain a certain amount of operational data. In this section the kinds of data that are required are described and means for tabulating the pertinent information are suggested. Basically, data are required on the two primary air base operations: run-ups and takeoffs of jet aircraft. Generally the analysis of an air base noise problem requires that both types of operations be considered. In some problems, this is not true, and only one or the other type of operation is really important. However, it is difficult to predict when this particular situation will arise. Therefore it is wise to gather all the necessary information on both types of operations before proceeding with the problem. As one becomes proficient in analyzing and solving air base noise problems he will be able to predict, for individual problems, what operations and what kinds of information are required to carry out an analysis.

The information that must be gathered is indicated by Tables III and IV below for takeoff and run-up operations respectively. The information must, of necessity, be somewhat detailed, but need not be extremely accurate. In general, numbers within 5% to 10% of the correct values are sufficient for the engineering procedures that are used in this Guide. The procedure to follow is simply to fill out Tables III and IV as discussed below.

For takeoffs one lists in the first column of Table III the various types of aircraft operating from the base. For each type of aircraft the average number of takeoffs per hour in each of the following three time periods* is tabulated:

*The exact time periods given have been selected to describe the normal workday, the normal evening, and the normal nighttime (when people are expected to be asleep). For situations where the time periods indicated are not truly representative of these conditions, the times should be suitably altered.

0600-1800

1800-2300

2300-0600

In the last column, the flight profile number is given for each type of aircraft. These numbers are, of course, obtained by reference to Fig 8 on page 24.

For each active runway at an air base the percentage utilization should be noted in Table III, as indicated. Percentage runway utilization is defined as the percentage of total takeoffs per day that occur on a particular runway. If the percentage runway utilization varies with the type of aircraft, then the runway utilization table should be filled out for each utilization distribution.

On a map of the air base and its environs, the flight paths for the various aircraft should be noted as closely as possible. An illustration showing how this information is recorded is shown in Fig 12. For three of the runways the flight path is straight out, and for the remaining runway a right turn is indicated.

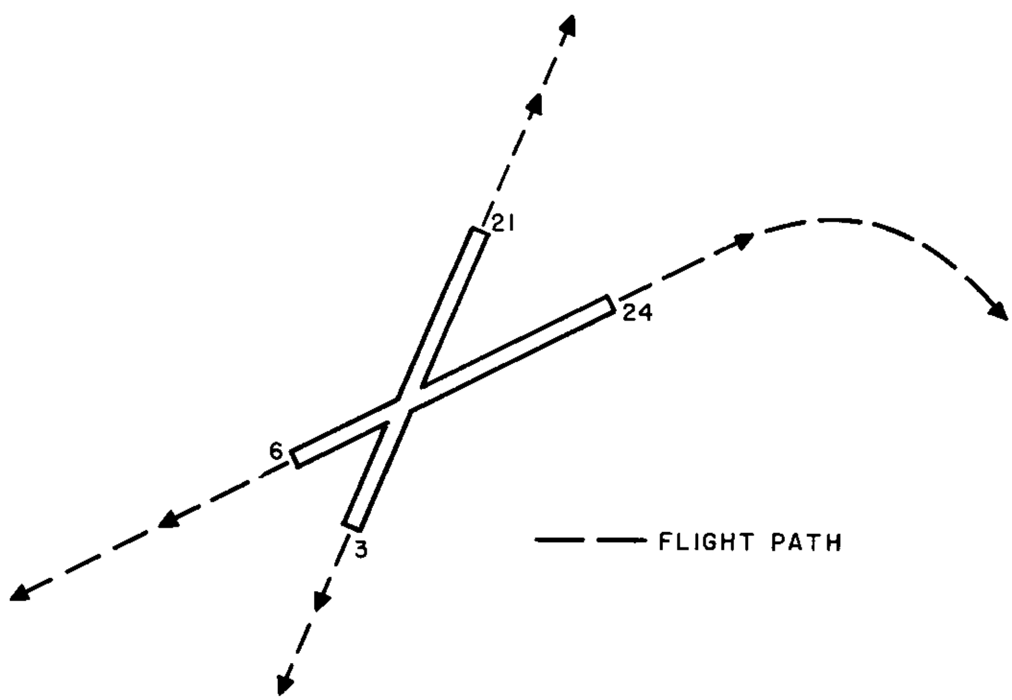


FIG. 12 RECORDING FLIGHT PATH INFORMATION

TABLE III

SUGGESTED FORM FOR RECORDING OPERATIONAL INFORMATION ON TAKEOFF OPERATIONS

AIRCRAFT ACTIVITY

Type of Aircraft	Average Number of Takeoffs Per Hour			Flight Profile
	0600-1800	1800-2300	2300-0600	

RUNWAY UTILIZATION

RUNWAY	% UTILIZATION

TABLE IV

SUGGESTED FORM FOR RECORDING OPERATIONAL INFORMATION ON RUN-UP OPERATIONS

Time	Type of Aircraft	Avg No. of Run-ups per Hour	Position and Orientation	Average Minutes Per Run-up			
				A/B	96%-100%	88%-96%	80%-88%
0600-1800 (Daytime)							
1800-2300 (Evening)							
2300-0600 (Nighttime)							

The data described above give a complete description for engineering purposes of the takeoff operations that occur at a particular base. One can determine for each type of aircraft, the average number of takeoffs per hour in each of three time periods and on any one of the active runways. Further, for each type of aircraft the flight profile and flight path is known.

The required information for run-up operations is described in Table IV. Again the information is divided into three different time periods: daytime, evening, and nighttime. In each of these periods the average number of run-ups per hour for each type of aircraft must be noted. In addition, the location of the run-up on the base, and orientation of the aircraft at this location must be given (most conveniently, perhaps, by reference to a map of the air base). If one type of aircraft is run-up at more than one location, or with more than one orientation, then it must be so noted in the table as a separate entry. For each run-up the average number of minutes at each of the following power settings should be noted:

A/B

96%-100%

88%-96%

80%-88%

From Table IV one can determine, for each of three time periods, the average number of minutes per hour that each type of aircraft is run-up at each of several engine settings. Also, from an accompanying map of the base one can locate each of the run-ups.

In summary, these operational data permit a detailed description of the operations of the base. For each type of operation the noise data presented in Subsections A, B and C above permit a description of the noise output of each aircraft taking off or running up. Taken together, the noise data and the operational data enable one to describe the total noise output of the air base. The many ways which both kinds of data are used in the analysis of the various types of air base noise problems are described in Section IV below.

SECTION IV

ENGINEERING PROCEDURES FOR ANALYSIS AND SOLUTION OF AIR BASE NOISE PROBLEMS

The selection of a particular means for analyzing and solving an air base noise problem will depend, of course, on the type of problem. In this Guide air base noise problems are classified according to the type of activity involved, that is, in terms of the activity area. There are, broadly speaking, five activity areas:

1) On- and Off-Base Housing Areas
2) Offices and Work Areas
3) Group Meeting, Study, and Rest and Relaxation Areas
4) Hospitals
5) Important Communication Areas

Procedures for analyzing noise problems associated with each of these activity areas are taken up separately in Subsections A through E below. First the noise criteria or acceptable noise levels are presented and discussed. Secondly, procedures for calculating the noise exposure for any given set of air base operations are described. In general the calculated noise exposure is compared with the selected criterion to determine how severe the noise problem is. If the noise exposure at the receiver is greater than the exposure that is considered acceptable (noise criterion), the next step is to see what adjustments can be made in the path or what changes can be made with regard to the noise source (or sources) in order to reduce the noise exposure to an acceptable value.

Detailed examples are presented, and several of the many possible kinds of noise problems that might arise in relation to each type of activity area are described.

A. On- and Off-Base Housing[5,6]

1. Noise criteria. The response of a community to noise from air base operations is dependent on many factors. The amount of noise reaching a community and its frequency content are, of course, the prime factors. However, one must also take into account the time of day that the noise reaches the community, the season of the year, the normal background noise that exists in the community, the previous exposure of the community to air base noise, and the relations that exist between the community and the air base. All these factors and others combine to influence the response of the community to noise. They must be included in the analysis of an air base noise problem having to do with on- or off-base communities.

Table V lists correction numbers to be used to account for the various factors listed above. In solving any problem, these factors are added algebraically to the average ANL estimated to exist in a given community. The sum of the correction numbers and the average ANL is called the:

Composite Noise Rating (CNR)

When evaluating the CNR for "on-base" communities, one finds that a community area on a typical air base can usually be classified as a "normal suburban community" with "considerable previous exposure to noise from air base operations". (See Table V, page 40.)

The CNR must also be related to the community response, which can be evaluated in a number of different ways. One might, for example, examine the number and severity of the overt complaints that are communicated from individuals in the community to the proper authorities. Another method is to study adverse reaction to the noise as evidenced from group meetings within the community, or from newspaper articles or editorials. Community response, or readiness to respond, may also be determined through carefully planned and executed opinion surveys. Fluctuations in real estate values and evidence of dissatisfaction through frequent changing of hands of property may provide further data on community response.

Ideally, it is desirable to find from all of these types of evidence some overall index that can be used to specify the community response on a rank order scale. Unfortunately, however, data of all types described above are not usually available. Frequently, the only information comes from complaints that are communicated by telephone or by letter to the authorities, or from community meetings or other group action. Consequently, the responses that have been selected to describe community reaction are divided roughly into the three categories given in the first two columns of Table VI. The corresponding values of CNR are given in the third column of Table VI.

TABLE V

SUGGESTED CORRECTION IN DECIBELS TO BE ADDED ALGEBRAICALLY TO THE AVERAGE ANL TO OBTAIN THE COMPOSITE NOISE RATING. ALGEBRAIC SUM OF NUMBERS IN FOUR CATEGORIES IS TAKEN

NOTE: When considering on-base living quarters, the table obviously will not be entirely applicable. Corrections 1 and 2 are appropriate. Correction 3 will apply if background noise is related to normal base operations and considered in terms of "truck traffic on base" (heavy, light, etc.), "railroad or heavy vehicle traffic on base", etc. The second item of correction 4 will usually apply as noted on page 39.

Type of Correction	Description	Correction in db
1. Seasonal Correction	Summer* (Year-round operations) Winter	0 -5
2. Time of Day**	Daytime 0600-1800 Evening 1800-2300 Nighttime 2300-0600	-5 0 +5
3. Correction for Back-ground Noise	Very quiet suburban or rural community remote from large cities and from industrial activity and trucking.	+5
	Normal suburban community not located near industrial activity.	0
	Residential urban community not immediately adjacent to heavily travelled roads and industrial areas.	-5
	Noisy urban community near relatively busy roads or industrial areas.	-10
4. Correction for Previous Exposure and Community Attitudes	Community has had some previous exposure to noise from air base operations, but little effort is made to foster good public relations; this correction may also be applied in a situation where the community has not been exposed to noise from air base operations previously, but some effort has been made to foster good public relations.	-5
	Community has had considerable previous exposure to noise from air base operations, and air base-community relations are good.	-10
	With good public relations, the correction can be applied for an operation of limited duration; it cannot be applied for an indefinite period.	-15

* In extremely warm climates where most houses are air conditioned during the summer, with all windows closed, a -5 db correction can be applied.

** The exact time periods given are selected to describe the normal work day, normal evening, and normal nighttime (when people are expected to be asleep). For situations where the time periods indicated are not truly representative of these conditions, the time periods should be suitably altered.

TABLE VI

EMPIRICAL RELATION BETWEEN COMMUNITY RESPONSE AND COMPOSITE NOISE RATING

Description of Community Response		Composite Noise Rating
Off-Base (Civilian)	On-Base (Military)	
Essentially no complaints are reported; the noise may, however, be reported to interfere occasionally with certain activities of the residents.	Essentially no complaints are reported; the noise may, however, be judged to be interfering occasionally with certain activities of personnel.	Less than 45 db
Some residents in the community may complain, perhaps vigorously. Concerted group action is probably not brought against the authorities, but the possibility of such action exists.	Personnel complain among themselves or through channels. Morale will be lowered generally because of these complaints. The possibility exists that personnel are not adequately carrying out assignments because of lack of rest, lowered morale, etc., and this possibility should be carefully checked.	45 to 55 db
Concerted group action may be brought against the authorities. The community action may vary from strong threats to vigorous action.	Personnel complain bitterly among themselves or through channels. Morale is obviously low. Personnel clearly have difficulty in carrying out jobs properly.	Greater than 55 db

When the community is one of the base housing areas and community members are military personnel, the response will be somewhat more difficult to judge. Group action or threats against the base will not, of course, take place. However, the degrees of disturbance to personnel living on base follow a similar scale, and morale and job performance will be affected as the CNR increases. Table VI on the previous page gives what may be considered a "best estimate" of probable response of a military community.

From Table VI it is clear that the CNR in a community should not exceed 45 db. Using this value of 45 db as a reference one can, by working backwards, determine for the average air base-community situation what value of AVG ANL should not be exceeded. Usually the seasonal correction is 0 db (operations occur all year), the background noise correction is 0 db (normal suburban community not located near industrial activity), and the previous exposure correction is -10 db, (considerable previous exposure, and air base-community relations are good). The total of these corrections is -10 db. When this value is added to the time-of-day corrections, the total correction for each of the three time periods becomes:

Daytime	-15 db
Evening	-10 db
Nighttime	- 5 db

If the CNR should not exceed 45 db, it follows that the AVG ANL for each of these time periods should be not greater than:

Daytime	60 db
Evening	55 db
Nighttime	50 db

The above values are only suggested AVG ANL's that should not be exceeded in a community. For particular situations Table V should be consulted for the appropriate correction numbers.

Note that the AVG ANL's were derived for each of the three time periods. For any community noise problem it is necessary to consider each of these time periods separately, primarily because of the variation in community activity throughout a 24-hour period. It is expected that the community reaction will be governed by the noise produced during the time period having the highest CNR. Therefore, the CNR should be calculated for each of the three time periods and, if corrective action is required, first emphasis should be placed on reducing the noise exposure in the critical time period.

Summary

Community noise problems are analyzed in the following manner: By means of the techniques described below, the noise exposure in a community is computed in terms of the AVG ANL. To this AVG ANL one adds algebraically the appropriate corrections from Table V on page 40 to determine the CNR. The expected community response is then estimated by reference to Table VI on page 41.

2. Computation of Noise Exposure in Communities. To determine the noise exposure in a community, either on or off the base, AVG ANL out-of-doors in the community is computed. If several communities are involved, or if the noise exposure over a rather large area is to be determined, the best approach is to calculate the noise exposure in terms of a set of contours of AVG ANL. For only one community, or for a limited area, an entire set of contours is not necessary, and the problem is very much simplified. In the discussion that follows it will be assumed that a set of contours for the entire area surrounding the air base is required, since this is the more difficult type of problem. The treatment of the simplified case will then be obvious.

In the analysis of any community noise problem, if the controlling, or critical, time period can be determined initially, then only this time period needs to be considered, and the total analysis time will be cut by as much as two-thirds. Therefore, the first step will be to determine which time period is the most critical.

Because it is convenient to consider takeoff and run-up operations separately, the critical time period is determined separately for each of these operations. The procedure to be followed in each case is outlined step by step on page 44.

Examples of the application of these procedures to specific problems are worked out in detail in Tables VII (for takeoffs) and VIII (for run-ups) on pages 45 and 46.

a) Determination of Critical Time Period

Takeoffs

Procedure:

1. Convert each type of aircraft (a/c) to its equivalent number of Group I a/c (from Table I on page 14).
2. For each time period multiply number of takeoffs per hour of each a/c by its equivalent number of Group I a/c.
3. For each time period, total the values determined in step 2.
4. Multiply the total in the 0600-1800 time period by 1, in the 1800-2300 period by 3, and in the 2300-0600 time period by 10. (These multiplying factors account for the fact that intruding jet noise is more disturbing in the evening than in the daytime, and more disturbing during the nighttime hours than in the evening.)
5. Compare the three products obtained in step 4. The time period with the highest value is the most critical period for takeoff operations.

   (See example in Table VII on page 45.)

Run-Ups

Procedure:

1. For each aircraft run-up condition, that is, for each run-up of an a/c at a particular engine power setting, determine the equivalent number of Group I a/c.

   For aircraft run-ups at military power and with afterburner, the equivalent number of Group I a/c is given directly in Table I on page 14.

   For aircraft run-ups between 80% rpm and military power the equivalent number of Group I a/c is found by multiplying the value found in Table I for military operation by the value given in Table II for the appropriate engine setting.
2. For each time period multiply the equivalent number of Group I a/c for each run-up condition from step 1 by the corresponding number of run-ups per hour.
3. Multiply the products of step 2 by the number of minutes at each run-up condition.
4. For each time period add all of the values obtained in step 3.
5. Multiply the total in the 0600-1800 time period by 1, the total in the 1800-2300 time period by 3, and the total in the 2300-0600 time period by 10.
6. Compare the three products obtained in step 5. The time period with the highest value is the most critical period for run-up operations.

   (See example in Table VIII on page 46.)

TABLE VII

EXAMPLE OF DETERMINATION OF CRITICAL TIME PERIOD FOR TAKEOFFS

At Windsor AFB takeoff operations involve the following jet aircraft: F100's (A/B), F86D's (A/B), F84F's, and, occasionally, B52's. The average number of takeoffs per hour in each of the three time periods is given in Columns 2, 3 and 4 below. From Table I on page 14 the number of equivalent Group I aircraft is found for each aircraft and entered in Column 5. These values are multiplied by the numbers in Columns 2, 3 and 4 to obtain the values shown in Columns 6, 7 and 8, respectively. Columns 6, 7 and 8 are then totalled. These totals, 62 for 0600-1800, 40 for 1800-2300, and 1 for 2300-0600, are multiplied by 1, 3 and 10, respectively. Comparison of the products reveals that the highest product, 120, occurs for the period 1800-2300, which is, therefore, the most critical time period from the point of view of community reaction to noise from the takeoff operations described in this example.

				STEP 1	STEP 2		
1	2	3	4	5	6	7	8
					(2) x (5)	(3) x (5)	(4) x (5)
Type of Aircraft	Number of Takeoffs/Hr.			Equivalent Number of Group I A/C	Equivalent No. of Takeoffs/Hr. of Group I A/C		
	0600 to 1800	1800 to 2300	2300 to 0600		0600-1800	1800-2300	2300-0600
F100(A/B)	3	2	0	10	30	20	0
F86D(A/B)	5	2	1/3	3	15	6	1
F84F	7	4	0	1	7	4	0
B52	1	1	0	10	10	10	0
			STEP 3	→ TOTALS	62	40	1

STEP 4

0600-1800: 62 x 1 = 62

1800-2300: 40 x 3 = 120 ← Highest Value

2300-0600: 1 x 10 = 10

STEP 5 Comparison of the products shows that the highest value, 120, occurs for the period 1800-2300 which is, therefore, the most critical time period for takeoff operations.

TABLE VIII

EXAMPLE OF DETERMINATION OF CRITICAL TIME PERIOD FOR RUN-UPS

At Windsor AFB two types of aircraft are run-up, F100's and F84F's. The average number of run-ups per hour in each time period is given in Columns 2, 3 and 4 below. The average number of minutes per run-up condition is given in Column 6. For military and afterburner operation of the F100's and F84F's the equivalent number of Group I aircraft is read directly from Table I and entered in Column 5. For the F100 at 90% rpm, the value for the F100 at military power is obtained from Table I (3) and is multiplied by the value from Table II at 90% rpm (0.3) to obtain 0.9 which is shown in Column 5. In a similar manner the equivalent number of Group I aircraft is obtained for the F84F at 85%. Columns 5 and 6 are then multiplied together and the product is multiplied by the numbers in Columns 2, 3 and 4, respectively. The resulting products are shown in Columns 7, 8 and 9 and represent, in each time period, the equivalent number min./hr at each run-up condition for Group I aircraft. These columns are added and the totals, 116 for 0600-1800, 60 for 1800-2300, and 12 for 2300-0600 are multiplied by the numbers 1, 3 and 10, respectively. Comparison of these products reveals that the highest product, 180, occurs in the period 1800-2300. This time period is, therefore, the most critical one from the point of view of community reaction to noise from the run-up operations described in this example.

STEP I (Column 5); STEPS 2 + 3 (Columns 7–9)

1	2	3	4	5	6	7	8	9
						(2)x(5)x(6)	(3)x(5)x(6)	(4)x(5)x(6)
Run-Up Condition	No. of Run-ups/Hr			Equivalent Number of Group I A/C	Number of Min. per Run-Up	Equivalent No. Min/Hr. per Run-up Condition for Group I Aircraft		
	0600 to 1800	1800 to 2300	2300 to 0600			0600 to 1800	1800 to 2300	2300 to 0600
F100(A/B)	2	0	0	10	1	20	0	0
F100(MIL)	2	2	0	3	5	30	30	0
F100(90%rpm)	2	2	0	0.9	10	18	18	0
F84F(MIL)	4	1	1	1	10	40	10	10
F84F(85%rpm)	4	1	1	0.1	20	8	2	2
					TOTALS =	116	60	12

STEP 4

STEP 5

0600-1800: 116 x 1 = 116
1800-2300: 60 x 3 = 180 ←Highest Value
2300-0600: 12 x 10 = 120

STEP 6

Comparison of the products show that the highest value, 180, occurs for the period 1800-2300 which is, therefore, the most critical time period for run-up operations.

In the examples, worked out in Tables VII and VIII, the controlling time period, for both takeoff and run-up operations at Windsor AFB, is 1800-2300, the "evening" period. Therefore, the detailed analysis of the community-air base noise problem should be restricted to this one time period. If the procedure described above should reveal that the controlling time period is different for run-ups and takeoffs, then the computation of the noise exposure (that is, drawing of AVG ANL contours) must be performed for each of the two controlling time periods. Then the final composite AVG ANL contours (representing a combination of takeoff and run-up operations) are studied for each time period to determine in which time period the noise exposure is the greatest. This noise exposure is then used to determine the CNR from which the community response can be estimated.

b) Computation of Average ANL

When the controlling time period (or time periods) has been determined, the next step is to compute the noise exposure in the specific on- or off-base community, or in the area surrounding the air base. Again, the procedure is to consider run-ups and takeoffs separately. Once the noise exposure for each is known, they can be combined to describe the noise exposure arising from all air base operations involving jet aircraft.

TABLE IX

CORRECTIONS TO BE APPLIED TO AVERAGE ANL CONTOURS
WHEN THE NUMBER OF AIRCRAFT TAKING OFF
PER HOUR ON A RUNWAY IS OTHER THAN ONE PER HOUR

Number of Aircraft per Hour	Correction in db
0.2 - 0.6	- 5
0.7 - 2	0
2.1 - 6	+ 5
7 - 20	+10
21 - 60	+15

Takeoffs

At this point the basic operational data are studied to find out whether the flight profiles for all jet aircraft taking off fall into: 1) just one of the flight profile regions of Fig 8, or 2) more than one. If all flight profiles are the same, the procedure is as follows:

Procedure:

1. From the above analysis to determine the critical time period (Table VII on page 45), select the total equivalent Group I a/c taking off per hour in the critical time period.

2. Determine the equivalent number of Group I a/c taking off per hour on each runway by multiplying the total from step 1 by the percentage utilization for each runway.

3. Using the values obtained in step 2, select from Table IX on page 47 the correction in db to apply to the AVG ANL contours of Fig 10.

   (It will be recalled that the contours were drawn for one takeoff per hour of a Group I a/c and must be adjusted for other than one takeoff per hour.)

4. Apply these corrections to the AVG ANL contours of Fig 10 that correspond to the proper takeoff profile. The resultant adjusted contours should be drawn in 10 db steps only, for example, at 50 db, 60 db, 70 db, etc.

5. On a map of the air base and surrounding area overlay the corrected contours (drawn to the same scale as the map of the base) on their corresponding runways.

6. Combine contours (see example below for details). This can best be done by combining two sets of contours at a time. For example, at an air base with four runways (actually two runway strips with four directions of takeoff), combine the contours on two runways, then add to these composite contours those for a third runway, and then to the composite of the three add the contours from the fourth

runway. The final set of composite contours represent the total noise exposure from takeoff operations of jet aircraft.

If more than one takeoff profile is involved, the procedure is basically the same except for a few minor changes.

Procedure:

1. In the critical time period only, determine, for each flight profile, the total equivalent Group I a/c taking off per hour.

2. For each of these values, carry out steps 2, 3, 4 and 5 outlined above. The result will be more than one set of AVG ANL contours -- for two flight profiles there will be two per runway; for three there will be three sets of contours for each runway.

3. For each runway, combine the sets of contours for the different flight profiles (see example below for details). The result will be one set of AVG ANL contours for each runway.

4. Perform step 6 outlined above.

PROBLEM

Assume that the takeoff activity at Windsor AFB is as noted on Table VII on page 45. The layout of the runways on the base is shown in Fig 13, and the runway utilization is:

Runway 3 - 60%
Runway 17 - 20%
Runway 21 - 10%
Runway 35 - 10%

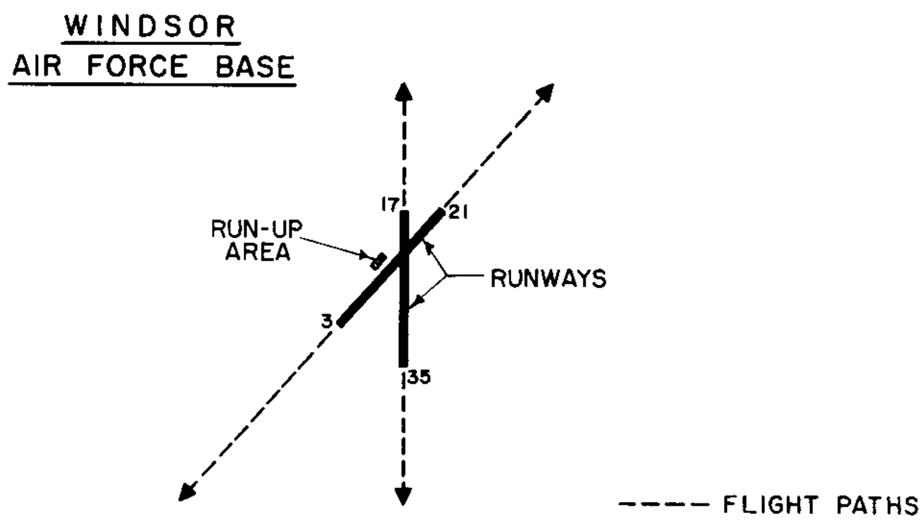


FIG. 13 RELATIVE LOCATION OF RUNWAYS AND RUN-UP AREA AT WINDSOR AIR FORCE BASE.

Operational information shows that the F100's, F86D's, and F84F's are all characterized by Flight Profile No. 2, and the B52 by Flight Profile No. 3. Hence the analysis must be carried out for both flight profiles.

The critical time period has been found to be between 1800 and 2300.

SOLUTION

Step 1 - The total equivalent number of Group I a/c taking off per hour between 1800-2300 is found to be:

Flight Profile No. 2 - 30
Flight Profile No. 3 - 10

Step 2 - Multiplying each of these values by the percent runway utilization given above gives the following values for the number of equivalent Group I aircraft taking off per hour on each of the four runways:

Runway	Flight Profile No. 2	Flight Profile No. 3
3	18	6
17	6	2
21	3	1
35	3	1

Step 3 - From Table IX on page 47 the corrections to be applied to the average ANL contours are found to be:

Runway	Flight Profile No. 2	Flight Profile No. 3
3	+10 db	+5 db
17	+ 5 db	0 db
21	+ 5 db	0 db
35	+ 5 db	0 db

Step 4 - At this point assume for the time being that no aircraft with Flight Profile No. 3 are involved, and consider only those aircraft with a No. 2 Flight Profile. Then, to the AVG ANL contours for Flight Profile No. 2 from Fig 10, the above corrections in db are added.

Step 5 - These adjusted contours have been overlaid on their corresponding runways in Fig 14.

Step 6 - The AVG ANL contours for Runways 17 and 3 as well as those for Runways 21 and 35 are combined as shown in Fig 14. Next, these two composite sets of contours are combined to give the final composite set of AVG ANL contours as shown at the bottom of Fig 14. These contours represent the noise output of all takeoff operations (with a No. 2 Flight Profile) at Windsor AFB.

The manner in which AVG ANL contours are combined is illustrated in some detail in Fig 15. Here the adjusted contours (in 10 db

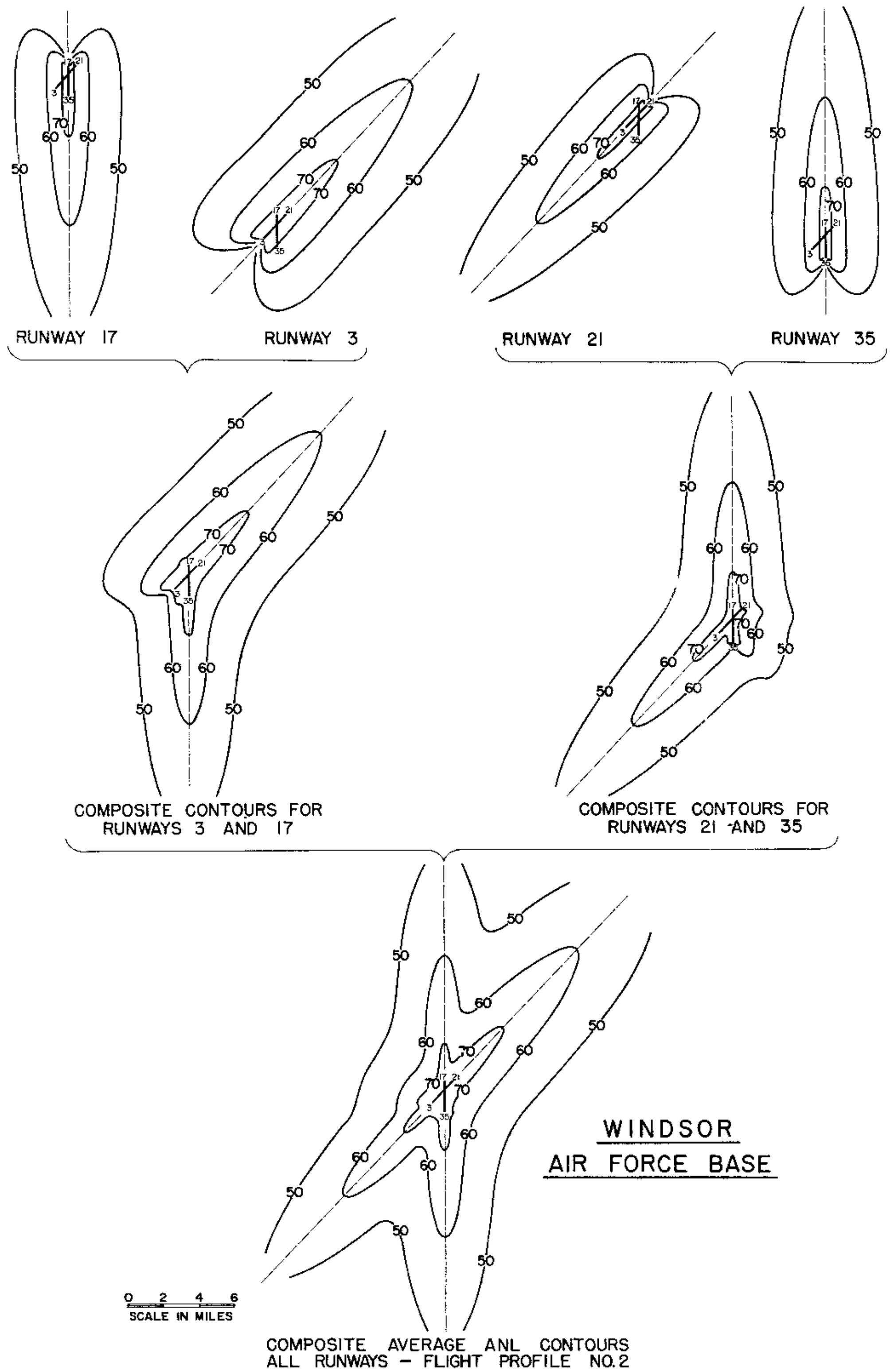
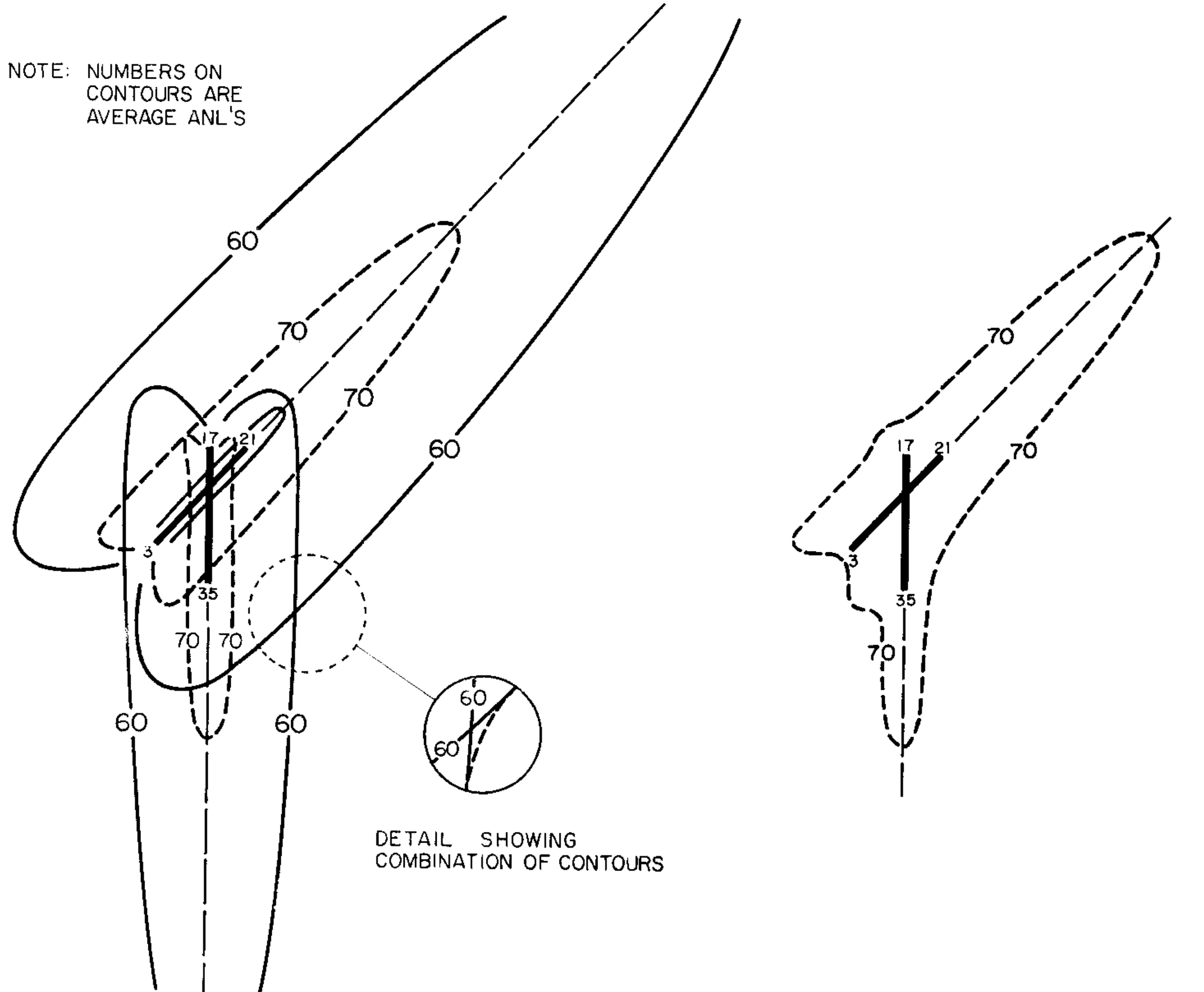


FIG. 14 ILLUSTRATION OF COMBINATION OF AVERAGE ANL CONTOURS FOR TAKEOFFS ON FOUR RUNWAYS.



A. TAKEOFF CONTOURS FOR EXAMPLE OVERLAID ON RUNWAYS 3 AND 17.

B. COMPOSITE OF 70 DB AVERAGE ANL CONTOURS FOR RUNWAYS 3 AND 17.

FIG. 15 ILLUSTRATION OF COMBINATION OF AVERAGE ANL TAKEOFF CONTOURS.

intervals) for both Runways 3 and 17 have been overlaid on their corresponding runways. The composite of these contours is also shown for an AVG ANL of 70 db. It is obtained by simply connecting contours with the same db values. At points where two contour lines with the same value cross, the contours are connected simply by "faring" them together, as shown in the inset in Fig 15.

If the aircraft having a No. 3 Flight Profile are also considered in the analysis, the procedure is as follows:

The corrections previously determined in step 3 on page 51 are applied to the AVG ANL contours of Fig 10 for Flight Profile No. 3. Then for each runway there exist two sets of corrected contours, one for No. 2 Flight Profile operations, and the other for No. 3 Flight Profile operations. These two sets of contours are combined for each runway. In Fig 16 an illustration of the combination of the contours for Runway 3 is shown. In like manner, the two sets of contours on Runways 17, 21, and 35 are combined. These resultant composite contours are then combined by the same process as shown in Fig 15 to give composite contours for all takeoff operations described in the example involving aircraft with both No. 2 and No. 3 Flight Profiles.

Run-Ups

In discussing the procedure for determining the composite AVG ANL contours for run-up operations, it will be assumed for the sake of simplicity that all aircraft are run-up at only one position, with one angular orientation.

Procedure:

1. From the analysis to determine the critical time period described on page 46, find the equivalent number of minutes per hour per run-up condition for Group I aircraft in the critical time period.

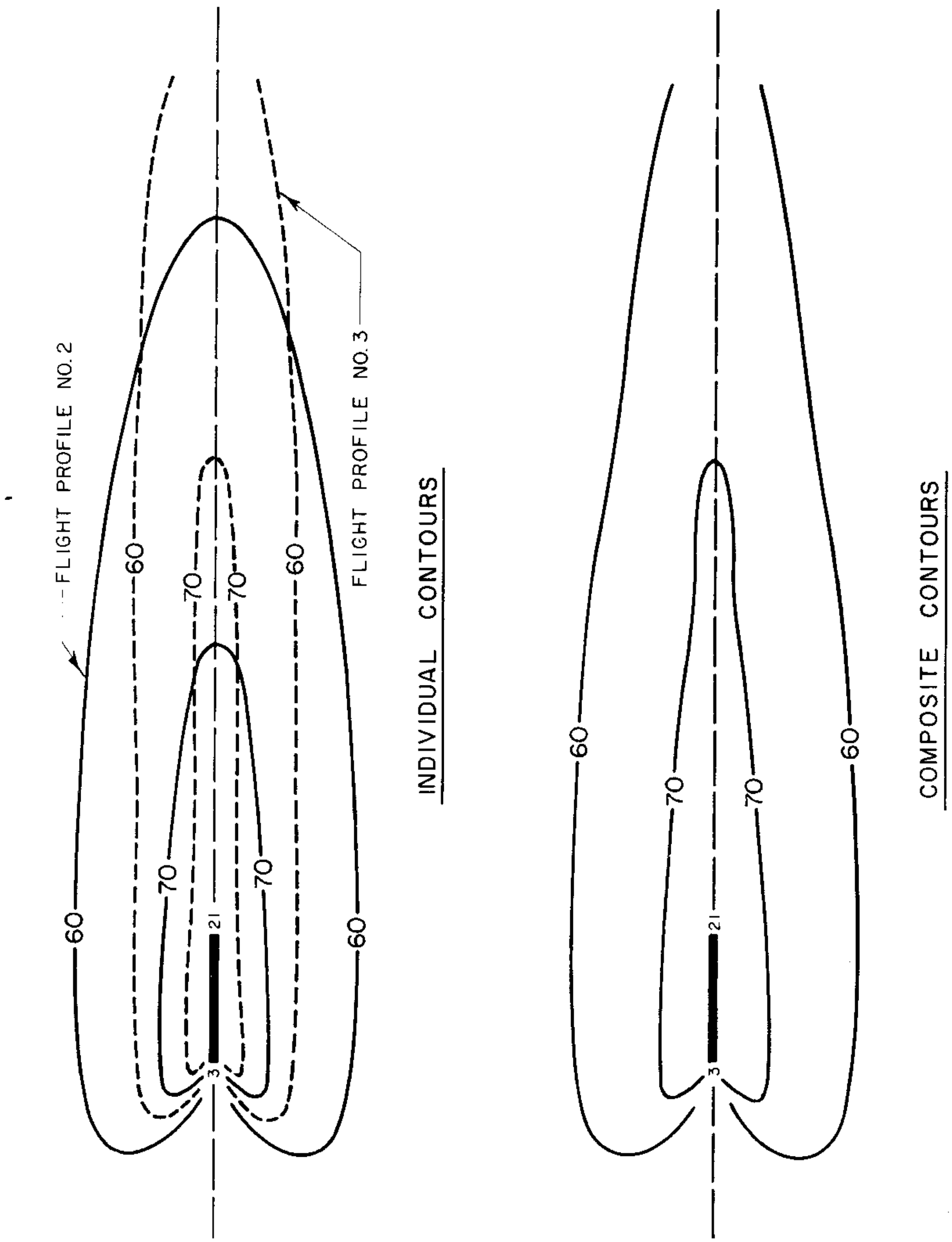


FIG. 16 ILLUSTRATION OF COMBINATION OF AVERAGE ANL CONTOURS FOR TWO DIFFERENT FLIGHT PROFILES.

2. For this value in minutes or fractions of minutes per hour, select the appropriate time duration correction in decibels from Table X below.

3. Apply this correction to the ANL run-up contours of Fig 4. With the application of this correction the contours become AVG ANL contours, since the decibel values on the contours represent noise level as well as time duration. The contours in this form are then directly comparable with the AVG ANL contours for takeoff operations.

4. On a map of the base (drawn to the same scale as the run-up contours) overlay the AVG ANL contours obtained in Step 3 above at the proper location and with the proper angular orientation.

TABLE X

TIME DURATION CORRECTIONS IN DECIBELS FOR RUN-UP OPERATIONS

Effective Duration of Noise Each Hour	Time Duration Correction in Decibels
0.5-2.0 seconds	-35
2-6 seconds	-30
6-20 seconds	-25
20-60 seconds	-20
1-3 minutes	-15
3-10 minutes	-10
10-30 minutes	- 5
30-100 minutes*	0
100-300 minutes*	+ 5

*Effective durations of more than 60 minutes each hour may occur occasionally.

If other aircraft are run-up at the same position, but with a different angular orientation, then, for just those aircraft, the above procedure is repeated. The result will be a set of AVG ANL contours representing the noise output of the aircraft with a different angular orientation. These contours are then combined with those previously derived to obtain a set of contours which describe, in terms of AVG ANL, the noise produced by all run-ups at this one position.

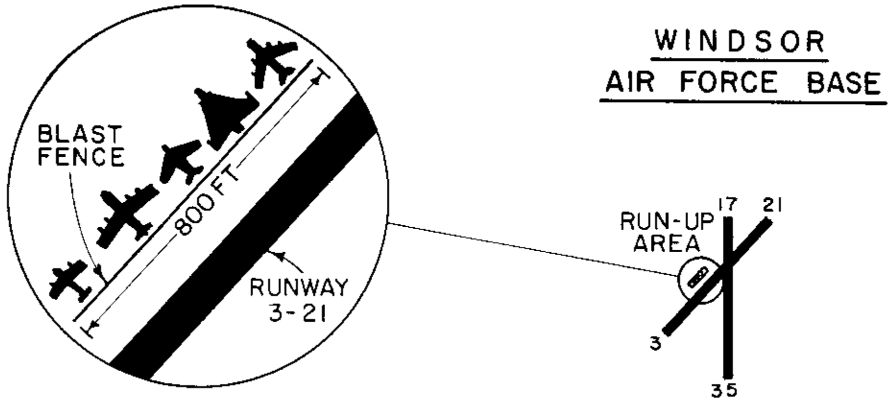
Whether or not a different angular orientation is involved will depend upon some judgment. It is difficult to make simple rules that will apply in all cases. If the difference in angle for two aircraft is less than about 10°, then one should assume there is no difference in orientation. However, a matter of 30° or 40° can be very important in some instances, and negligible in others. A study of the run-up contours in Fig 4 reveals that this amount of angular change would make an appreciable difference in noise level in the region from 120° to 160°, for instance, and very little difference in the angular region forward of the aircraft. The shape of these run-up contours should be used as a guide to determine the angular regions within which a change in orientation will be significant.

If run-ups occur at several positions within the same general run-up area, and if the orientation of each of the aircraft in this run-up area is the same, then one must refer to Fig 5 on page 20 to determine the region around the aircraft within which the run-up contours will not be valid.

If the noise exposure at a fixed location relative to the run-up area is desired, rather than contours over a large area, one again refers to Fig 5 to determine whether or not the run-ups can be considered to be concentrated at one point or whether the exposure from each individual run-up must be calculated.

PROBLEM

Assume that the maintenance run-ups at Windsor Air Force Base follow the run-up schedule indicated in Table VIII on page 46. All run-ups occur in one run-up area located adjacent to Runway 3-21 as shown in Fig 17. All aircraft in this area are oriented so that their jet exhaust is



LOCATION OF MAINTENANCE RUN-UP AREA.

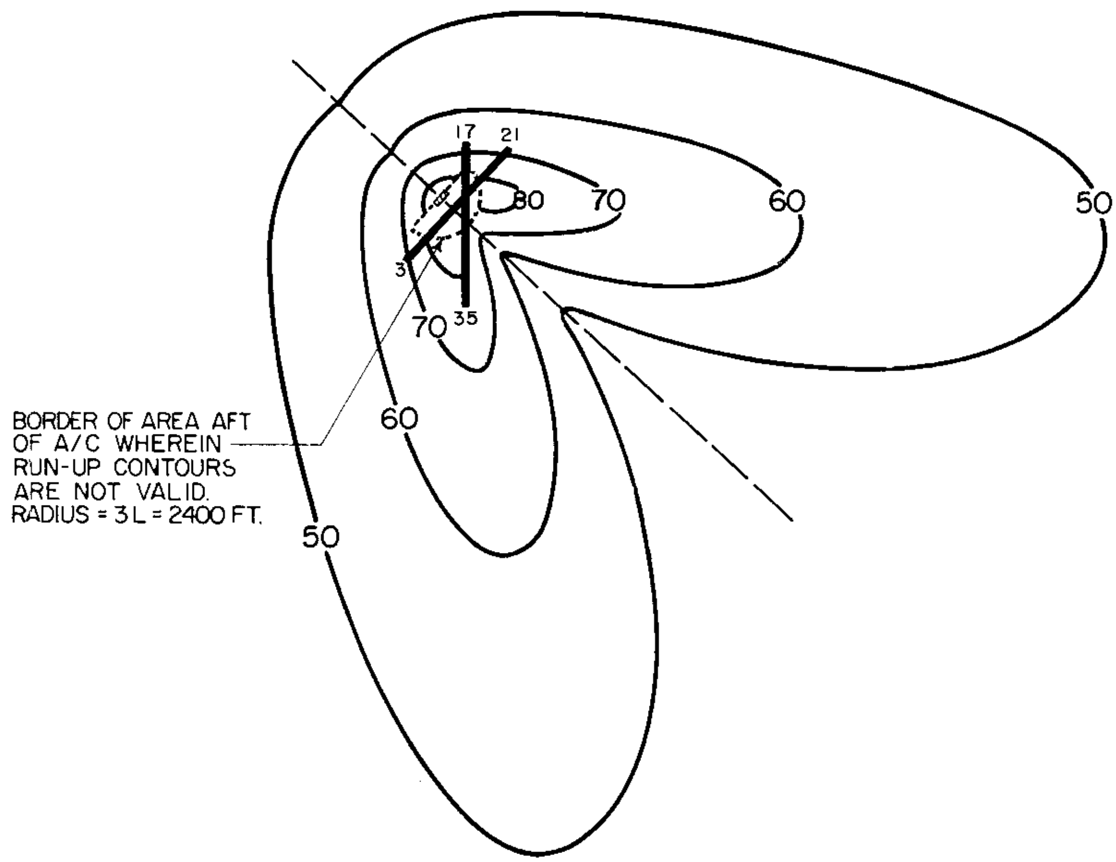


FIG. 17 AVERAGE ANL CONTOURS FOR RUN-UP OPERATIONS OF EXAMPLE DESCRIBED IN TEXT.

directed perpendicular to the runway as shown in the inset in Fig 17. The problem is to determine AVG ANL noise contours that represent the total noise produced by all run-ups occurring in the critical time period, which, as previously determined, is from 1800 to 2300.

SOLUTION

From Table VIII the equivalent number of minutes per hour for run-up operations of Group I aircraft is 60 minutes for the time period 1800 to 2300. The correction in db to be applied to the run-up ANL contours of Fig 4 is found from Table X to be 0 db for 60 minutes. Therefore, the decibel values on the run-up contours need not be changed, and can now be considered as AVG ANL's.

The next step is to overlay the average ANL contours for the run-ups at the proper location and with the proper orientation on a map of the base (drawn to the same scale), as has been done in Fig 17. These contours represent the AVG ANL's produced by the total run-up operations in the period 1800-2300.

c) Combination of Takeoff and Run-Up Contours

The composite contours for takeoff operations and run-up operations are next combined in a manner similar to that described above (see Fig 15 on page 53). The resulting composite contours, as shown in Fig 18, describe the noise produced by all takeoff and run-up operations involving jet aircraft at an air base.

d) Calculation of Composite Noise Rating

From the composite contours for both run-up and takeoff operations, which are assumed to be drawn on a map of the air base and its environs, determine the AVG ANL in the community in question. To this value of AVG ANL (or range of AVG ANL if the community area is quite large) add algebraically the appropriate correction numbers from Table V on page 40. The addition of the AVG ANL and the correction numbers gives the Composite Noise Rating for the community in question in the critical time period.

e) Estimation of Community Response

For the Composite Noise Rating determined in d) above, estimate the community response from Table VI on page 41.

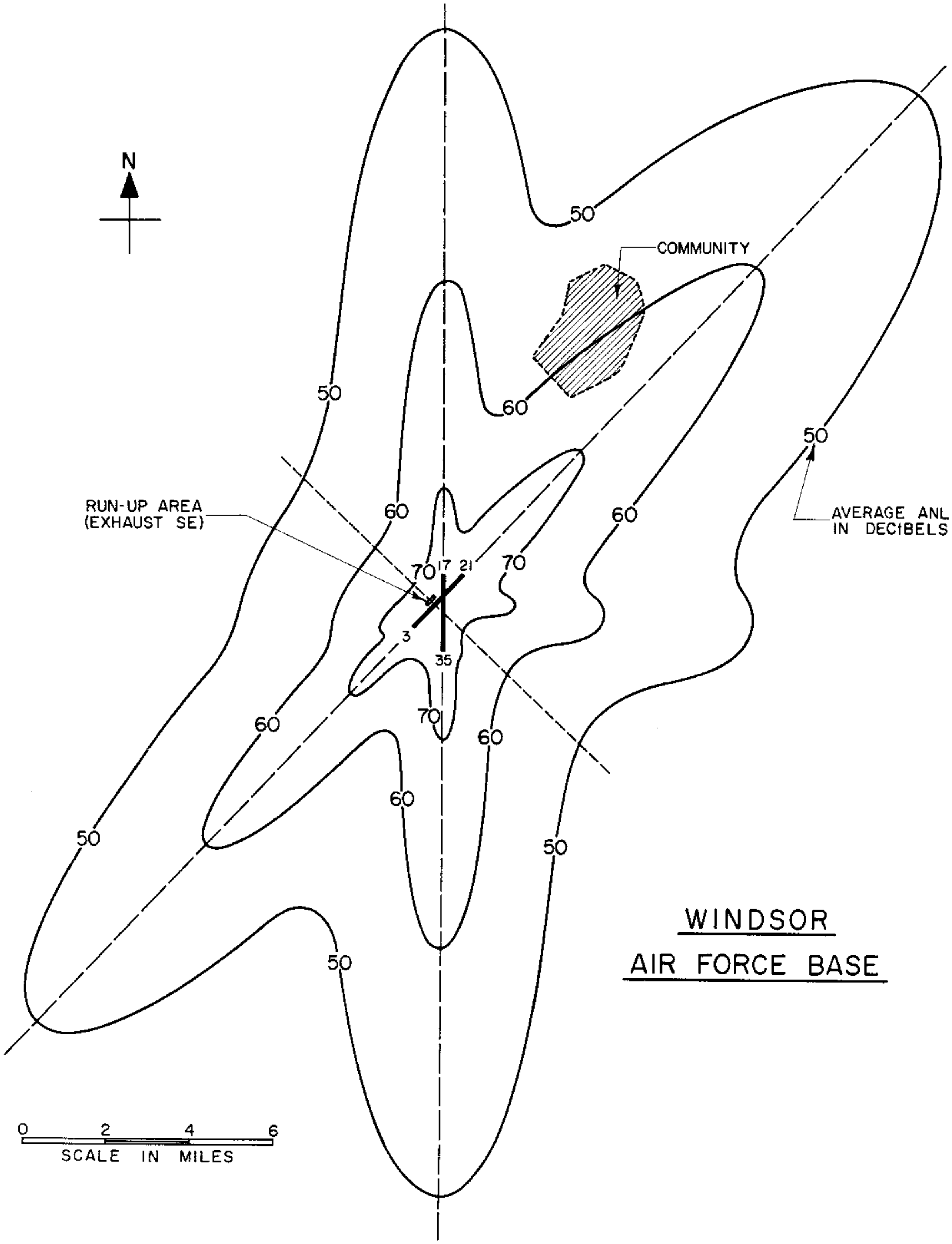


FIG. 18 COMPOSITE AVERAGE ANL CONTOURS FOR ALL JET RUN-UP AND TAKEOFF OPERATIONS AT WINDSOR AIR FORCE BASE.

Example

A community has been assumed to be located adjacent to Windsor AFB, as shown in Fig 18. From a study of the composite AVG ANL contours in Fig 18, it is seen that the AVG ANL in this community is approximately 60 db. In order to determine the Composite Noise Rating (CNR), it is necessary to apply to this AVG ANL value the necessary corrections from Table V on page 40. Assuming that the base operations continue all year, that the community is a "normal suburban community not located near industrial activity", that it has had "considerable previous exposure to noise from air base operations", and that "air base-community relations are good", the corresponding corrections are as follows:

Seasonal Correction	0 db
Time of Day Correction	0 db
Background Noise Correction	0 db
Previous Exposure Correction	-10 db
Total	-10 db

Applying the total correction of -10 db to the AVG ANL of 60 db, one finds that the CNR is 50 db.

For a CNR of 50 db, Table VI on page 41 indicates that "some residents in the community may complain, perhaps vigorously". Also, "concerted group action is probably not brought against the authorities, but the possibility of such action exists".

Clearly, the situation that exists is one that requires some attention by the air base authorities. The conditions should be studied to determine what means can be taken to reduce the noise exposure in the community. In this instance the CNR, and hence the AVG ANL, is high by 5 db. An examination of Fig 18 shows that the AVG ANL in the community is due solely to takeoff operations on Runway 3. If possible, measures should be taken to reduce the noise from these particular takeoff operations.

One possibility is for the air base to institute a right-hand turn for takeoffs on Runway 3. A re-analysis of the problem would indicate how much of a turn is required (in other words, how much the contours must be "curved" to reduce the AVG ANL in the community by 5 db). Another possibility is to reduce the percentage utilization of Runway 3.

3. Applications of Procedures. In Section IV basic procedures for analyzing on- and off-base community noise problems associated with air base operations have been described in some detail. First, the importance of considering the three time periods, daytime, evening, and nighttime has been stressed. A method has been described for determining which of these time periods is the most critical in any noise problem. In the critical time period one can describe the noise produced by run-ups and by takeoffs, separately, by means of noise contours. Combining the various noise contours results in a composite set of contours representing the noise output of all air base operations involving jet aircraft. These composite contours can be used to determine the noise exposure (AVG ANL) in an off-base or on-base community area. Application of simple correction numbers to account for other factors that influence community response permits the determination of the Composite Noise Rating which is then used to estimate the expected community response.

There are various ways in which these procedures can be applied to the numerous noise problems that arise in connection with on- and off-base community areas. Some of these noise problems and the approaches that might be used are described below.

Evaluation of Existing Situation. This problem (which was worked out in detail above) is one in which composite contours are developed simply to determine the nature and extent of the noise exposure in an existing on- or off-base housing area. Using the contours one can then determine which of the air base operations are the primary contributors to the noise exposure, and broadly speaking, what measures might be taken to reduce the exposure.

Determining Effect of New Aircraft. A natural extension of the analysis wherein one evaluates an existing situation is to assess the situation at some future time when new aircraft operate from the base. The procedure in this instance is to carry out the analysis described above twice, once for the existing situation, and once for the future operating conditions. The resultant contours for "present" and "future" conditions can then be compared. This comparison will indicate where and by how much the noise exposure will change.

In this way, by means of a "paper analysis", one can anticipate noise problems, and, in particular, one can obtain some idea of the severity of the noise problem. Obviously, foreknowledge of an approaching noise problem is valuable information since corrective action can be taken before the actual problem arises.

Determining the Effect of a Runway Extension. The effect of a runway extension on the noise output can be readily determined by application of the procedures described in this section. Composite contours for run-ups and takeoffs are drawn for the existing situation, and also for the situation which will exist when the runway has been extended. The two sets of contours are then compared. Actually, extension of a runway does little to change the composite contours provided the type of aircraft using the runway does not change. Run-up contours are not affected and neither are the contours for takeoffs on any other runway except the one that is being extended. Only the contours for that one runway will change, and they will simply be shifted by the distance that the runway is extended.

Determining the Effect of Relocating a Run-up Area. Composite noise contours are drawn for both the "before" and "after" conditions, that is, before and after the relocation of the run-up area. In both cases the noise contours for takeoff operations will, of course, remain the same. If the nature of the run-up operations remains the same, then the run-up contours will remain the same, and they will simply have to be repositioned on a map of the air base. Following repositioning they are then combined with the takeoff contours to develop a new set of composite contours which describe the total output of the air base after relocation of the run-up area. The "before" and "after" composite contours can then be compared to ascertain the effect of moving the run-up area.

Determination of the Effect of Modifying Flight Operations. Again this is a "before" and "after" situation. If flight operations are modified by altering flight paths, changing the runway utilization, or, perhaps, by closing down a runway and/or opening a new runway, the noise contours for takeoff operations will change. In any event, the run-up noise contours before and after the change will remain the same. Therefore, one must determine the composite noise contours for the existing situation and for the new situation. Comparison of these two composite sets of contours will then indicate the effect of the modification of flight operations on the total noise output of the air base.

Determination of the Effect of Run-Up Noise Suppressors. One can determine rather readily by means of the procedures described in this section whether or not run-up noise suppressors can solve an existing or "future" air base-community noise problem. Noise contours are drawn for both takeoff operations and run-up operations. These contours are combined to form a set of composite noise contours describing the noise output from all air base operations involving jet aircraft. If a noise problem exists in regard to a particular housing area, examination of the contours will reveal which of the two types of operations, run-ups or takeoffs, are the primary contributors to the noise exposure in the community. If takeoff operations are the controlling factor, obviously run-up noise suppressors will not effect any reduction of the noise exposure in the community.

If run-up operations control the noise exposure, then one can determine how much noise reduction is required to:

a) reduce the noise exposure to that produced by takeoff operations, and

b) reduce the noise exposure to an acceptable value.

It is important to consider both a) and b) above in determining the amount of noise reduction required for run-up operations. For instance, if the CNR must be reduced by 15 db to solve a problem, one must determine whether 15 db reduction in the AVG ANL's produced by run-ups is really effective. The AVG ANL's from takeoff operations may, for instance, be only 10 db less than those from run-ups. Therefore, reducing run-up noise by 10 db would bring about a situation where takeoffs and run-ups would be equal contributors. Thus, reduction of run-up noise in excess of 10 db would not reduce community noise exposure.

Siting On-Base Housing. These engineering procedures can also be used to aid in the siting of new housing on an air base. For this type of problem, information should be collected on air base operations as far into the future as possible. For the future operations, composite noise contours representing both takeoff and ground run-up operations are constructed. From Table VI on page 41 an acceptable CNR is selected -- generally 45 db or less. For this CNR, and for the corresponding corrections from Table V on page 40, one works in reverse to determine the acceptable AVG ANL value. For instance, if the total of the corrections amounts to -10 db, and the desired CNR is 45 db, the acceptable AVG ANL is 55 db.

Once the acceptable AVG ANL has been determined, the next step is to select from the composite contours the particular contour corresponding to this value. This contour marks the dividing line between two areas, an inner area closest to the noise sources in which the housing should not be constructed, and an outer area in which the housing can be placed anywhere. The final choice of a site in the latter area would depend on other factors such as accessibility, location of other base structures and utilities.

If the choice of a site is restricted, these results could be used to determine what modifications to future operations would be necessary to produce an acceptable CNR at a selected housing site.

As indicated in the above discussion of various typical air base-community noise problems, the basic approach in any analysis is to construct AVG ANL contours that represent all run-up and takeoff operations on an air base. In many problems, construction of these contours for a "before" and "after" situation will provide sufficient information for the solution of the noise problem in question. In others they need only be computed for an existing situation.

B. Offices and Work Areas

The principal objectives in this section are to give a description of the noise environment that is considered satisfactory in various types of offices and work areas, and to discuss means for providing such an environment in these spaces at an air base. The noise environment can be described in terms of the ANL, and values of ANL that are usually considered to be acceptable in office and work areas are tabulated. Procedures for computing ANL's in existing or proposed spaces at an air base are also presented, together with tabulated data on the noise reduction and shielding provided by various types of building structures. Finally, the way in which this information may be used practically is illustrated by a discussion of several typical noise problems involving office and work spaces at an air base.

1. Noise criteria. A set of noise criteria applicable to offices and work spaces has been compiled. This tabulation is a result of considerable practical experience and systematic studies in which the preferences of people who occupied certain spaces were assessed and compared with measurements of noise conditions in these spaces[7]. One important finding of these studies was that the amount of speech communication required and the ease with which such communication can be carried on are important factors in the selection of a satisfactory noise environment in work or in office spaces.

Most of the data obtained from the studies involve noise conditions that were relatively steady, for which the ANL did not fluctuate much more than 5 db on either side of an average level. The noise in most spaces at an air base is of this general character during periods in which jet noise is not present, but the noise generally fluctuates markedly as aircraft run up and take off at the base. It is not unusual to measure fluctuations or changes in the ANL as great as 30 to 40 db. Some studies of the reaction of air base office personnel to the fluctuating noise typical of air base operations have been made, and data from these studies are incorporated in the criteria to be given here[8].

The criteria for office and work spaces are summarized in Table XI on page 67. The right-hand column describes the communication environment and the left-hand column gives the criterion levels, designated as NC values. The NC values are to be interpreted as follows: In the absence of jet noise or in situations where the noise is relatively continuous, the ANL in decibels should not exceed the NC values given in Table XI by more than 5 db. When fluctuations due to jet noise -- takeoffs and run-ups -- are present, the ANL's may exceed the values given in Table XI by more than 5 db for brief periods of time without appreciably influencing the acceptability of the office or work spaces for the communication conditions described in the table. The allowable MAX ANL's and their durations are given in Table XII on page 68.

TABLE XI

NOISE CRITERIA FOR OFFICES AND WORK SPACES[5,7]

A. Recommended Noise Criteria for Offices	
Noise measurements made for the purpose of comparing the noise in an office with these criteria should be performed with the office in normal operation, but with no one talking at the particular desk or conference table where speech communication is desired (i.e., where the measurement is being made). Background noise with the office unoccupied should be lower, say by 5 to 10 db.	
Noise Criteria	Communication Environment
NC-20 to NC-30	Very quiet office - telephone use satisfactory - suitable for large conferences.
NC-30 to NC-35	"Quiet" office, satisfactory for conferences at a 15-ft table; normal voice 10 to 30 ft; telephone use satisfactory.
NC-35 to NC-40	Satisfactory for conferences at a 6 to 8 ft table; telephone use satisfactory; normal voice 6 to 12 ft.
NC-40 to NC-50	Satisfactory for conferences at a 4 to 5 ft table; telephone use occasionally slightly difficult; normal voice 3 to 6 ft; raised voice 6 to 12 ft.
NC-50 to NC-55	Unsatisfactory for conferences of more than two or three people; telephone use slightly difficult; normal voice 1 to 2 ft; raised voice 3 to 6 ft.
Above NC-55	"Very noisy"; office environment unsatisfactory; telephone use difficult.
B. Recommended Noise Criteria for Work Spaces, Shop Areas, etc.	
Noise Criteria	Communication Environment
NC-60 to NC-70	Person-to-person communication with raised voice satisfactory 1 to 2 ft; slightly difficult 3 to 6 ft. Telephone use difficult.
NC-70 to NC-80	Person-to-person communication slightly difficult with raised voice 1 to 2 ft; slightly difficult with shouting 3 to 6 ft. Telephone use very difficult.
Above NC-80	Person-to-person communication extremely difficult. Telephone use unsatisfactory. See Table XV on page 101 and related text for comments on use of earphones, loudspeakers, and ear protectors in intense noise.

TABLE XII

ALLOWABLE MAXIMUM AIRCRAFT NOISE LEVELS REQUIRED IN OFFICE AND WORK SPACES TO ACHIEVE SPECIFIED NC-CRITERIA

Run-Ups	NC CRITERIA							Takeoffs
Time during which ANL is within 10 db of max. value min/hr	NC-25	NC-35	NC-45	NC-55	NC-65	NC-75	NC-85	Number of take-offs per hour of noisiest aircraft
Less than 1/2*	65	70	75	80	85	90	95	3 or less*
1/2 to 3	50	60	70	75	80	90	95	4 to 15
3 to 20	40	50	60	70	75	85	90	more than 15
more than 20	30	40	50	60	70	80	90	

* Some judgment will be required in translating the expressions "less than" and "or less" to low limits of takeoff and run-up activity in specific problems. The choice of the minimum amount of takeoff activity that might be considered in a particular problem, for example, may depend on the importance of telephoning, number of long distance calls, etc. If "or less" turned out to mean one takeoff per day, the restriction on allowable MAX ANL's would be unreasonable; and takeoff activity in this instance could be neglected.

The left column in Table XII gives the time in minutes per hour during which the ANL in the office or work spaces, resulting from jet run-up operations, is within 10 db of its maximum value. The entries in the main body of the table show the MAX ANL that is recommended for the specified duration if the spaces for which particular NC values in Table XI have been selected are to be considered acceptable. For example, if the desired criterion in an office space is NC-35, and the intruding noise from run-ups is within 10 db of its maximum value for an average of 2 minutes each hour, then the allowable MAX ANL is 60 db.

The last column of Table XII lists the number of takeoffs per hour of the noisiest aircraft, that is, having the highest "relative noise output" (Table I on page 14). In a similar manner, therefore, one can determine, for a specified number of takeoffs and a desired NC criterion, the allowable MAX ANL from takeoffs.

The above interpretation of ANL's for fluctuating noise applies only to normal office and work situations. In an important communications area, such as a control tower, the requirements are more stringent than in normal offices and work spaces, since communication is usually required at all times. Specific requirements for the more critical communication areas are discussed in Subsection IV-E.

> Important: The MAX ANL's discussed above and used in the comparison with the NC criteria in office and work space noise problems must be calculated in the manner described in Subsection IV-B-2 below.

2. Computation of noise exposure in office and work spaces. The description of the noise exposure inside an office or work area arising from run-up or takeoff operations of jet aircraft is limited in this Guide, for simplicity and ease of usage, to a specification of the MAX ANL. Knowing the MAX ANL in a space and also something about the time schedule of jet operations, one can describe the noise environment in a space in terms of an NC criterion by reference to Table XII. Conversely, for a given time schedule of jet operations, the allowable MAX ANL in a space for a specified NC criterion can also be determined from Table XII.

The MAX ANL can be calculated for one particular location, or over a wide area such as an entire air base. The latter case represents the more difficult problem since contours of MAX ANL are required rather than specific MAX ANL's at a point. Therefore, the problem of drawing MAX ANL contours is discussed first. Knowing how they are derived, one can easily determine the MAX ANL at any particular location.

Contours of MAX ANL are determined by a consideration of both takeoff and run-up operations. In most noise problems involving offices or work spaces, the noise from run-ups is the controlling factor. However, in some instances the noise from takeoff operations is important, and means for considering both types of operations are discussed here.

The necessary procedures utilize the MAX ANL contours of Fig 9 for takeoff operations for three different flight profiles, as well as the ANL contours for run-ups in Fig 4. Both types of contours apply for Group I aircraft only. The method of modifying contour values to develop MAX ANL contours for run-ups and takeoffs of particular types of aircraft is described in detail below.

Once MAX ANL contours describing all run-up and takeoff operations are available, they can be used to analyze and solve a number of different kinds of noise problems involving offices and work spaces. These contours are the basic working elements in the analysis of this type of problem. They are drawn only for the time period of interest. Generally the work day will fall into the 0600-1800 category, one of the three time periods described in the preceding section.

MAX ANL contours are developed as follows:

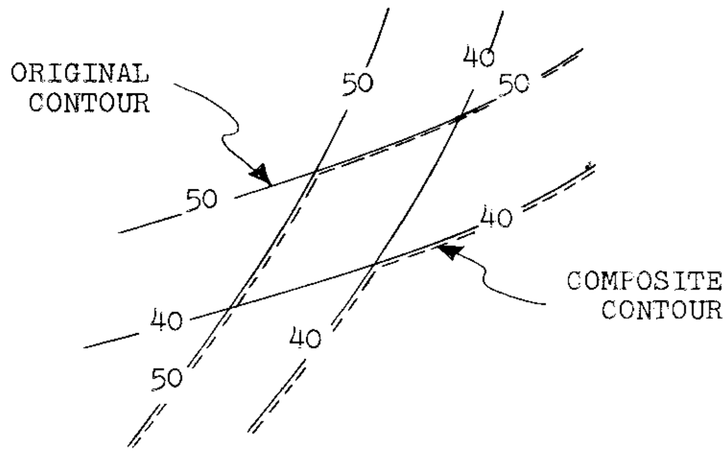
Takeoffs

For all aircraft with one type of flight profile, MAX ANL contours are derived as follows:

Procedure:

1. From Fig 9 select the MAX ANL contours that correspond to the flight profile in question.
2. From the operational data for takeoffs, and from reference to Table I on page 14, select the a/c with the highest relative noise output.
3. Add the highest relative noise output value in db from Step 2 to the MAX ANL contours in Step 1.
4. Overlay corrected MAX ANL contours on a map of the base (to the same scale as the contours) for each runway.
5. Combine MAX ANL contours, two sets at a time, to develop a composite set of contours of MAX ANL for takeoff operations on all runways.

Contours are added or combined in essentially the same manner as described in Subsection IV-A. The only exception is that where two contours of the same MAX ANL intersect, the contours are not "fared in" as before, but connected as shown below:



6. For a/c with other flight profiles, repeat Step 1 through Step 5 above. Combine resultant composite contours with the composite contours obtained in Step 5 above.

7. Note the total number of takeoffs per hour for the aircraft involved.

The end result of the above procedure is a set of composite contours representing MAX ANL's for all takeoff operations. As previously mentioned, these contours are drawn for the time period in question which, for noise problems involving office and work spaces, would usually fall within the 0600-1800 period. The next step is to construct MAX ANL contours for run-up operations.

Run-ups

Contours of MAX ANL for run-up operations are based on the run-up contours of Fig 4. One simply needs to determine the proper correction numbers to apply to these contours in order to convert them to MAX ANL contours for a particular noise problem. These correction numbers are established after a study of the run-up operations.

For all aircraft at the same location and with the same orientation the MAX ANL contours are determined as follows:

Procedure:

1. For each aircraft run-up condition list the number of minutes per hour per run-up and the relative noise output in the form suggested below:

Aircraft Run-Up Condition	Minutes Per Hour	Relative Noise Output

The "minutes per hour" values can be obtained directly from the tabulated operational data for run-ups. The "relative noise output" values in db can be obtained by reference to Tables I and II.

2. Select the highest relative noise output value.

3. Apply the correction value in db from Step 2 above to the ANL run-up contours of Fig 4. The result is a set of MAX ANL contours for the particular set of run-up operations.

4. Overlay these contours on a map of the air base at the proper location and with the proper orientation.

5. Determine from the data tabulated in Step 1 above the total number of minutes per hour for all aircraft run-up conditions at/or within 10 db of the maximum relative

noise output. In other words, the total number of min/hr is required for all run-up operations whose relative noise output is equal to the highest relative noise output, the highest minus 5 db, and the highest minus 10 db. Note this value.

For aircraft run-ups at the same location but with a different orientation, repeat Step 1 through Step 5 above. Then combine the various sets of run-up contours and add the values determined in Step 5. The contours are combined in the same manner as described above for the takeoff contours. No "faring in" of the contours is necessary. The result is a set of MAX ANL contours for all run-up operations in one run-up area.

For other run-up areas, repeat the above procedure.

Effect of Intervening Buildings

The contours that have been developed above for run-up and takeoff operations describe the MAX ANL's that exist outdoors assuming a clear, unobstructed area between the aircraft and the building or buildings in question. If buildings intervene between an aircraft run-up area and a particular building, the MAX ANL's outside the building will be somewhat less than predicted by the MAX ANL contours, as shown previously in Fig 6 on page 21.

Effect of Building Structures

Once the MAX ANL is known outside a building, the next step is to determine the MAX ANL inside the structure. The difference between the ANL outside and the ANL inside is dependent on the wall structure of a building and is called the ANL reduction in db. For various types of wall structures that one might encounter on an air base, values of ANL reduction (rounded off to the nearest 5 db) can be found in Table XIII. If the weight of the basic outer wall structure in lbs/sq ft is known, one can determine the ANL reduction for the following conditions:

a) No windows in the outer wall structure.

b) Fixed-in-place windows, either of standard thickness (about 1/8") or 1/2 in. thick, closed and covering approximately 15% to 40% of the outer wall area.

c) Normal operable sash windows closed and covering approximately 15% to 40% of the outer wall area.

d) All windows half open.

e) All windows completely open.

For example, if the MAX ANL outside a building having an outer wall structure of approximately 15 lbs/sq ft is 75 db, the MAX ANL inside the building, assuming normal operable sash windows --closed, is 50 db. On the other hand, in the summertime when the windows are probably all completely open, the MAX ANL will rise from 50 db to 65 db inside the building.

Table XIII states that, for a wall with no windows, the ANL reduction in db increases with increasing weight, reaching a value of 50 db for a wall in the 76-150 lb/sq ft range. With fixed-in-place windows of standard thickness (about 1/8") the ANL reduction never exceeds 30 db. With normal operable sash windows the value drops to 25 db, and if the windows are open it becomes approximately 10 db.

There is one exception to the relationship between weight of wall and ANL reduction that is implied in Table XIII. The exception is cinder block construction, whose ANL reduction is not simply related to its weight. The ANL reduction of a cinder block wall is found by the following procedure:

> For the weight of the cinder block structure in lbs/sq ft find the ANL reduction in db for the "no windows" condition in Table XIII on page 75. Reduce that value by 10 db. For other than a "no windows" condition, read off values on the same line as the reduced ANL value. For example, for a cinder block wall weighing 60 lbs/ft^2, the actual ANL reduction for "no windows" is 45 minus 10 or 35 db.

Since windows reduce the effectiveness of a wall structure, and since windows are generally open in warm weather for cooling or ventilation, the value of air conditioning merits some discussion. There are two basic types of air conditioning: central air conditioning, and window-unit air conditioning. Central air conditioning would eliminate the need for operable sash windows and would, therefore, permit the use of fixed-in-place windows with their attendant better values of ANL reduction. Window air conditioners on the other hand, provide essentially free passage of air from the outside to the inside and, consequently, free passage of noise as well. Corresponding ANL reduction values lie somewhat between those for operable sash windows and for open windows. A good compromise figure is about 20 db for the ANL reduction.

If air conditioning is considered for a building it would be better from the point of view of noise control to use central air conditioning rather than window units. Central air conditioning implies that the windows on the building cannot be opened. A still better condition would exist, of course, if, in addition to central air conditioning, the building contained no windows,

TABLE XIII

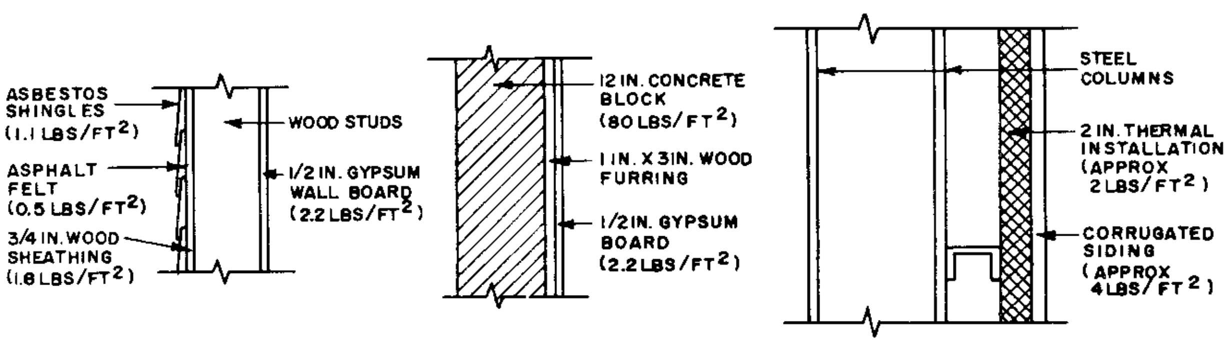
ANL REDUCTION OF WALL STRUCTURES

Wt. of Basic Wall* in lbs/ft^2	ANL Reduction in DB				
		Fixed-in-Place Windows (15% - 40% of Wall)		Normal Operable Sash Windows (15% - 40% of Wall)	
	No Windows	1/2" Glazing	Double Weight Glazing (1/8")	All Windows Closed	All Windows Open
2-3	20	20	20	20	10
4-6	25	25	25	25	10
7-11	30	30	30	25	10
12-20	35	35	30	25	10
21-40	40	35	30	25	10
41-75	45	35	30	25	10
76-150	50	35	30	25	10

* Basic wall structure must cover entire wall area (exclusive of windows) - studs, columns, angles, furring, etc. are not to be considered part of weight of wall.

Exception to table - cinder block walls - see text.

Examples of Typical Air Base Structures:



WEIGHT $\simeq 5\frac{1}{2}$ LBS/FT^2 WEIGHT = 82 LBS/FT^2 WEIGHT $\simeq$ 6 LBS/FT^2

Then the structure would provide the values of ANL reduction shown in Table XIII under the heading "no windows".

Optimum Office Layout

MAX ANL's inside a building will not be the same everywhere in the building. They will be highest in offices on the side of the building toward the runways and the run-up areas. On the side of the building away from the noise sources the noise levels will be somewhat lower. This variation in MAX ANL within a building can be used to advantage in locating offices and work areas with different criterion requirements.

Although every situation will be different, and no simple quantitative rules exist that will cover every possible set of conditions, there are some simple guides that will aid in the choice of office locations wherein the ANL's will be at a minimum in a particular building. These are illustrated by a number of examples in Fig 19.

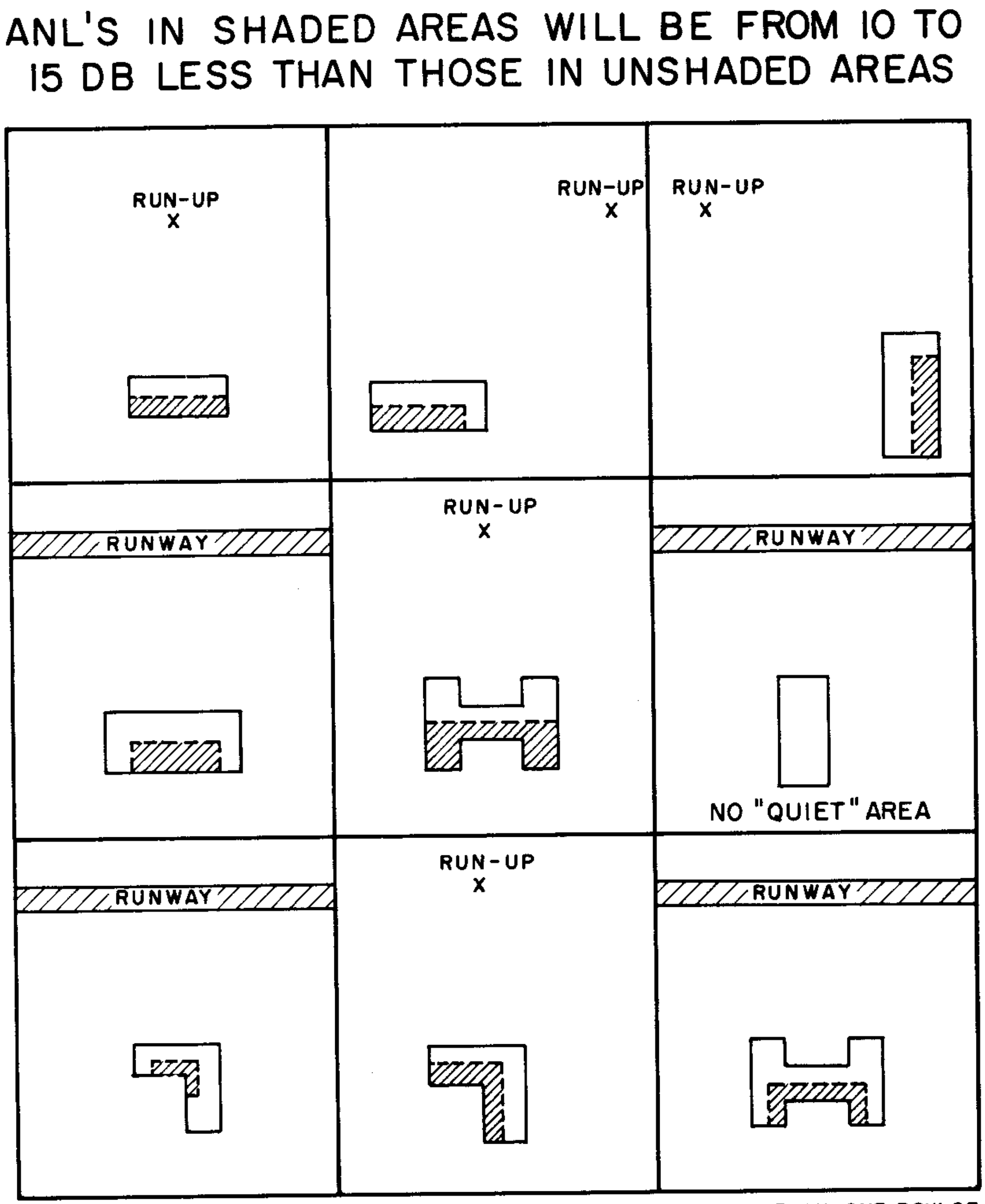
Combining Run-Up and Takeoff Contours (Detailed Example)

Perhaps the best way to describe how run-up and takeoff MAX ANL contours are combined is to discuss an actual practical example.

PROBLEM

Assume that the problem in this instance is to find where on Drake AFB an ordinary frame building (weight of wall = 5 to 6 lbs/ft^2) can be located so that the noise environment inside the building will not exceed an NC-45 criterion in the most exposed offices, and an NC-30 criterion in a few selected offices. There is only one runway strip at Drake AFB with takeoffs in both directions -- on Runways 5 and 23. In the time period from 0600-1800 the following takeoff operations occur on the average:

Aircraft	Takeoffs Per Hour
F100(A/B)	4
F86D(A/B)	5
F84F	7



NOTE : ALL BUILDINGS SHOWN ARE ASSUMED TO HAVE NO MORE THAN ONE ROW OF OFFICE SPACES ALONG EACH OUTER WALL

FIG. 19 LOCATION OF "NOISY" AND "QUIET" AREAS IN A BUILDING.

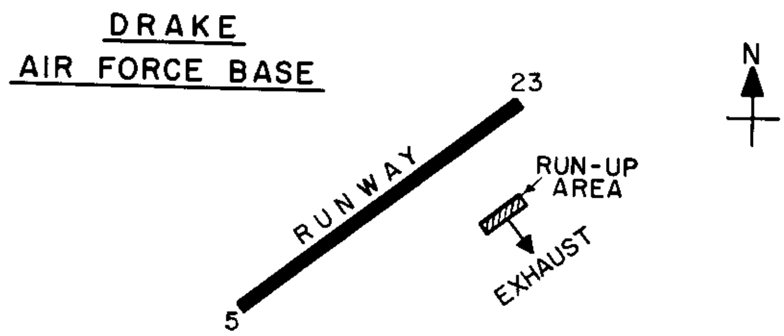


FIG. 20 RELATIVE LOCATION OF RUNWAY 5-23 AND RUN-UP AREA AT DRAKE AIR FORCE BASE.

The runway utilization is 50% on Runway 5 and 50% on Runway 23. The flight profiles for all aircraft are assumed to correspond to Flight Profile No. 2.

Run-up operations occur at only one location and with one orientation. The location of the run-up area relative to the Runway 5-23 is shown in Fig 20, and the run-up operations are described as follows:

Aircraft Run-Up Condition	Number of Run-Ups/Hr	Minutes Per Run-Up
F100 (A/B)	1	1
F100 (Mil)	1	3
F100 (90% rpm)	1	5
F84F (Mil)	2	5
F84F (85% rpm)	2	10

Assume that there are no intervening buildings to be considered.

SOLUTION

MAX ANL contours for takeoffs are derived as follows: Since all the aircraft taking off have the same flight profile, No. 2, the MAX ANL contours of Fig 9B on page 26 are used. Next, the relative noise output for each of the aircraft is determined from Table I on page 14. These values are as follows:

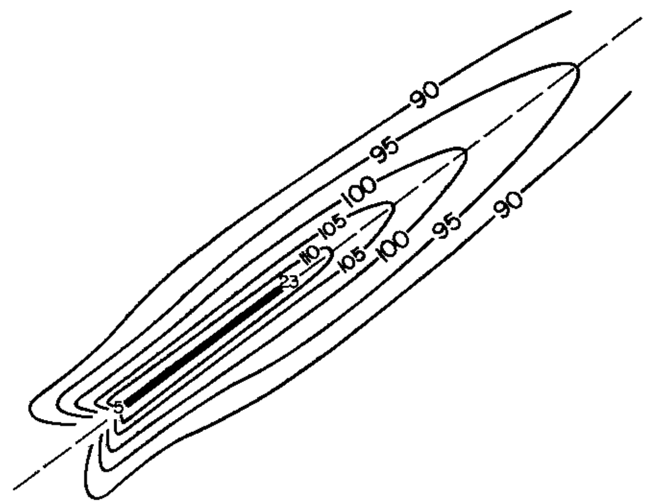
Aircraft	Takeoffs per Hour	Relative Noise Output
F100 (A/B)	4	+10 db
F86D (A/B)	5	+ 5 db
F84F	7	0

From this tabulation the highest relative noise output is found to be +10 db. This correction in db is added to the values on the MAX ANL contours. These MAX ANL contours are then overlaid at their appropriate runway positions on a map of the air base, as illustrated in Fig 21-A for runway 5. Next, the contours for runways 5 and 23 are combined, and the composite contours, shown in Fig 21-B, represent the MAX ANL values for all takeoff operations.

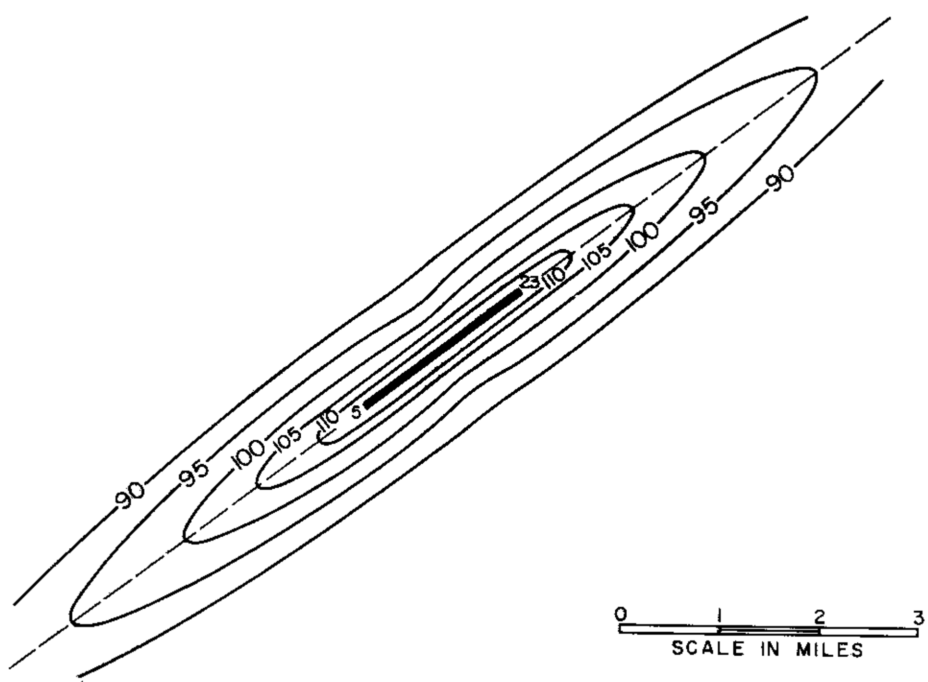
The remaining step is to find the total number of takeoffs per hour of the aircraft with the highest relative noise output. From the tabulation above it is seen that the F100 (A/B) has a relative noise output of +10 db, the highest of all assumed aircraft. For the F100 (A/B) there are 4 takeoffs per hour, two in each direction.

MAX ANL contours for run-up operations are constructed in the following manner: The relative noise output for each aircraft run-up condition is determined by reference to Tables I and II. These values are listed below:

Aircraft Run-up Condition	Relative Noise Output	Total Minutes Per Hour
F100 (A/B)	+10 db	1
F100 (Mil)	+ 5 db	3
F100 (90% rpm)	0	5
F84F (Mil)	0	10
F84F (85% rpm)	-10 db	20



A. MAX ANL CONTOURS FOR TAKEOFFS ON RUNWAY 5.



B. COMPOSITE MAX ANL CONTOURS FOR TAKEOFFS ON RUNWAYS 5 AND 23.

FIG. 21 ANALYSIS OF BUILDING SITING PROBLEM AT DRAKE AIR FORCE BASE.

From a study of the table it is seen that the highest relative noise output is +10 db. The procedure calls for the addition of this correction of +10 db to the numbers on the run-up contours.

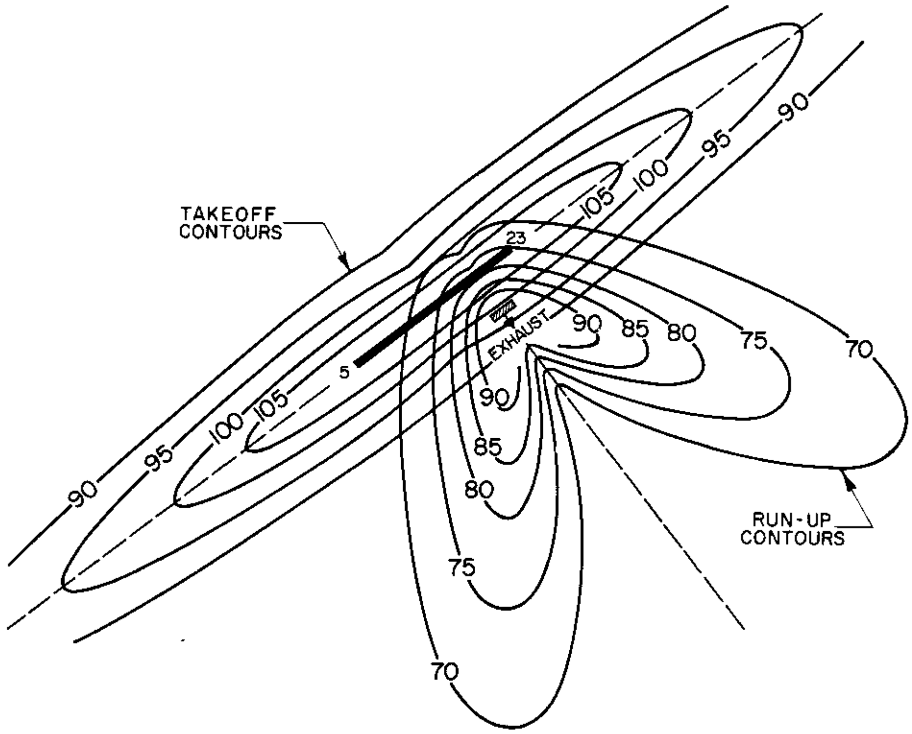
These contours with their corrected contour values are then overlaid on a map of the air base at the proper location, and with the proper orientation, as shown in Fig 22-A (along with the composite MAX ANL contours for takeoffs).

Next, the total number of minutes per hour for all aircraft run-up conditions whose relative noise output is within 10 db of the highest relative noise output must be determined. From the table above it is noted that there are four run-up conditions which satisfy this requirement, and the corresponding number of minutes per hour is 19.

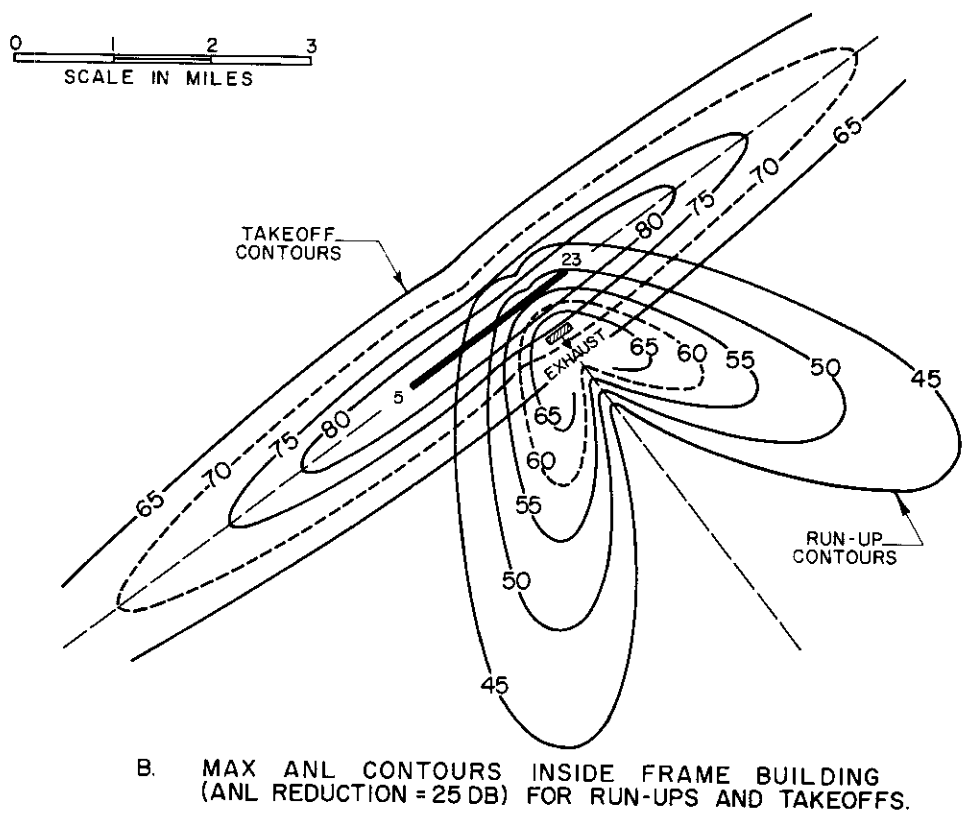
The takeoff and run-up MAX ANL contours shown in Fig 22-A describe the MAX ANL's existing outside a building located anywhere in the area. From Table XIII on page 75, the ANL reduction of the proposed frame building is 25 db, assuming all windows are closed. Therefore, the next step is to reduce all the values on both the takeoff and run-up contours by 25 db. The resultant contours, shown in Fig 22-B, represent MAX ANL's that would exist inside this frame structure.

The next major step is to combine the run-up and takeoff contours to determine essentially one contour line for both run-ups and takeoffs that divides the air base into two areas: one area in which the proposed building should not be placed, and one in which the building can be located anywhere. The procedure is as follows: From Table XII on page 68 determine, for the existing run-up and takeoff operations, the MAX ANL values that should not be exceeded in order that the desired criterion (in this case, NC-45) be met. The analysis above showed that there were four takeoffs per hour of the noisiest aircraft. In Table XII, for four takeoffs per hour, and for a desired criterion of NC-45, the allowable MAX ANL is 70 db. Therefore, if only takeoff operations existed, the dividing line between the two areas mentioned above would be the 70 db MAX ANL takeoff contour line.

In the run-up analysis above the total minutes per hour of run-ups whose relative noise output is within 10 db of the highest relative noise output was found to be 19 minutes. From Table XII, for a duration of 19 minutes per hour, and for a desired criterion of NC-45, the allowable MAX ANL is 60 db. In other words, for run-up operations



A. MAX ANL CONTOURS OUTDOORS FOR RUN-UPS AND TAKEOFFS.



B. MAX ANL CONTOURS INSIDE FRAME BUILDING (ANL REDUCTION = 25 DB) FOR RUN-UPS AND TAKEOFFS.

FIG. 22 ANALYSIS OF BUILDING SITING PROBLEM AT DRAKE AIR FORCE BASE.

alone, the dividing line between the two areas is the 60 db MAX ANL contour.

Each of these "dividing-line" contours, that is, the one for takeoffs (MAX ANL = 70 db), and the one for run-ups (MAX ANL = 60 db), have been indicated by dashed lines in Fig 22-B and drawn separately in Fig 23-A. The next step is to combine these two contours to form one single contour line. This combination is accomplished in the usual way with no "faring in" of the curves. The resultant single contour line is shown in Fig 23-B.

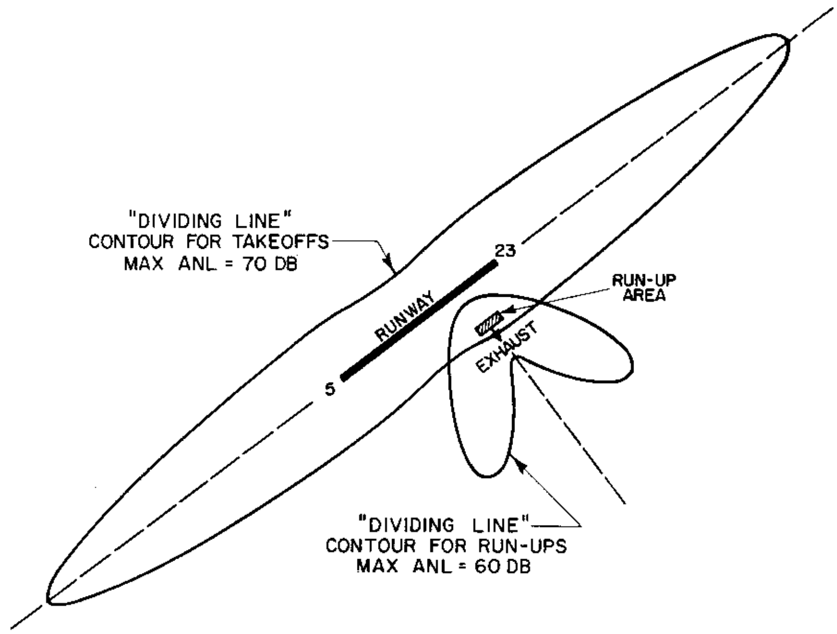
This single continuous contour is the end result of this type of analysis. For the run-up and takeoff operations assumed, this contour line encloses an area in which an environment over the working day corresponding to the NC-45 criterion will not be met. Therefore the proposed frame building should not be located anywhere within this area. Outside of this line the NC-45 criterion conditions will not be exceeded, and therefore the building can be located anywhere in this area.

A further requirement on the building was that it also house some offices in which an NC-30 criterion not be exceeded. This requirement can be satisfied by locating these particular offices in that part of the building where the ANL's will be the lowest. This area can be selected by reference to Fig 19 on page 77. Obviously the offices with the more stringent criterion requirements should be located on the side of the building away from the noise sources. For run-ups the location of the noise source is easily determined. For takeoffs, however, the location of the noise source is not the runway alone, but the runway plus that part of the flight path contained within the final takeoff contour line -- as illustrated in Fig 23. In other words, an aircraft taking off really characterizes an extended noise source.

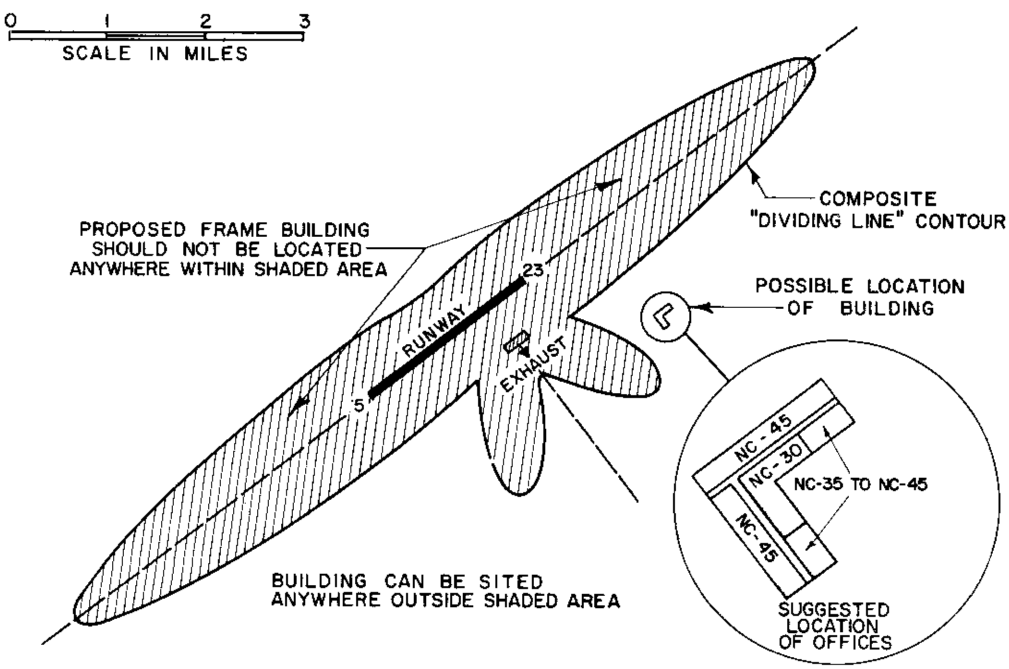
On the basis of these considerations the office areas in the proposed building have been distributed as shown in Fig 23-B. Actually, for the L-shaped building shown, one can assume a gradation of office areas, from NC-30 up to NC-45.

3. Application of Procedures. In this section several kinds of noise problems involving office and work spaces are considered. The manner of application of the above procedures is described in some detail.

Siting a Building of Known Construction. In this type of problem a building of known construction is to be located



A. "DIVIDING LINE" MAX ANL CONTOURS FOR RUN-UPS AND TAKEOFFS.



B. END RESULT OF ANALYSIS SHOWING AREAS WHERE FRAME BUILDING SHOULD AND SHOULD NOT BE LOCATED.

FIG. 23 ANALYSIS OF BUILDING SITING PROBLEM AT DRAKE AIR FORCE BASE.

somewhere on the air base. The problem is to determine where the building can be located so that the corresponding noise criteria for the interior spaces will not be exceeded. The analysis of this type of problem has already been described in detail in the preceding section. The result of such an analysis is a single contour line (or perhaps two closed contour lines in certain instances, such as shown in Fig 24) which divides the air base into two areas; one in which the building can be placed anywhere, and one in which the building should not be located at all. This "acceptable" area along with such other factors as accessibility of the building to other facilities on the air base, soil conditions, availability of water and power, etc., can be used to determine the optimum choice of a site.

Siting a Building of Unknown Construction. In this type of situation there may be several possible sites for a proposed building. The problem is to determine what type of building construction is required at each of these sites in order that the necessary communication environment be satisfied in the building.

As an illustration of the analysis of this problem, assume that at Drake AFB a proposed building can be located at any one of five sites, A, B, C, D and E. Assume further that the air base operations are the same as in the preceding analysis concerning Drake AFB, and that conditions corresponding to an NC-45 criterion should not be exceeded anywhere in the building. (Some NC-35 areas are required, but these can be obtained by proper location of offices.)

The procedure for analyzing this type of problem is as follows: The various steps described in the previous analysis (pages 76-83) are carried out up to the point where the correction for the ANL reduction of the building structure is accounted for. In other words, contours of MAX ANL's existing outside a building are drawn for both takeoff and run-up operations, separately, for the assumed air base operations.

At this stage in the analysis one site at a time is evaluated. Assume, for example, that the MAX ANL at Site A from takeoff operations is 80 db, and from run-up operations is 90 db. From Table XII we find that for the given operations (that is, four takeoffs per hour of the noisiest aircraft, and 19 minutes per hour for run-up operations within 10 db of the run-up operation with the highest relative noise output), and for the desired criterion, the MAX ANL should not exceed 70 db for takeoffs, and 60 db for runups. In summary, the conditions are:

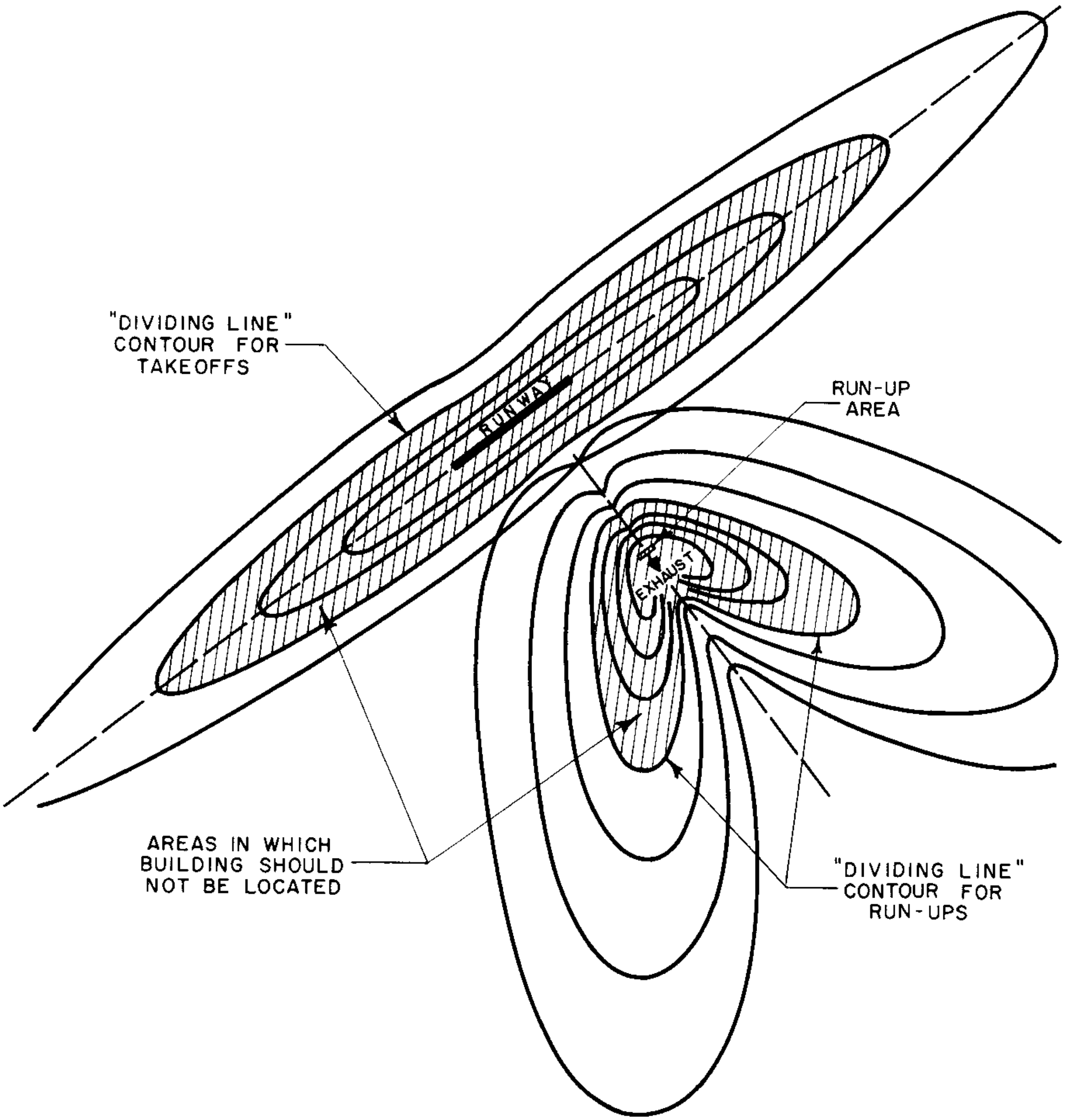


FIG. 24 EXAMPLE OF SITUATION IN WHICH ANALYSIS REVEALS TWO AREAS OR "ISLANDS" WHEREIN BUILDING SHOULD NOT BE LOCATED.

	MAX ANL Outside	Allowable MAX ANL Inside	Required ANL Reduction
Takeoffs	80 db	70 db	10 db
Run-ups	90 db	60 db	30 db

The amount of ANL reduction required is obtained simply by subtracting from the MAX ANL outside, the allowable ANL inside the building. For takeoffs the ANL reduction required is 10 db, and for run-ups the reduction required is 30 db. The highest of the two values controls the type of structure required. Therefore the ANL reduction required is 30 db. Reference to Table XIII on page 75 indicates that any structure with operable sash windows will not satisfy this requirement. The minimum wall structure that is adequate is one weighing 7 to 11 lbs/ft^2 and containing fixed-in-place double-weight glazing (1/8 in. thick).

The above procedure is repeated for each of the proposed sites. The ANL reduction is determined for takeoff and run-up operations separately. The highest of the two values thus determined is equal to the ANL reduction required. This value can then be used, along with Table XIII, to determine the type of structure and corresponding window conditions that are required.

The proper location of offices with more stringent criterion requirements (than NC-45, in this particular problem) can be determined by reference to Fig 19 on page 77.

Evaluating an Existing Situation. In this type of problem a building exists and the object is to determine, for the particular operations involved, the noise environment in the office (or work) spaces in the building. In other words, what are the MAX ANL's in the office spaces on the side of the building facing the takeoffs and run-ups? (For other office spaces, the MAX ANL's will be lower, and these values can be estimated by reference to Fig 19.)

The procedure in analyzing this type of problem is as follows: For the known takeoff and run-up operations construct contours of MAX ANL's existing outside a building in the manner described previously. For the type of wall structure of the building and for the corresponding window conditions, determine the ANL reduction afforded by the building from Table XIII on page 75.

Reduce the values on both the takeoff and run-up contours by this ANL reduction in db. Overlay these contours on a map of the air base in their appropriate positions. At the building location determine the MAX ANL values in db for both takeoffs and run-ups.

Assume that the MAX ANL's inside the building are 60 db for takeoffs and 70 db for run-ups. (The building is assumed to be a frame structure with an ANL reduction of 25 db with windows closed.) Also assume that there are a total of four takeoffs per hour of the noisiest aircraft (the aircraft with the highest relative noise output), and that there are a total of 15 minutes of run-up operations at run-up conditions within 10 db of the highest relative noise output for a run-up condition. These values are summarized in the table below.

	MAX ANL from Contours	Description of Operations	Corresponding NC Criterion
Takeoffs	60 db	4 TO's/hr	NC-35
Run-ups	70 db	15 min/hr	NC-55

For these conditions the corresponding NC criterion from Table XII on page 68 is noted. For a MAX ANL of 60 db and for 4 takeoffs per hour, it is NC-35. Similarly, for a MAX ANL of 70 db and for 15 minutes per hour of run-up time, the corresponding NC criterion is NC-55. In other words, for takeoff operations the NC-35 criterion is satisfied everywhere in the building. On the other hand the noise levels for run-up operations are appreciably higher, and the environment in the offices would be that described by an NC-55 criterion. Clearly, the run-up operations are the controlling influence in this instance.

Since the object of this particular problem is to evaluate the existing situation, the next step is to determine the environment that is acceptable for the spaces in this building. This is done by reference to Table XI on page 67. Assume that the activities in the building are such that in the outer offices facing the noise sources an NC-45 criterion should not be exceeded. Therefore, the ANL's are 10 db too high and are caused by run-up operations alone. An additional ANL reduction of 10 db is required before an acceptable noise environment will be achieved.

The next question is: How can the MAX ANL's be reduced by 10 db? There are several possibilities. The outer wall structure of the building could be improved, i.e., its ANL reduction value could be increased. In this instance, however, the wall structure is simply too light (probably 5 to 6 lbs/ft^2) and little can be done to improve its effectiveness. As a matter of fact, since the ANL reduction of 25 db for the assumed structure is achieved with windows closed, the conditions could actually be worse. Opening the windows will reduce the ANL reduction from 25 db to 10 db.

The possibility of using a run-up noise suppressor for the run-up operations might be considered. For this particular problem the ANL reduction required of the suppressor would be only 10 db. More details on the effectiveness and use of run-up noise suppressors are given in Section V below.

Other possible solutions to the problem are either to reorient the aircraft in the run-up area so as to reduce the run-up noise at the building in question, or to move the run-up area farther away. In both instances the procedure is essentially the same and is described in the next example.

Effect of Moving a Run-Up Area. A run-up area can be moved to solve a noise problem of the type described in the example above, or it may be moved for reasons other than noise control. In the first instance it should be moved only far enough away to solve the problem. In the second instance the effect of moving the run-up area, in terms of the possible creation of new noise problems, should be considered.

The procedure in analyzing both types of noise problems is the same and is as follows: Contours of MAX ANL inside a building for takeoff operations are derived in the same manner described above. For run-up operations, MAX ANL's inside the building are determined for each of the run-up locations in question. Each of these run-up contours is combined in turn with the MAX ANL contours for takeoffs. The resultant contours are then compared to determine in detail the effect of moving the run-up area.

Specifically, if the problem is one of reducing the MAX ANL values inside the building by a specified amount, for instance, the 10 db required in the above problem, the procedure is as follows: Using overlays of the MAX ANL contours for run-up operations, move the contours on a map of the air base to various possible run-up locations until one is found for which the MAX ANL values have been reduced by 10 db. In a similar manner, one can reorient the run-ups simply by changing the position of the run-up contours on a map of the air base until the desired MAX ANL inside the structure is achieved. Of course, the solution might be achieved by a combination of moving the run-ups and reorienting them. One can easily carry out this particular procedure by simply repositioning the overlay run-up contours on the map of the air base.

Evaluating a Future Situation. This problem is one in which it is desired to determine the effect of future air base operations on the noise environment inside air base structures. Future operations may mean the introduction of new aircraft which will undergo both takeoff and run-up operations. It also may mean the utilization of a new run-up area. Or it might mean the construction of one or more new buildings.

This type of problem is simply a variation on one or more of the problems described above. For the takeoff and run-up operations, either known or assumed, MAX ANL contours outside structures are developed. If the type of structure is known, then the values on the contours are reduced by the ANL reduction corresponding to the type of structure in question. For specified activity within the building(s), the appropriate NC criterion can be determined by reference to Table XI on page 67. Knowing the criterion and pertinent run-up and takeoff information, one can, by reference to Table XII on page 68, evaluate the situation.

If the analysis indicates that the desired criterion will be exceeded, measures can be taken to reduce the noise. For example, one might consider changing the type of building structure, moving the run-ups, relocating the building, or utilizing run-up noise suppressors.

Determining Type of Building Structure Required. In this type of problem the location of the building is fixed, the activities within the building are known, and the corresponding noise criterion value can be selected from Table XI. For the known or assumed run-up and takeoff operations the question is: What type of outer wall structure is required for this particular building in order that the selected noise criterion not be exceeded?

This problem is a variation on the one described above wherein both siting a building and determining its noise reduction requirements were considered at the same time. In this instance the building location is known, and the problem is simply one of determining the ANL reduction that is required.

The procedure is as follows: The MAX ANL value for both takeoff and run-up operations is determined at the building location. For the pertinent takeoff and run-up conditions, the allowable MAX ANL is found in Table XII. The allowable and existing MAX ANL values are compared for both takeoffs and run-ups to determine the ANL reduction required for both. The highest value of ANL reduction is the one that must be satisfied in order that the selected noise criterion be met. From Table XIII one can then determine what type of structure and associated window conditions are necessary.

If the amount of ANL reduction required cannot be achieved by a practical wall structure, then it may be necessary to employ other noise control measures. In this event the ANL reduction requirements are shared in some manner by the wall structure and the other noise control measures. For instance, if the ANL reduction required is 50 db, it may be practical to construct a building with an outer wall which will provide 30 db reduction, and obtain the remaining 20 db by means of a change in aircraft operations, a noise suppressor, etc.

Although it is not possible to anticipate and discuss every possible type of air base noise problem associated with offices and work areas, the above examples illustrate the range of applicability of the engineering procedures presented in this section. By proper use of these procedures one can determine, for known or assumed air base operations involving jet aircraft, where to locate buildings on a base, the effect of moving run-up areas, the relative effect of run-up and takeoff noise on the office and work space environment, the required structure of a building, the effect of run-up noise suppressors and the minimum noise reduction they must afford, the effect of future operations on the noise in office and work spaces, where best to locate run-up areas, how best to orient aircraft in these run-up areas, etc.

C. Group Meeting, Study, and Rest and Relaxation Areas

1. Noise Criteria. In this subsection such spaces as theaters, chapels, libraries, schools, dining halls, recreation areas, day rooms, etc. are considered. The acceptable NC criterion values for these spaces are given in the Table XIV. From Table XIV one can find the NC value which corresponds to the type of space or area in question.

TABLE XIV

NOISE CRITERIA FOR GROUP MEETING,
STUDY, AND REST AND RELAXATION AREAS

NC Criterion	Type of Space and Activities
NC-25 to NC-35	Group gatherings to listen to speech and music -- low background noise and good hearing conditions required.
NC-35 to NC-45	Areas where some concentration and relaxed communication may be desirable -- reading rooms -- sedentary relaxation -- radio and television listening -- on-duty resting.
NC-45 to NC-55	Good communication conditions not essential -- some distraction due to external noise can be permitted -- internal noise generation due to other activities may be present.

Although the criterion designations are the same as those given in the preceding section for offices and work spaces, the spaces under consideration in this section are not necessarily ones in which the ability to communicate is of primary importance. Table XIV shows that other factors are considered, such as: rest and relaxation, studying, concentrating, etc.

In general, for most of the spaces that fall into the category described above, the intruding noise levels from jet operations can be permitted to rise above the applicable criterion levels for short periods of time. This situation is similar to that for offices and work areas where the criterion could also be exceeded intermittently. Therefore, in analyzing noise problems associated with these spaces, the basic requirement is to satisfy MAX ANL values in accordance with Table XII on page 68. In other words, if after examination of Table XIV above, one decides that the applicable criterion is NC-45, for instance, then, for the particular run-up and takeoff operations involved, Table XII will give the MAX ANL values that should not be exceeded.

In special cases a certain amount of judgment will have to be exercised. For instance, if the intruding noise levels from jet operations are of sufficiently long duration to interfere seriously with a chapel service, then the applicable criterion level probably should not be exceeded during this period. In more general terms, if one decides that the applicable criterion levels in Table XIV should never be exceeded in a particular space, then the procedures for analyzing such a noise problem are the same as those described in the next subsection entitled "Hospitals".

2. Computation of Noise Exposure. Since the noise exposure is given in terms of the MAX ANL values, the procedure for calculating the noise exposure is the same as described in Subsection IV-B above. MAX ANL contours are developed for both run-up and takeoff operations. The ANL reduction of a structure is determined by reference to Table XIII on page 75. Reducing the contour values by the ANL reduction in db results in the MAX ANL's inside a structure. These values can then be compared directly with the desired noise criterion for the space in question. For details regarding these procedures, see Subsection IV-B.

3. Application of Procedures. Examples that might be described in this section would be similar to those described in some detail in Subsection IV-B. The only difference is that the spaces involved are different, and the selection of a criterion for these spaces is made by reference to Table XIV on page 92 instead of Table XI on page 67.

D. Hospitals

1. Noise Criteria. In important and critical areas in hospitals, such as wards, operating rooms, consultation rooms, etc., the intruding noise levels due to jet operations should not exceed the NC-30 criterion at any time. In other words, the maximum allowable ANL is 35 db in these spaces.* For other less critical spaces in a hospital, the applicable criterion should be chosen by reference to Table XI on page 67 or Table XIV on page 92. In other words, office areas in a hospital would very likely come under the "office and work area" category described in Subsection IV-B. Other types of spaces might come under the categories described in Subsection IV-C.*

In this section, however, it is assumed that the design goal is a MAX ANL of 35 db everywhere in the hospital. Variations on this objective, such as arrangement of spaces in a hospital in order to locate the critical areas on the side of the building away from the noise sources, are discussed later.

2. Computation of Noise Exposure. In general, the procedures for calculating the noise exposure are the same as those as described in Subsection IV-B. Briefly, the steps are as follows:

Procedure:

1. For all run-up operations on the air base construct contours of MAX ANL's that would exist outside a building structure. (See Subsection IV-B for details.)

2. For all takeoff operations construct contours of MAX ANL's that would exist outside a building structure. (See Subsection IV-B for details.)

3. Combine the MAX ANL contours for run-ups with those for takeoffs. The result is a set of composite contours describing MAX ANL's that would exist outside buildings for all takeoff and run-up operations on the air base involving jet aircraft.

The composite contours for run-ups and takeoffs representing MAX ANL's, either outside or inside a structure, are the basic contours required for the analysis of any air base noise problem involving hospitals.

---

* For any NC criterion value the corresponding ANL is 5 db higher. See Appendix D.

4. Account for the effect of intervening buildings by modifying the contours in accordance with the information given in Fig 6 on page 21.

5. If required, account for the ANL reduction of a structure by simply reducing all the values on the contours by an amount equal to the ANL reduction in db from Table XIII on page 75.

3. Application of Procedures. In this section examples are presented illustrating the use of the MAX ANL contours derived above in noise problems involving hospitals on an air base.

Siting a Hospital. The general applicability of the MAX ANL contours that have been derived above can be illustrated by considering the problem of siting a hospital on an air base. Assume that a hospital structure has an ANL reduction, as determined from Table XIII on page 75, of 30 db. The problem is to determine where on the base this hospital building can be located so that an ANL of 35 db (NC-30 criterion) will not be exceeded inside the building at any time.

For the sake of simplicity it is assumed that the necessary calculations have been made in accordance with the procedures outlined above and in Subsection IV-B, and that the resulting composite takeoff and run-up contours are as shown in Fig 25. The values on these contours are the MAX ANL's that would exist inside the assumed structure.

These two sets of contours are combined and the composite contours, representing MAX ANL's inside the building for all takeoff and run-up operations are as shown in Fig 26. Since the allowable MAX ANL inside the building is 35 db, the problem of siting the hospital is one of simply locating this particular contour line. As indicated in Fig 26, the hospital should not be located anywhere inside this contour line since an ANL of 35 db will be exceeded in the enclosed area. Outside the contour line, the hospital can be located anywhere.

By means of this type of analysis, one can very quickly determine how much more (or less) area is available for siting a hospital, if the noise reduction of the hospital structure is changed. Another way to pose this type of problem is to ask: "Where can the hospital be located if its wall structure provides an ANL reduction of 20 db, 30 db, or 40 db?" For the composite contours shown in Fig 26

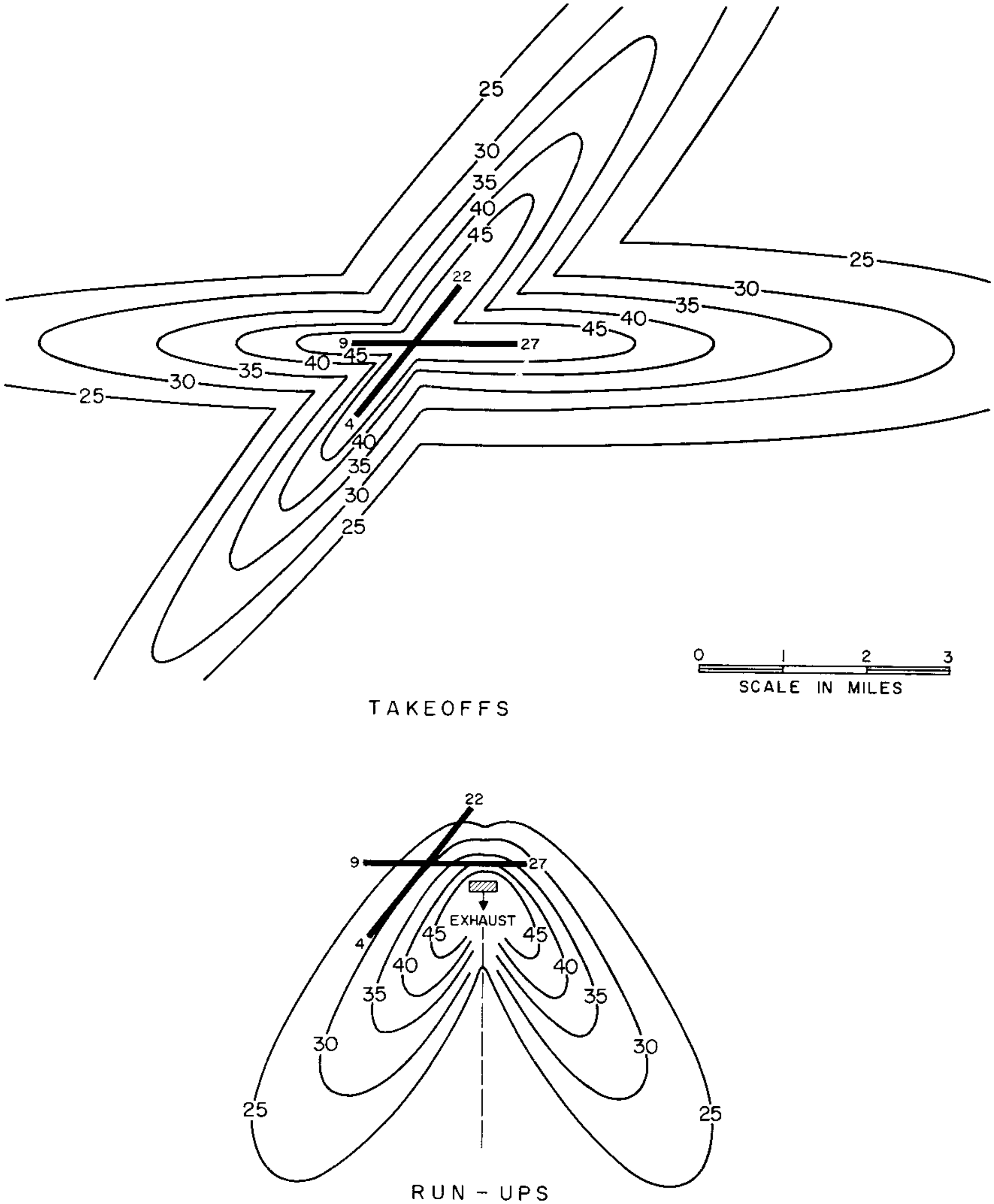


FIG. 25 HOSPITAL SITING PROBLEM: CONTOURS OF MAX ANL THAT WOULD EXIST INSIDE HOSPITAL WITH ANL REDUCTION EQUAL TO 30 DB.

the answer to this question is given in Fig 27. Clearly, as the effectiveness of the wall structure of the hospital increases, that is, as its ANL reduction increases, the area available for siting the hospital becomes larger.

Determining Type of Structure for Hospitals. If only one location on a base is available for a hospital, the problem becomes one of determining the type of wall structure required. This problem is analyzed in the following manner: Composite MAX ANL contours representing both takeoff and run-up operations are constructed in the manner described above, with one exception. No correction to the contours is made for the ANL reduction of a structure. By means of these contours one determines the value of the MAX ANL at the proposed site. The difference between this value and an ANL of 35 db equals the required ANL reduction in db.

For example, suppose the composite contours indicate that the MAX ANL at a proposed site is 75 db. The required ANL reduction is 75 minus 35, or 40 db. Reference is then made to Table XIII on page 75 to determine the type of structure that will satisfy this requirement.

Other Examples. There are many other ways in which these procedures can be used to analyze air base noise problems involving hospitals. One can utilize the MAX ANL contours to determine the effect of modifying flight operations, reorienting aircraft in a run-up area, moving a run-up area, utilizing a run-up noise suppressor, etc. All of these problems are handled in a manner similar to those described in Subsection IV-B above. The only requirement is that the MAX ANL contours be constructed in the manner described in this section. Once these contours are available, any one of these problems can be analyzed.

The only substantial difference between hospital noise problems and those described in Subsection IV-B is that the criterion for critical areas in hospitals is fixed at NC-30 (ANL of 35 db) and should never be exceeded.

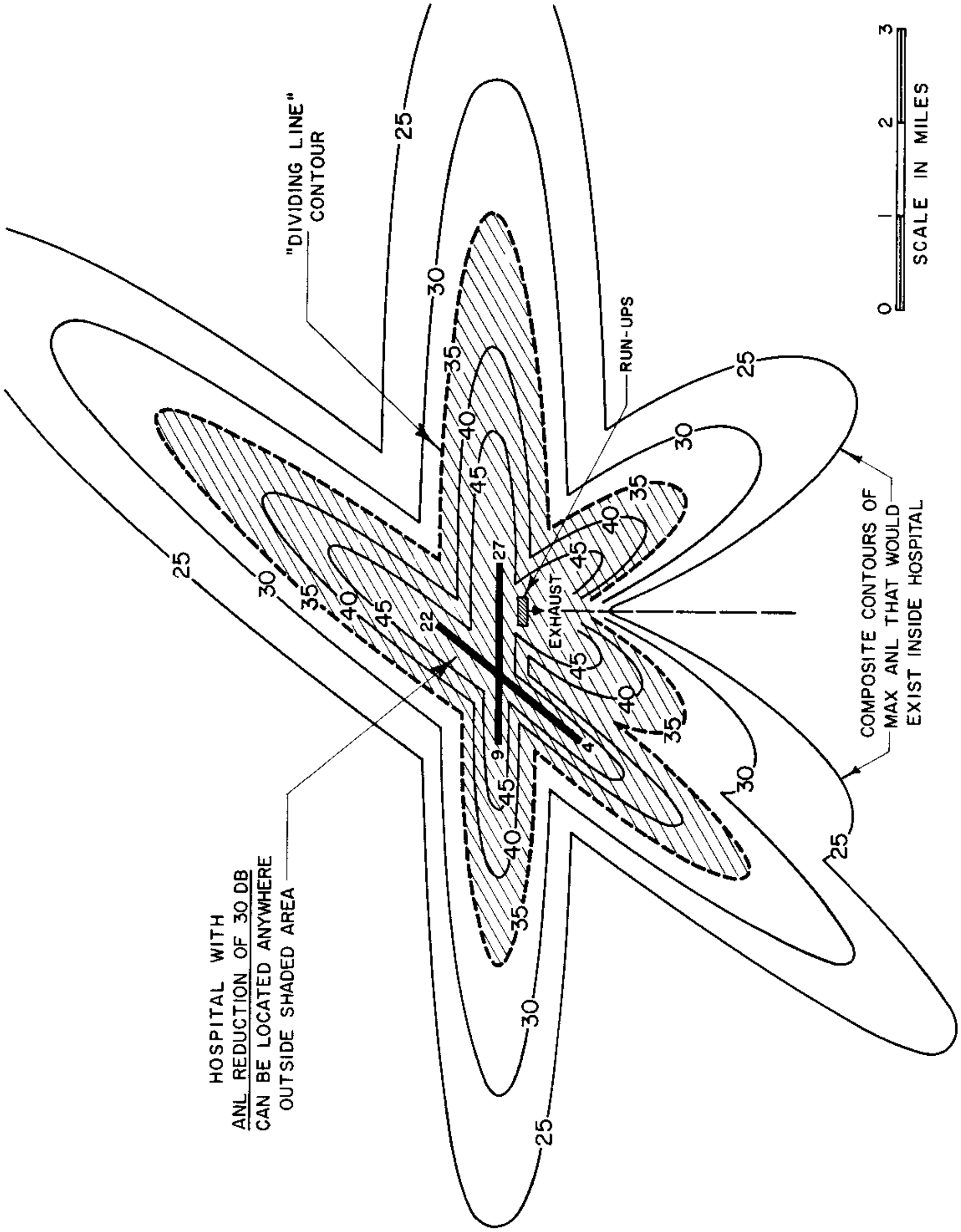


FIG. 26 END RESULT OF HOSPITAL SITING PROBLEM.

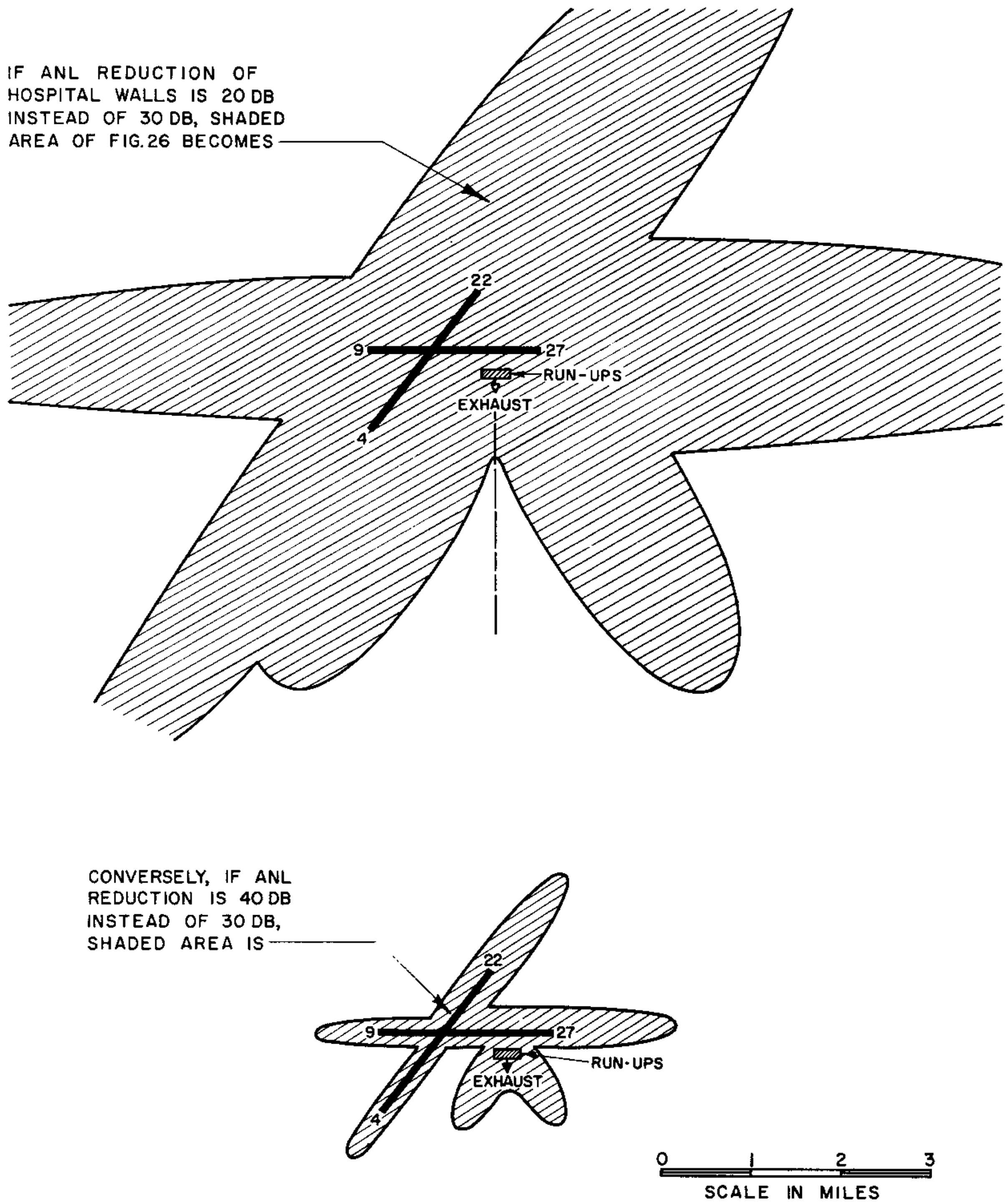


FIG. 27 EFFECT ON RESULT OF HOSPITAL SITING PROBLEM IF ANL REDUCTION OF STRUCTURE IS CHANGED.

E. Important Communication Areas

1. Noise Criteria. Important communication areas are broadly defined as those in which no interruption of communication can be permitted at any time. In these areas the transmission of information is vital, and the interruption of speech, even by the short transient noise produced by aircraft taking off or flying overhead, may have serious consequences.

A leading example of an important communication area is a control tower. Regardless of the time of day or type of air base operation, it is important that communication never be interrupted in a control tower by intruding jet noise. Other areas on an air base with the same kind of requirements fall into this category.

The noise criteria for important communication areas are given in Table XV. For a particular space in question the desired communication environment is selected from the second column in Table XV. Associated with the environmental description is a range of speech interference levels* (SIL's) in db. The higher values in any range are considered marginal for the corresponding communication conditions, and the lower values are considered most desirable. Some judgment must be used in selecting a particular value of SIL for any given space. The value of SIL chosen is not to be exceeded at any time during the working period.

2. Computation of Noise Exposure. It is clear from a study of Table XV that the noise exposure required in an analysis of these types of air base noise problems is the SIL existing either outside or inside a building. SIL's could be obtained directly by the use of SIL contours, just as ANL's are determined by the use of the ANL contours. However, to minimize the number of sets of contours required for the analysis of air base noise problems, a procedure has been developed whereby the ANL contours can be used to compute SIL's.

Since the requirement for any important communication area is that the desired SIL value never be exceeded, the basic objective of any analysis is to calculate the MAX SIL that exists either outside or inside the structure. MAX SIL's are calculated in the following manner:

Takeoffs

Procedure:

1. Select from Fig 9 on pages 25-27 the MAX ANL contours that correspond to one of the flight profiles in use by aircraft taking off.

* The SIL is defined as the arithmetic average of the SPL in the three octave bands: 600-1200, 1200-2400, 2400-4800 cps[9].

TABLE XV

NOISE CRITERIA FOR AREAS IN WHICH NO INTERRUPTION OF COMMUNICATION CAN BE PERMITTED

Speech Interference Level (db)	Communication Environment
30-40	Communication in normal voice satisfactory 6 to 30 ft; telephone use satisfactory.
40-50	Communication satisfactory in normal voice 3 to 6 ft; and raised voice 6 to 12 ft; telephone use satisfactory to slightly difficult.
50-60	Communication satisfactory in normal voice 1 to 2 ft; raised voice 3 to 6 ft; telephone use slightly difficult.
60-70	Communication with raised voice satisfactory 1 to 2 ft; slightly difficult 3 to 6 ft; telephone use difficult. Ear plugs and/or ear muffs can be worn with no adverse effects on communications.
70-80	Communication slightly difficult with raised voice 1 to 2 ft; slightly difficult with shouting 3 to 6 ft; telephone use very difficult. Ear plugs and/or ear muffs can be worn with no adverse effects on communication.
80-85	Communication slightly difficult with shouting 1 to 2 ft; telephone use unsatisfactory. Ear plugs and/or ear muffs can be worn with no adverse effects on communications.

2. Study the takeoff operational data for all aircraft using this flight profile and determine, by reference to Table I on page 14, the aircraft having the highest relative noise output.

3. Apply the relative noise output correction in db from Step 2 to the values on the MAX ANL contours.

4. Overlay these MAX ANL contours on a map of the air base to the same scale and determine, for each of the runways, the MAX ANL that exists at the location in question.

5. Convert these MAX ANL's to MAX SIL's by applying the proper corrections from Fig 28.

6. Determine the MAX SIL inside a structure by reducing the MAX SIL outside a structure from Step 5 by the SIL reduction in db from Table XVI on page 104 for the particular structure in question.

7. Repeat Step 1 through Step 6 for aircraft using another type of flight profile.

The result of the above procedure is a set of MAX SIL values at a point in question (inside or outside a structure) due to all takeoff operations. No drawing or combining of contours is necessary.

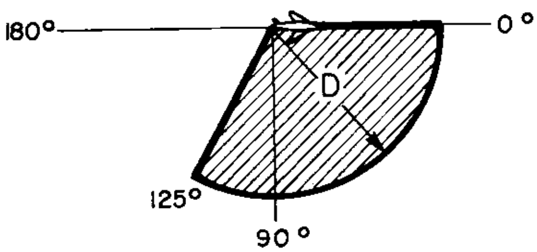
Run-Ups

Procedure:

1. For each run-up location and orientation, study the operational data for run-ups to determine the run-up condition with the highest relative noise output, as determined from Tables I and II on pages 14 and 15.

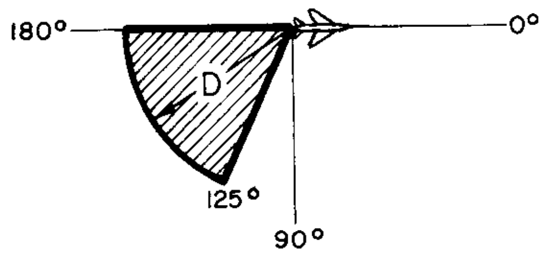
RUN – UPS

0°–125°



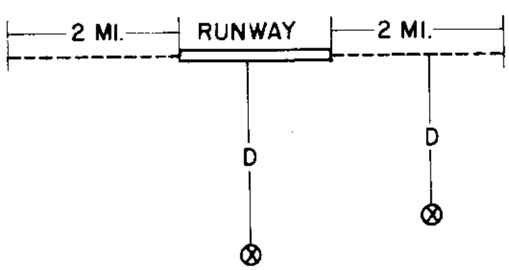
DISTANCE (D) FT	CORRECTION DB
LESS THAN 1500	-5
1500 TO 4000	-10
BEYOND 4000	-15

125°–180°



DISTANCE (D) FT	CORRECTION DB
LESS THAN 1000	-10
1000 TO 3500	-15
BEYOND 3500	-20

TAKEOFFS



NOTE: D IS DISTANCE TO RUNWAY OR EXTENTION OF RUNWAY CENTER-LINE (UP TO 2 MILES FROM END OF RUNWAY).

DISTANCE (D) FT	CORRECTION DB
LESS THAN 1000	-10
1000 TO 2000	-15
2000 TO 4000	-20
BEYOND 4000	-25

FIG. 28 CORRECTIONS TO BE APPLIED TO ANL (OR MAX ANL) TO OBTAIN SIL (OR MAX SIL)

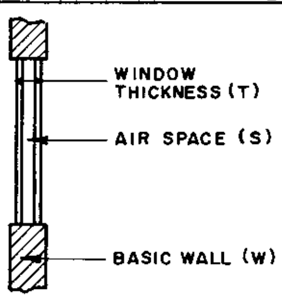
TABLE XVI
SIL REDUCTION OF WALL STRUCTURES

Wt. of Basic Wall* in lbs/ft^2	SIL Reduction in DB				
		Fixed-in-Place Windows (15% - 40% of Wall)		Normal Operable Sash Windows (15% - 40% of Wall)	
	No Windows	1/2" Glazing	Double Weight Glazing (1/8")	All Windows Closed	All Windows Open
2-3	35	35	30	25	10
4-6	40	35	30	25	10
7-13	45	35	30	25	10
14-25	50	35	30	25	10
26-50	55	35	30	25	10
51-100	60	35	30	25	10
101-200	65	35	30	25	10

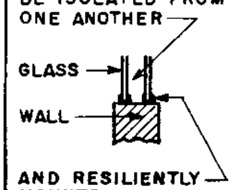
* Basic wall structure must cover entire wall area (exclusive of windows) - studs, columns, angles, furring, etc., are not to be considered part of weight of wall.

Exception to table - cinder block walls - see text(p. 74).

Examples of double glazing construction (e.g., in control towers):



WALL SECTION
ASSUMPTIONS
1) GLASS AND BASIC WALL AREA APPROXIMATELY EQUAL
2) WINDOWS FIXED-IN-PLACE
3) NO LEAKS IN STRUCTURE

SIL Reduction db	W Lbs/Ft^2	T In.	S In.	Remarks
35	2-3	COMMERCIALLY AVAILABLE DOUBLE GLAZING USED PRIMARILY FOR THERMAL INSULATION		
40	4-6	1/4	3/4	GLASS PANELS MUST BE ISOLATED FROM ONE ANOTHER  AND RESILIENTLY MOUNTED
45	7-13	1/8	2	
50	14-25	1/8	3	
55	26-50	3/16	6	
60	51-100	1/2	4	
65	101-200	1/2	12	

2. Apply the relative noise output correction from Step 1 to the run-up ANL contours of Fig 4 on pages 18-19.

3. Overlay the run-up contours of Step 2 on a map of the air base having the same scale at their proper location and with the proper orientation.

4. Determine the MAX SIL existing outside a structure at any point on the air base by applying the proper correction in db from Fig 28 on page 103.

5. If the MAX SIL that exists inside a structure is desired, reduce the MAX SIL outside by the SIL reduction in db obtained from Table XVI for the corresponding wall structure.

6. Repeat Steps 1 through 5 for other run-up locations and/or orientations.

7. Compare the MAX SIL's (inside or outside a structure) from the run-up operations with the MAX SIL produced by takeoff operations (see above).

Following the above procedures one can determine, for takeoff operations and the various run-up operations, the MAX SIL's that exist inside or outside a building for each operation. The actual MAX SIL is, of course, the highest of these various SIL values that have been calculated. For example, if takeoff operations produce a MAX SIL of 45 db in a control tower, and run-ups at two different locations produce MAX SIL's of 35 and 50 db, then the actual MAX SIL inside the control tower is obviously 50 db.

The MAX SIL at a point from run-up operations will, of course, be somewhat less than determined above if buildings intervene between the run-up area and the building or location in question. Corrections to be applied can be determined from Fig 29. It is important to emphasize at this point that these corrections for the effect of intervening buildings should be applied only in the

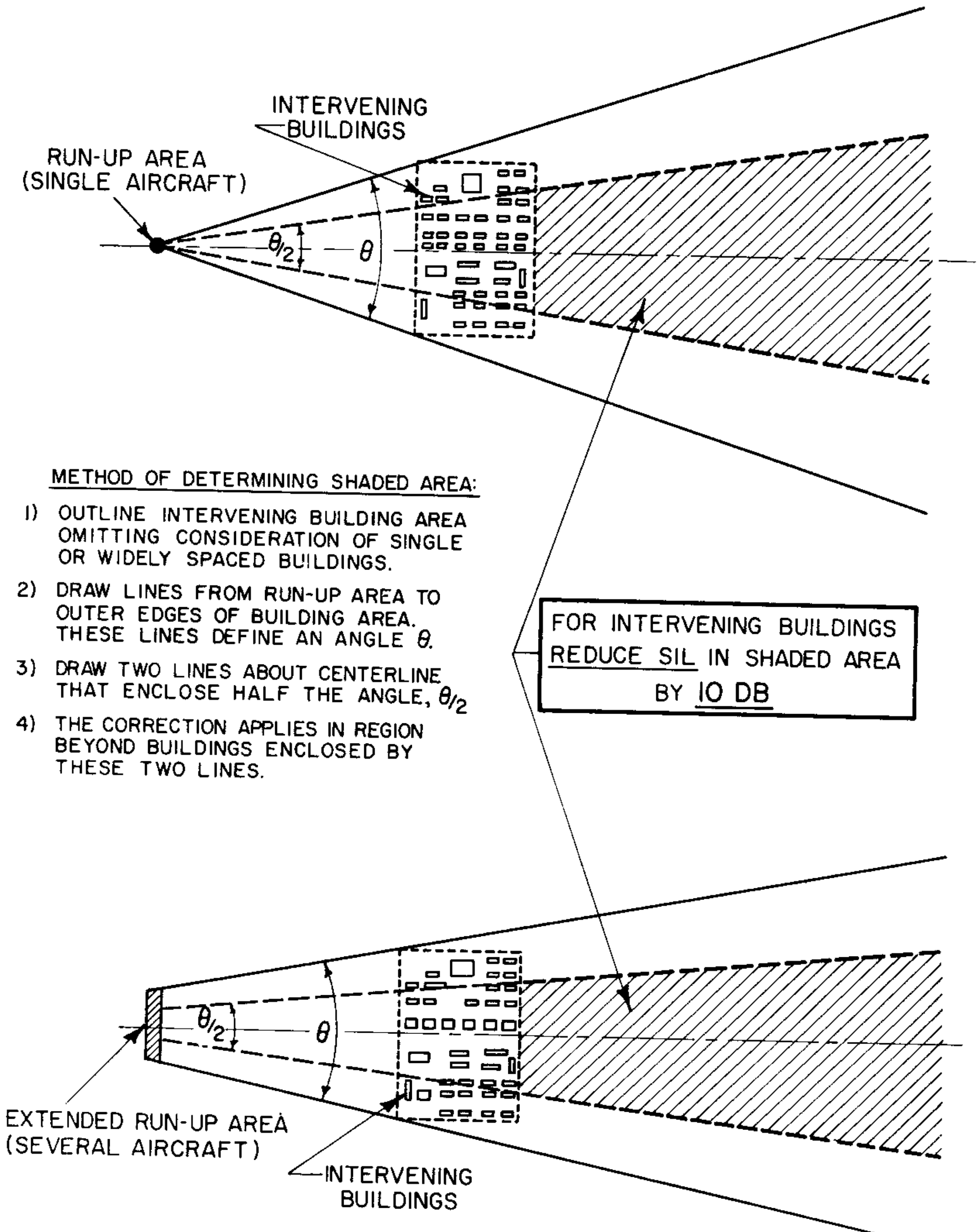


FIG. 29 SIL REDUCTION OF INTERVENING BUILDINGS.

case of run-up operations and only when most intervening buildings are higher than (or at least as high as) the building or location in question. A particular "important communication area" for which these conditions might not exist is a control tower whose height is usually greater than that of other air base buildings. Although buildings may intervene between a run-up area and a control tower, if the run-up area can be seen from the tower, then no "intervening building" correction should be considered.

Summary

The above procedures permit the calculation of the MAX SIL in db inside or outside a structure resulting from all operations on an air base involving jet aircraft.

PROBLEM

Assume that a building with 12" brick walls and central air-conditioning (assumes fixed-in-place "double weight" glazing) is to be built at Position A at Wing AFB. The location of the proposed site relative to the two runways on the air base and the two run-up areas is shown in Fig 30.

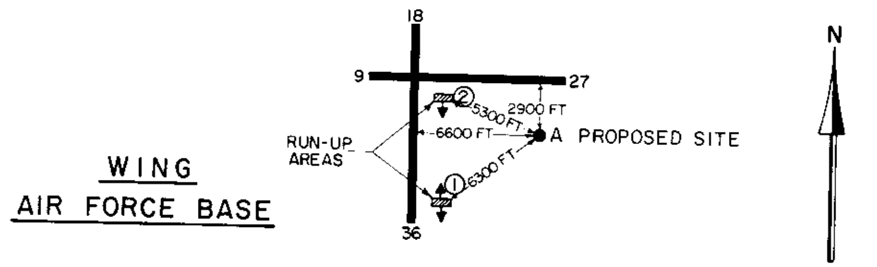
The takeoff and run-up operations at Wing AFB are as follows: F100's (A/B) and T33's take off on all four runways and operate within the area designated by Flight Profile No. 2 on page 24. The F100's are run up at Location No. 1 at afterburner, military, and 90% rpm. Run-ups at Location No. 1 can occur with two different orientations: aircraft exhaust pointed north, or aircraft exhaust pointed south. Only T33's are run up at Location No. 2 and their exhaust is pointed south at all times.

The requirement regarding the noise environment for this particular building is that the noise level inside the building due to run-up and takeoff operations should not exceed an SIL of 40 db. The problem is to determine the MAX SIL in the building from all takeoff and run-up operations.

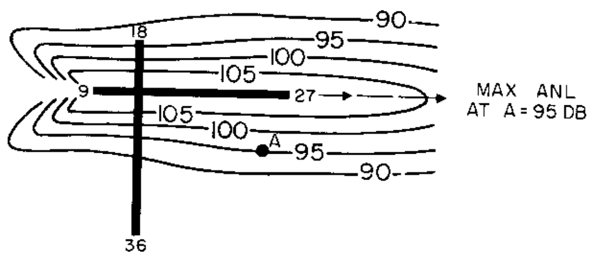
SOLUTION

The analysis of this problem requires the determination of the MAX SIL's at Position A for 7 different operations. These operations are as follows:

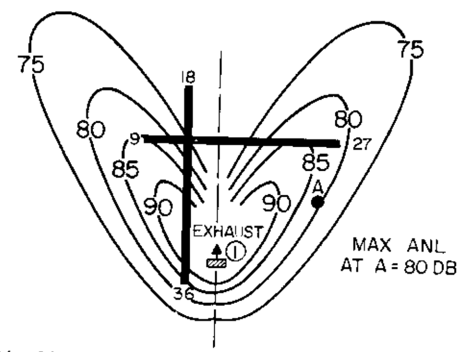
1. Takeoffs on Runway 9.
2. Takeoffs on Runway 18.
3. Takeoffs on Runway 27.



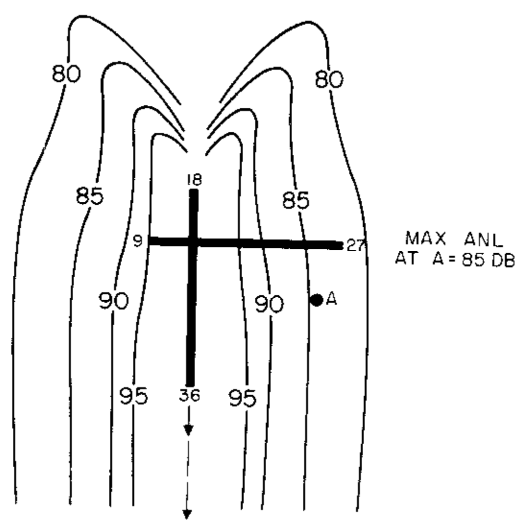
LOCATION OF RUNWAYS AND RUN-UP AREAS AT WING AIR FORCE BASE.



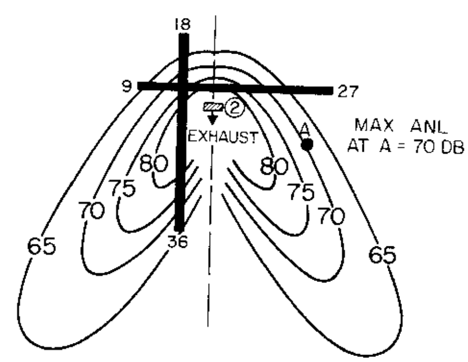
MAX ANL CONTOURS FOR F 100'S TAKING OFF ON RUNWAY 9.



MAX ANL CONTOURS FOR RUN-UPS AT LOCATION 1 – EXHAUST NORTH.



MAX ANL CONTOURS FOR F 100'S TAKING OFF ON RUNWAY 18.



MAX ANL CONTOURS FOR RUN-UPS AT LOCATION 2 – EXHAUST SOUTH.

FIG. 30 ILLUSTRATION OF ANALYSIS OF NOISE PROBLEM IN IMPORTANT COMMUNICATION AREA. (SEE TEXT)

4. Takeoffs on Runway 36.
5. Run-ups at Location 1-exhaust north.
6. Run-ups at Location 1-exhaust south.
7. Run-ups at Location 2-exhaust south.

The MAX SIL at Position A for each of these conditions can be determined rapidly. There is no need to combine contours as in previous problems. In fact, as pointed out above, no contours really need be drawn on a map of an air base (although examples of contours overlaid on the air base will be shown to illustrate the procedure). One simply overlays the properly corrected contours of MAX ANL on a map of Wing AFB (to the same scale) and reads the MAX ANL values that exist at Position A. Then, by reference to Fig 28, each of these MAX ANL's can be converted to MAX SIL's. These values are noted and compared to determine the highest value.

Procedure:

Takeoffs - From Table I on page 14 it is found that the aircraft with the highest relative noise output is the F100 (A/B) and its corresponding correction is +10 db. This value of +10 db is applied to the MAX ANL contours from Fig 9B for takeoffs of aircraft with a No. 2 flight profile. The corrected contours are overlaid on the map of Wing AFB (see Fig 30 for an illustration of overlaying the MAX ANL contours on Runways 9 and 18 to determine the MAX ANL's that exist at Position A). For takeoffs on each of the four runways the MAX ANL values have been determined and are listed below:

Runway	MAX ANL	Correction From Fig 28	MAX SIL Outside	SIL Reduction	MAX SIL Inside
9	95	-20	75	-30	45
18	85	-25	60	-30	30
27	95	-20	75	-30	45
36	85	-25	60	-30	30

Position A is more than 4,000 ft from Runways 18 and 36, so the correction to be applied to the MAX ANL to obtain the MAX SIL is, from Fig 28 on page 103, -25 db for these two runways. For Runways 9 and 27, Position A is 2900 ft away and the correction is -20 db. The resulting MAX SIL's existing outside the structure are tabulated above.

The 12" brick wall structure weighs approximately 120 lbs/sq ft, so the SIL reduction in db is, from Table XVI on page 104, -30 db. When this correction is applied to the MAX SIL's outside the building, the MAX SIL's inside the building become the values listed in the last column of the table on the previous page.

Run-Ups - As noted above, three separate run-up situations must be considered. They are discussed separately below.

Location 1 - exhaust pointed north: For the various aircraft run-up conditions at Location No. 1, the highest relative noise output is, from Tables I and II, +10 db. This correction is added to the run-up contours of Fig 4. These corrected run-up contours are then overlaid on a map of the base, and the MAX ANL at Position A is read (to the nearest 5 db) from the contours. This step is illustrated in Fig 30 where it is noted that the MAX ANL at Position A for this condition is 80 db.

The next step is to convert the MAX ANL value to the MAX SIL. Position A is located 6300 ft from run-up Location No. 1, and is at an angle of slightly less than 125° from the forward end of the aircraft. For this distance and angle, the correction to be applied to the MAX ANL to obtain the MAX SIL is, from Fig 28 on page 103, -15 db. Therefore, the MAX SIL outside the building is 80 minus 15 or 65 db.

Since the SIL reduction of the structure is 30 db, the MAX SIL inside the structure is 65 minus 30, or 35 db. Therefore, the

MAX SIL Inside = 35 db

Location 1 - exhaust pointed south: The same corrected run-up contours used above for Location No. 1 (with the exhaust pointing north) are also used. They are simply reoriented by 180°. The MAX ANL at Position A is found to be 65 db. The distance to Position A is still 6300 ft, and in this case the angle from the forward end of the aircraft is approximately 60°. From Fig 28 the MAX ANL to MAX SIL correction is the same, -15 db. Therefore, the MAX SIL outside is 65 minus 15, or 50 db. Applying the 30 db SIL reduction one finds that the

MAX SIL Inside = 20 db

Location 2 - exhaust pointed south: At this location only T33 aircraft are run up. The corresponding relative noise output for this condition is 0 db (see Table I). Therefore, the numbers on the run-up contours remain unchanged. Overlaid on the map of the air base these contours show that the MAX ANL at Position A is 70 db.

The distance from run-up Location No. 2 to Position A is about 5300 ft and the angle from the forward end of the aircraft to Position A is approximately 110°. For these conditions the correction to be applied to the MAX ANL to obtain the MAX SIL is, from Fig 28, -15 db. Therefore the MAX SIL outside the building is equal to 70 minus 15 or 55 db. Subtracting 30 db from this value one finds that the

MAX SIL Inside = 25 db

In summary, the MAX SIL's inside the building are:

Operation	MAX SIL
Takeoff on Runway 9	45
Takeoff on Runway 18	30
Takeoff on Runway 27	45
Takeoff on Runway 36	30
Run-up - Location 1 - south	20
Run-up - Location 1 - north	35
Run-up - Location 2	25

An examination of these values reveals that the MAX SIL inside the proposed structure will be 45 db. This value is produced by F100 aircraft taking off on Runways 9 and 27. All other conditions result in a MAX SIL which is less than 45 db. The desired environment is characterized by an SIL of 40 db so the MAX SIL inside the proposed building will be high by 5 db.

What can be done to solve this problem? In regard to takeoff operations, F100 takeoffs could be restricted to Runways 18 and 36. Then the MAX SIL's inside would not exceed 35 db and the desired condition would be achieved.

In the event that the above restriction is not possible, one could restudy the criterion requirement to see whether or not a

MAX SIL of 45 db would be considered acceptable for some spaces in the building. Certainly in some offices in the building the MAX SIL would be somewhat less than 45 db, perhaps as low as 30 to 35 db. Therefore, a carefully planned office layout may provide a solution.

Another possibility, if the above two suggestions are not acceptable, is to improve the SIL reduction of the building structure itself. Examination of Table XVI on page 104 reveals that the SIL reduction of 30 db is far less than the potential SIL reduction of the 12" brick structure alone (no windows). Clearly the presence of the windows limits the available SIL reduction. Since the SIL reduction must only be 5 db greater (35 db instead of 30 db), one might consider heavier glass for the windows, or even building the structure with no windows at all (at least on the sides of the building facing the takeoffs and run-ups).

Of course, the MAX SIL could be reduced by moving the building to a site farther away from Runways 9 and 27, being careful not to increase the MAX SIL from run-ups above the desired value. The problem then becomes one of "siting an important communication area" which is discussed below.

3. Applications of Procedures. In this section several ways in which the procedures described above can be used to solve air base noise problems involving important communication areas are discussed.

Evaluation of an Existing Situation. Discussed in detail in above example.

Siting an "Important Communication" Building. In siting important communication areas, the procedure is to determine the MAX SIL at several proposed sites and then compare these values with one another, and with an acceptable criterion. This approach is somewhat different than those described in previous sections of this report in relation to siting other buildings (on-base housing, office spaces, work spaces, etc.). In those problems the end result was a contour line, or lines, which defined areas on an air base where the building in question should and should not be located. Such techniques are not easily adaptable to noise problems involving the siting of important communication areas. Therefore, the approach is basically one of determining the noise exposure at each of several sites and then comparing these results.

The specific procedure to be followed has actually been described in the preceding example. In a siting problem, instead of having one location (such as Position A in the above example) to evaluate, there will be several locations.

For each of these locations the MAX SIL for each of the run-up and takeoff operations is determined. These values are compared in order to obtain the MAX SIL that exists at a particular location. The same procedure is repeated for each of the other locations.

Although the most acceptable location is the one with the lowest MAX SIL, there may be several acceptable sites depending on the desired criterion level. For example, if the MAX SIL's at five different locations are 70, 50, 45, 40 and 35 db, the most acceptable location is the one where the MAX SIL is 35 db. However, if the requirement for the particular building is that the MAX SIL not exceed 45 db, then three of the five locations are acceptable.

Effect of Moving a Run-Up Area. Problems may arise wherein it is desirable to determine, for one or more important communication areas, what effect moving a run-up area will have on the MAX SIL in a particular building.

The procedure for analyzing this type of problem is straightforward. The MAX SIL's inside the building in question are determined for takeoff operations and for existing run-up operations. From these MAX SIL values one can determine the actual MAX SIL inside the building. This procedure is repeated for run-up operations at the new location. The MAX SIL's for all other run-up operations and for takeoffs remain the same, of course. For this new situation, one examines the MAX SIL's from all operations to determine the actual MAX SIL in the building. If moving the run-up area has affected the MAX SIL, the results will show how much the MAX SIL has changed.

A practical problem might be one in which the MAX SIL in a particular important communication area is too high. An analysis of the "existing situation" indicates that the primary noise source is a particular run-up location. Another run-up location is available and the question is whether moving the run-ups to the new location will alleviate the situation. To answer this question one simply calculates the MAX SIL for both conditions. Comparing these values, one can readily determine if the MAX SIL will be less after the run-up area is moved, and, if so, whether it meets the criterion.

Other Problems. There are a variety of problems that can arise involving important communication areas. By means of the procedures presented in this section, one can, as discussed above, evaluate existing situations, select possible sites, assess the effect of moving a run-up area, and, in addition, assess the effect of reorientation of aircraft in a run-up area, determine the necessary wall structure for a building housing important communication areas, determine the best orientation for a building (so that the most critical spaces are located on the side of the building away from the primary noise sources), evaluate the effect of run-up noise suppressors, etc.

Summary

The basic procedure in analyzing noise problems involving important communication areas is simply one of determining the MAX SIL existing inside an existing or proposed structure as a result of all air base operations involving jet aircraft. In this process one also determines the relative contributions from each type of operation on a base, which can be evaluated separately and compared.

SECTION V

METHODS OF NOISE CONTROL AT AIR BASES

Various procedures for analyzing air base noise problems have been described in Section IV. In some types of problems the end result of the analysis was the desired answer. This is true in problems concerned with the siting of buildings, the determination of the necessary wall structure for buildings, the laying out of office spaces within a building, etc. In contrast, the analysis of other air base problems led to the conclusion that the noise exposure at a particular location was too high. For instance, the Composite Noise Rating in a proposed on-base housing site may be too high, or the MAX ANL in a particular office building may exceed the acceptable criterion level, etc. In these cases the solution to the noise problem is to reduce the noise exposure. The analysis indicates how much noise reduction is required. The next question is: how can the required reduction be achieved?

A. General Methods of Noise Control

Noise control can be effected on an air base in many different ways. One or more of the following steps may be taken:

1) Increase Distance Between Source and Receiver

   The greater the distance between a noise source and a receiver, the lower the noise levels will be at the receiver. Consequently, the distance between runways and run-up areas and on-base housing areas, office buildings, important communication areas, etc., should be as great as conditions will permit.

2) Re-orient Aircraft Run-ups

   Because of the pronounced directional characteristics of the noise field around a jet aircraft, up to 25 db noise reduction can be achieved by simply turning the aircraft. Of course, a reduction in noise level at one location will often be accompanied by an increase at another position. In such cases a compromise must be worked out.

3) Change Flight Path

   One of the few ways that the noise exposure from takeoff operations can be reduced in nearby communities is to alter the flight path of takeoffs to avoid populated areas as much as possible. The noise exposure is reduced simply because the distance between the aircraft and the community is increased.

4) Change Runway Utilization

Since the number of aircraft flying over or near a community affects the noise exposure in the community, reducing the number of takeoffs on a particular runway will serve to reduce the noise exposure.

5) Change Time Schedule of Takeoffs or Run-Ups

In regard to community noise problems, it is desirable to minimize takeoff and run-up operations during the evening and, particularly, the nighttime periods. Every effort should be made to restrict operation to the daytime insofar as possible.

6) Utilize Shielding of Intervening Buildings and Natural Terrain Features

The advantage of the shielding provided by existing buildings or natural terrain features should be utilized wherever possible, particularly in the siting of new buildings.

7) Select Effective Wall Structures for Buildings

Comparatively speaking, a proper outer wall structure is much more effective in reducing the noise level in interior spaces than the use of acoustical material (acoustical tile, etc.) on the ceiling. Cracks, poorly sealed windows, open windows, etc., tend to destroy the effectiveness of a wall. When free from small cracks or openings, heavy walls are more effective than light walls.

8) Plan Office Layout Properly

In any one building, the noise levels from external jet operations will vary from location to location. This fact can be used to advantage in locating offices with different criterion requirements in the same building.

9) Select Best Locations for Run-Ups

Run-up areas should, of course, be located as far away as possible from on-base buildings and off-base communities. In particular, they should be located farther away from these on-base areas with the more critical criterion requirements.

10) Select Best Location for Building (Siting)

By this technique the noise from all jet operations on an air base is considered, and a location can be selected where the desired criterion will be satisfied.

11) Utilize Run-up Noise Suppressors

The noise produced by an aircraft during run-up operations can be reduced by the use of run-up noise suppressors (these are discussed in more detail in Subsection B below).

The above list is not meant to be all-inclusive. There are other ways of reducing noise from air base operations. How effective are these techniques? How much good will they do? The answers to these questions depend on the noise problem. For example, altering a flight path may completely solve a problem at one air base, but may have no effect at all or may possibly create new noise problems at another base. The actual effect of any one, or any combination, of noise control measures can only be evaluated by an analysis of the problem at hand. The procedures for carrying out such analyses have been described in detail in Section IV above, and many methods of noise control have been mentioned along with means for determining their effectiveness.

The only item that has not been discussed in adequate detail is the use of run-up noise suppressors. Since noise suppressors play an important part in noise control, this subject is covered in detail below.

B. Run-up Noise Suppressors 10/

There are several different types of run-up suppressors in use today.

A complete-enclosure type of run-up suppressor is one in which the aircraft is completely housed within a structure. Primary and secondary air, as well as the exhaust gases, pass through some type of acoustical treatment. By its very nature the complete-enclosure type of run-up suppressor is the more effective type. Other types of run-up suppressors consist of separate intake and exhaust units. These units may either couple directly to the aircraft or may be located close to the intake and exhaust openings of the aircraft (loosely coupled). In some cases both intake and exhaust units are utilized; in others, only the exhaust unit is employed. Within these units is located some type of acoustical treatment or diffuser element which provide some noise reduction while permitting free passage of air.

The use of both an exhaust and intake unit is more effective than using an exhaust unit only.

For any type of noise suppressor, the amount of noise reduction that can be realized depends on the actual design of the suppressor. In addition, the noise reduction of any suppressor will vary as a function of frequency, and also as a function of angle around the aircraft. The specification of the acoustical requirements of a noise suppressor should include values of noise reduction as a function of frequency (usually octave bands of frequency are adequate) and the angular region in which these noise reduction values should be met.

From the procedures described in Section IV, one can easily determine the angular region of importance. However, the procedures do not permit the determination of noise reduction requirements of a run-up suppressor as a function of frequency. They do provide the required reduction in terms of the AVG ANL reduction, MAX ANL reduction, or MAX SIL reduction, depending on the type of problem. For practical reasons it is important to know how to convert these requirements into the noise reduction in decibels in each of the octave bands.

The manner in which this conversion is performed is as follows:

AVG ANL Reduction

To convert a desired AVG ANL reduction in db to the desired noise reduction in octave bands for a run-up noise suppressor, apply the corrections given in Table XVII on page 119 (corrections are given for all octave bands except the 4800-10,000 cps band, which is generally unimportant). There are four sets of correction numbers given. These apply for two distance conditions: less than 1500 ft, and greater than 1500 ft, and for two angular ranges: 0^{o} - 125^{o}, and 125^{o} - 180^{o}. The angle is measured from the forward end of the aircraft.

EXAMPLE

An analysis indicates that the AVG ANL in an off-base community should be reduced by 15 db. This reduction will be completely realized by reducing the noise from the run-up operation. Further, the community is located at an angle of approximately 120^{o} from the forward end of the aircraft in the run-up area, and at a distance of about 3,000 ft. For these conditions, the noise reduction requirements of the run-up noise suppressor are listed below:

TABLE XVII

CORRECTIONS IN DB TO BE APPLIED TO THE AVERAGE ANL REDUCTION TO OBTAIN THE NOISE REDUCTION IN OCTAVE BANDS FOR A RUN-UP NOISE SUPPRESSOR

OCTAVE BAND cps	CORRECTIONS IN DB — Distance Between Run-Ups and Housing Area: Less than 1500 ft — Angle 0°-125°	Less than 1500 ft — Angle 125°-180°	Greater than 1500 ft — Angle 0°-125°	Greater than 1500 ft — Angle 125°-180°
20-75	-30	-25	-20	-20
75-150	-15	-10	-10	-10
150-300	- 5	0	0	0
300-600	0	0	0	0
600-1200	0	- 5	0	- 5
1200-2400	0	- 5	0	-10
2400-4800	0	-10	-10	-20
4800-10,000	-	-	-	-

OCTAVE BANDS cps	NOISE REDUCTION db
20-75	0*
75-150	5
150-300	15
300-600	15
600-1200	15
1200-2400	15
2400-4800	5
4800-10,000	-

MAX ANL Reduction

In a manner similar to that described above, corrections are applied to the MAX ANL reduction in db to obtain the noise reduction in db in each of the eight octave bands for a run-up noise suppressor. These octave band corrections are given in Table XVIII on page 122. Four sets of numbers are presented, corresponding to distances greater than or less than 1500 ft, and to the angular ranges of 0° to 125°, and 125° to 180°.

EXAMPLE

As an example, suppose that the desired reduction in MAX ANL for a building located 1200 ft away from a run-up area is 25 db. If the building is located approximately 150° from the forward end of the aircraft in the run-up area, the noise reduction requirements for the suppressor are:

OCTAVE BANDS cps	NOISE REDUCTION db
20-75	10
75-150	15
150-300	25
300-600	25
600-1200	15
1200-2400	15
2400-4800	10
4800-10,000	--

*The correction of -20 db applied to the AVG ANL reduction of 15 db results in a total NR required of -5 db. NR is never less than 0 db. Therefore, a value of 0 db is noted, meaning that there is no noise reduction required in the 20-75 cps band.

MAX SIL Reduction

In important communication areas, generally speaking, only the SIL is important. In other words, only the noise levels in the 600-1200, 1200-2400, and 2400-4800 cps octave bands must be considered. Therefore, only the noise reduction in those bands must be considered for a run-up noise suppressor. These noise reduction values are equal to the MAX SIL reduction required in db. For example, if the analysis of a problem involving an important communication area shows that the MAX SIL must be reduced by 20 db, a run-up suppressor which will satisfy this requirement must provide 20 db of noise reduction in the above three octave bands. The amount of reduction in the other octave bands is unimportant.

TABLE XVIII

CORRECTIONS IN DB TO BE APPLIED TO THE MAX ANL REDUCTION TO OBTAIN THE NOISE REDUCTION IN OCTAVE BANDS FOR A RUN-UP NOISE SUPPRESSOR

OCTAVE BAND cps	CORRECTIONS IN DB			
	Distance Between Run-Ups and Building(s)			
	Less than 1500 ft		Greater than 1500 ft	
	Angle		Angle	
	$0^{\circ}-125^{\circ}$	$125^{\circ}-180^{\circ}$	$0^{\circ}-125^{\circ}$	$125^{\circ}-180^{\circ}$
20-75	-10	-15	-15	-10
75-150	- 5	-10	-10	- 5
150-300	0	0	0	0
300-600	0	0	0	0
600-1200	- 5	-10	- 5	-10
1200-2400	- 5	-10	- 5	-15
2400-4800	-10	-15	- 5	-25
4800-10,000	-	-	-	-

SECTION VI

EXAMPLE OF ANALYSIS OF SEVERAL CONCURRENT NOISE PROBLEMS AT AN AIR BASE

Although previous sections have presented several detailed examples worked out through use of the various engineering procedures, these examples have usually dealt with one problem at a time. In practice there may be several noise problems on an air base requiring attention at the same time. Such problems may be interrelated in the sense that the analysis of one noise problem may not be complete until others have been studied also. The "obvious" solution to one problem may not be so obvious when viewed in the light of possible solutions to other air base noise problems.

It is the object of this Section to discuss and analyze several different hypothetical noise problems existing at one air base. Each problem will be treated separately at first, and then, where appropriate, the results of the analyses of some of the problems will be studied and compared to point up their interrelation and to suggest a means for arriving at a single practical and economical solution applicable to each of them.

A. Statement of Problem

1. Off-Base Communities. Several communities surround Valley Air Force Base (see Fig 31). Some of them, Stickney in particular, have voiced some complaints about jet activity from the base, although there has been no evidence of any concerted group action. However, there is an undercurrent of apprehension among the people in these communities because they have heard many rumors to the effect that the base is going to get more advanced fighters in the near future and these fighters make "a lot more noise" than the aircraft currently operating from the base. Also it is no secret, since it is under construction now, that a new runway "over two miles long" will be opened at the base soon and people are not quite sure how the use of this new runway will affect the amount of noise they hear.

2. Control Tower. On the base the control tower operators complain that from time to time they lose part of a message because of noise from jet aircraft in the maintenance run-up area. Aware of the newer, more powerful aircraft that will soon be on the base permanently, they have requested that something be done to control jet noise in their area.

3. Hangar "A" Offices. Strong complaints are also coming from the personnel who work in the offices on the east side of

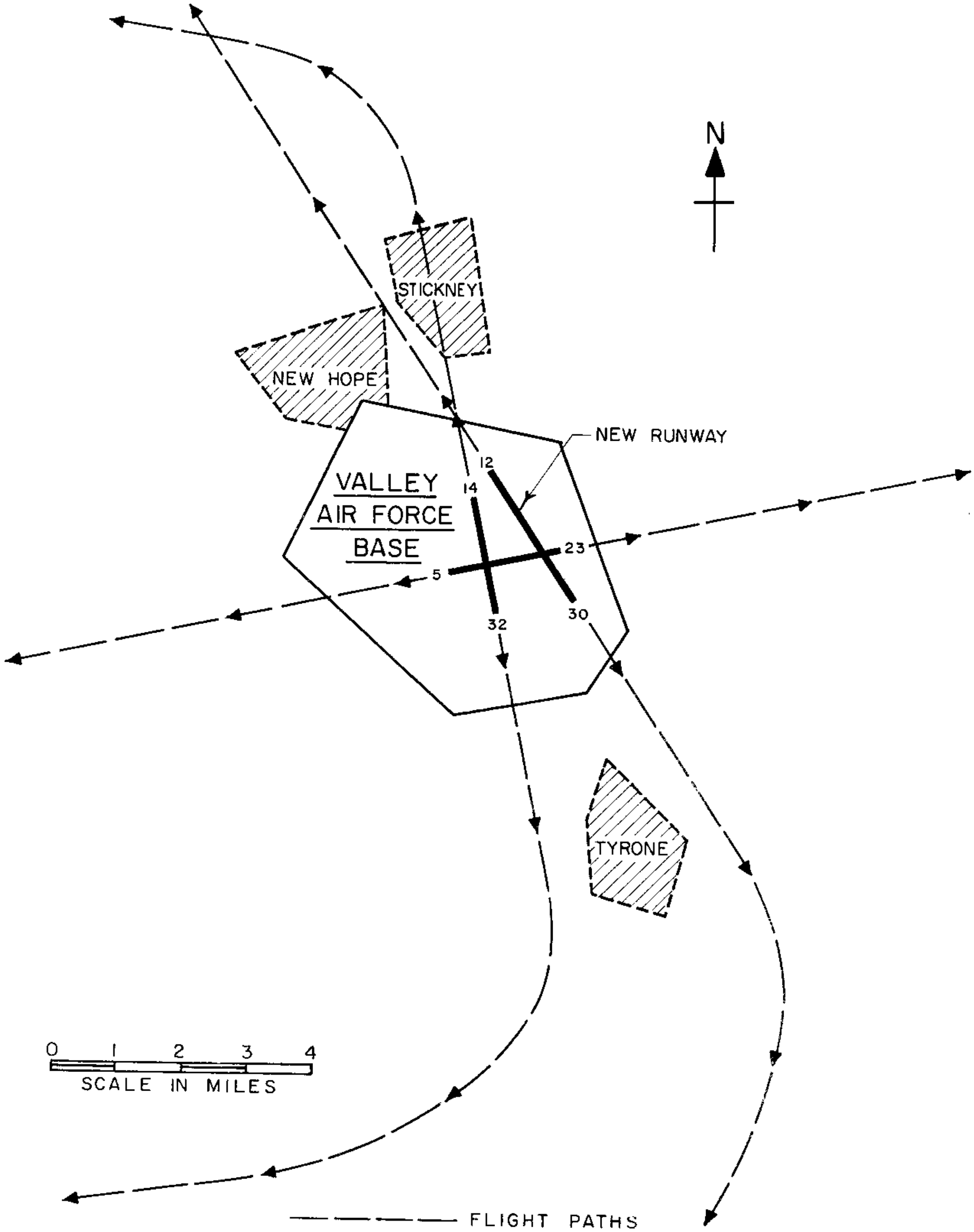


FIG. 31 VALLEY AIR FORCE BASE SHOWING SURROUNDING COMMUNITIES AND FLIGHT PATHS.

Hangar "A". They say that when aircraft are being tested in the run-up area they have a great deal of difficulty carrying on conferences and talking on the telephone, particularly during the summertime. If conferencing is required during run-ups, no more than three or four men can confer at a time and they have to crowd together around a desk or table to be understood.

4. Siting Office Buildings. A new building housing engineering and secretarial personnel is to be built on the base. It is to be of ordinary wood frame construction with operable sash windows. There are two possible sites, Site 1 and Site 2 as shown in Fig 32. Installations personnel would very much prefer Site 1, however there is some doubt as to the advisability of siting the building there because of possible interferences from noise from the run-up area. Consequently, it has been tentatively decided to use Site 2.

5. Proposed On-Base Housing. Finally, plans are underway to satisfy an urgent need for more family housing for base personnel. Details pertaining to the amount and type of housing have been worked out and only the final selection of a site remains. On the base proper only one location is available that would be satisfactory -- except that there is some doubt regarding the noise exposure in this area from the air base operations. In particular, there is concern over the effect of the newer aircraft that will probably arrive on the base before the housing project is completed.

B. Operational Information

At present Valley AFB uses Runways 5-23 and 14-32. Runway 12-30 is under construction and as soon as it is completed, Runway 14-32 will be closed. Present and estimated future takeoff activity at the base is as follows:

Type of Aircraft	Takeoffs per Hour				Flight Profile
	Present		"Future"		
	0600-1800	1800-2300	0600-1800	1800-2300	
B57	0.5	-	-	-	2
T33	0.8	-	1	-	2
F89(A/B)	0.3	0.2	0.5	-	2
F84F	0.3	-	2	-	2
F86D(A/B)	0.2	-	-	-	2
F100(A/B)	-	-	1	-	2
F102 (A/B)	-	-	.7	.2	2

Negligible activity occurs during the nighttime period, 2300-0600.

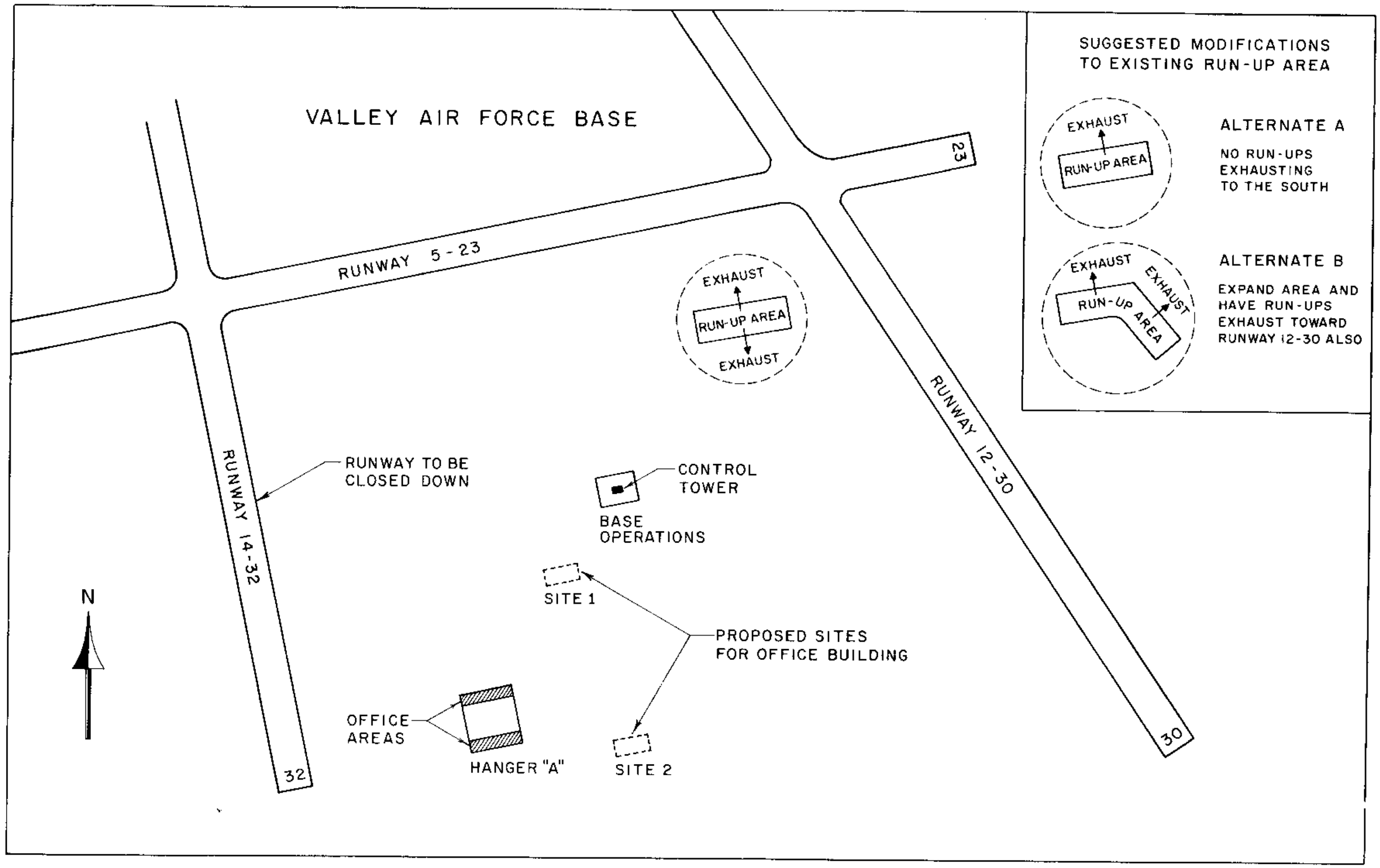


FIG. 32 VALLEY AIR FORCE BASE SHOWING LOCATION OF RUN-UP AREA AND SEVERAL BUILDINGS CONSIDERED IN EXAMPLE IN TEXT.

The flight paths for the various runways are shown in Fig 31, and runway utilization is as follows:

Runway	% Utilization	
	Present	Future
14	30	-
32	45	-
5	10	12
23	15	1
12	-	80
30	-	7

The aircraft run-up area is located as shown in Fig 32 on page 126. Aircraft can be run-up with two angular orientations, as indicated by the arrows (showing direction of the exhaust) in Fig 32. Run-ups occur only during the daytime period, 0600-1800. The operational data are as follows:

	Type of Aircraft	Av. No. of Run-ups/Hr.	Average No. of Minutes/Run-up			
			A/B	96%-100%	88%-96%	80%-88%
PRESENT	F89D	1/2	1/2	3	8	15
	F84F	1	-	2	5	20
	F86D	1	1/2	3	-	15
FUTURE	F102	1/2	1/2	3	-	10
	F100	1/2	1/2	3	-	10
	F84F	2	-	5	10	20

C. Analysis

Each of the problems indicated above will be analyzed one at a time. Where appropriate the results of the separate analyses will be compared and, as required, certain problems will be re-studied.

1. Control Tower. Since complaints are being made about the present noise conditions in the tower, this analysis begins by evaluating the present situation. Following that the effect of the "future" operations will be assessed.

The structure of the present tower affords an SIL reduction of about 35 db (see Table XVI on page 104). Discussion of communication conditions with tower personnel and observations of the radio reception in the tower indicates that a suitable criterion for the control tower is an SIL equal to 45 db.

The operational data for run-ups are examined and it is found that highest relative noise output of aircraft at present is +5 db. When this correction is applied to the run-up contours of Fig 4 and they are overlaid on a map of the air base, one finds that the MAX ANL outside the tower (occurring for run-ups whose exhaust points south) is 100 db. For the distance (about 1300 ft) and angle (about 140°) in question, the SIL is found (from Fig 28 on page 103) to be 15 db less than the ANL, or the MAX SIL outside is 85 db.

The MAX SIL inside equals 85 minus 35 or 50 db. Since the desired MAX SIL is 45 db, the criterion is exceeded by 5 db at present which is consistent with the subjective reaction of the tower personnel. (MAX SIL's outside produced by takeoff operations are found not to exceed 80 db, so takeoffs do not influence the MAX SIL in this problem.) For future run-up operations, the highest relative noise output becomes +10 db. Since no other changes take place except the change in relative noise output from +5 to +10 db, the MAX SIL inside the tower will be 10 db too high.

One possible solution to this problem, and one that has been put forth by tower personnel, is to construct a new control tower. Evidently they have put in a request for one some time ago, but funds have not been available. If a new tower is built, the above analysis states that its outer wall structure should have an SIL reduction equal to or greater than 45 db. Reference is made to Table XVI on page 104 for the type of structure that will satisfy this requirement.

2. Hangar "A" Offices. Again the basic approach is to evaluate the existing situation and then assess the effect of future aircraft. First, the MAX ANL outside the office area of Hangar "A" arising from present run-up operations is calculated. The run-up contours of Fig 4 are suitably corrected for the highest relative noise output (+5 db). They are then overlaid on the map of the air base, and it is found that the MAX ANL outside the offices is 90 db for aircraft tailed south, and 70 to 75 db for those whose exhaust points north.

To calculate the MAX ANL inside one must account for the ANL reduction of the hangar structure. A section through a typical hangar structure is shown in the lower right corner of Table XIII on page 75, and it is seen that the weight of such a wall is about 6 lbs/ft^2. With all windows closed the ANL reduction would be about 25 db. However, the complaints occur mostly during warm weather, so it is reasonable to assume that some of the windows in the offices are open during the day. From discussions with the office personnel it is learned that they do keep most of the windows open. This condition indicates an ANL reduction of about only 10 db.

Assuming this value, one finds that the MAX ANL inside is 80 db. Further study of the run-up operational data reveals that noise from run-ups is at, or within 10 db of this value for about 16 minutes per hour. For this duration, and for the desired criterion value -- for the type of activity in this office area, about NC-50 -- it is seen from Table XII on page 68 that the allowable MAX ANL is (by interpolation between values) 65 db. Therefore, the result of this analysis is that the MAX ANL's from present run-up operations are too high by 15 db.

For future operations, the highest relative noise output increases from +5 to +10 db, so that the MAX ANL outside the office area becomes 95 db. From a study of the operational data one finds that the noise from run-ups is within 10 db of this value for about 13 minutes per hour. The allowable MAX ANL from Table XII is, therefore, still 65 db. The MAX ANL inside will be 95 minus 10 or 85 db, which will be 20 db too high.

For takeoff operations the highest exposure is, at present, from takeoffs on Runway 14-32. The MAX ANL outside is 95 db, corresponding to 85 db inside with open windows. For less than three takeoffs an hour the allowable MAX ANL for an NC-50 criterion is 75 to 80 db. Therefore the noise from takeoffs is too high also, but comparatively less of a problem than the run-ups which confirms the reactions of the office personnel. In the future Runway 14-32 will be closed down and the noise exposure from takeoffs will arise from operations on Runway 5-23 and 12-30. For these future operations the MAX ANL's inside Hangar "A" offices will not exceed 80 db which just satisfies the criterion.

The results of the analysis of this particular problem are that the noise from run-up operations is the controlling factor producing MAX ANL's that are 15 db too high.

In the future the noise levels will rise by 5 db and the MAX ANL's will be 20 db too high. With closed windows (ANL reduction equal to 25 db), the criterion will be exceeded by 5 db now, and will be exceeded for "future" operations by 10 db.

3. Siting Office Building. In analyzing this particular problem only future operations need be considered. The approach is simply to determine the MAX ANL that will exist inside each structure and then, considering the duration of run-up operations, find from Table XII on page 68 whether or not the desired criterion is satisfied.

Using the same corrected ANL run-up contours employed in the Hangar "A" discussion above, one finds that the MAX ANL outside at Site 1 is 100 db, and at Site 2, 95 db. (These MAX ANL values result from run-ups whose exhaust is pointed south; the other run-ups will produce lower noise levels.) For the proposed structure, the ANL reduction (with the windows closed) is equal to 25 db. Therefore, the MAX ANL's inside are 75 db and 70 db, respectively.

The number of minutes that the noise from run-ups is within 10 db of the highest value is, for future operations, the same as in the above example, 13 minutes per hour. So, for this duration, and for an NC-50 criterion, the MAX ANL's can be allowed to go as high as 65 db. Therefore, at Site 1 the levels are exceeded by 10 db, and at Site 2 by 5 db.

For takeoff operations, since there are to be less than 3 takeoffs per hour of the noisiest aircraft, the allowable MAX ANL to satisfy an NC-50 criterion lies between 75 and 80 db (from Table XII). The MAX ANL from takeoffs will not exceed 70 db inside the structures at either site, so takeoffs pose no problem.

The conclusion is that neither one of these sites is really acceptable for the construction of the proposed frame building. The NC-50 criterion will be exceeded at either site because of noise from run-up operations, and by even more than 5 db and 10 db in the warm weather when windows are open. Everything else remaining the same, either the type of structure must be changed, or a new site must be considered.

4. Restudy of Problems. Clearly, in each of the above three noise problems, the noise from the run-up operations whose exhaust points south is the important contributing factor. Run-up noise suppressors furnishing

the proper amount of noise reduction would solve all of these problems. Several might be needed and the total cost would probably run into several hundred thousand dollars. This expense should be compared with what it might cost to build an adequate control tower, improve conditions in Hangar "A", and build a new office building with the required wall structure.

Another much more economical possibility is to modify the operations in the run-up area or to relocate some or all of the run-ups. The same general area could be utilized, but instead of lining up the aircraft roughly parallel to Runway 5-23 as they are now, they could be arranged along a line that parallels Runway 12-30, as indicated by Alternate A in Fig 32. In this way, advantage is taken of the directional characteristics of the jet noise field. For the new location, all buildings, either existing or proposed, lie forward of the aircraft in the run-up area. At present, because of the nose-to-nose arrangement of the aircraft, the buildings are always in a position aft of the aircraft, where the noise levels are the highest.

Another possibility is shown by Alternate B in Fig 32. As above, all aircraft would be exhausting away from the building area. (Blast fences could be employed to keep the runways clear, if necessary.)

Assuming Alternate A as a possibility, the analysis of the above three problems is repeated with the following results:

In the case of the <u>control tower</u>, the MAX ANL outside becomes 80 to 85 db. At an angle of 40° and a distance of 1300 ft, the ANL-to-SIL correction is -5 db, so the MAX SIL outside is 75 to 80 db. Inside, the MAX SIL is 35 db less, or 40 to 45 db, which just satisfies the criterion.

At <u>Hangar "A"</u> the MAX ANL outside becomes 70 to 75 db for present operations, and 75 to 80 db for future operations. For an ANL reduction of 10 db, the MAX ANL inside becomes 60 to 65 db at "present", and 65 to 70 db for "future" operations. Since the allowable MAX ANL is 65 db, the conditions at "present" would be satisfactory. For future operations the criterion is just marginally satisfied during the warm weather. With windows closed there would be no problem at all.

In restudying the problem of <u>siting the office building</u> one calculates the MAX ANL's at Sites 1 and 2 for the new run-up area and finds them to be 85 to 90 db and

80 to 85 db, respectively. Inside the proposed frame structure (assuming windows closed and an ANL reduction of 25 db) the MAX ANL's are 60 to 65 db and 55 to 60 db, respectively. Therefore, both Site 1 and Site 2 are acceptable since the allowable MAX ANL is 65 db.

For these particular on-base noise problems at Valley Air Force Base, relocating the run-up area would be a very satisfactory solution. However, as mentioned above, run-up noise suppressors would also solve the problems. At this point the question of economics arises, as it should in the analysis of most air base noise problems. Which of these solutions is the least expensive? Although several solutions to a particular noise problem may present themselves, they should each be evaluated in terms of their cost. If two solutions are equally satisfactory, then the less expensive one is the most acceptable. It is not the immediate expense that is important, of course, but the long-term cost.

For instance, suppose in the above problem that it had been found that the only solution, aside from the use of noise suppressors, was to move the run-up area across Runway 12-30, which is, of course, an active runway. In this instance, the long-term cost of such a move includes not only the initial expense of constructing a new run-up area, but the additional day-to-day expense in man-hours, etc., incurred in moving aircraft (and engines) to and from the new area. This expense should be compared with the total initial cost of the run-up suppressors plus the necessary future maintenance and replacement costs of these units. Further, one should consider the problems of crossing an active runway several times a day, ease of accessibility to the suppressors (coupling and decoupling time), etc. All of these factors are important in selecting the proper solution to a noise problem.

5. Off-Base Communities. Since there are several communities around Valley Air Force Base, an evaluation of the existing and "future" noise conditions can best be performed by constructing AVG ANL contours for the area surrounding the base for both conditions. These contours can then be compared to determine the change due to the introduction of the new aircraft, as well as the opening of Runway 12-30 and the closing of Runway 14-32.

First, the critical time period is determined. From the takeoff operational data on page 125, and from Table I on page 14, the equivalent number of takeoffs per hour of Group I aircraft is as follows:

Time Period	Equiv. No. of Takeoffs per Hr. of Group I Aircraft
Present	
0600-1800	4.1
1800-2300	0.6
Future	
0600-1800	21.5
1800-2300	2

For both present and future operations the takeoff activity is more than three times as great between 0600-1800 than in the 1800-2300 time period. The daytime period is the critical time period.

From the runway utilization data, and the data tabulated above, the equivalent number of takeoffs per hour of Group I aricraft on each of the runways has been calculated for the daytime period and listed below:

Runway	Equiv. Group I Takeoffs per Hour	
	Present	Future
14	1.2 (0 db)*	-
32	1.8 (0 db)	-
5	0.4 (-5 db)	2.6 (+5 db)
23	0.6 (-5 db)	0.2 (-5 db)
12	-	17.2 (+10 db)
30	-	1.5 (0 db)

* Figures in parentheses are corrections in db from Table IX on page 47 to be applied to AVG ANL takeoff contours of Fig 10B.

The corresponding corrections in db (also listed in the table above) are applied to the AVG ANL takeoff contours of Fig 10B (for Flight Profile No. 2). These corrected contours are overlaid on a map of the air base and

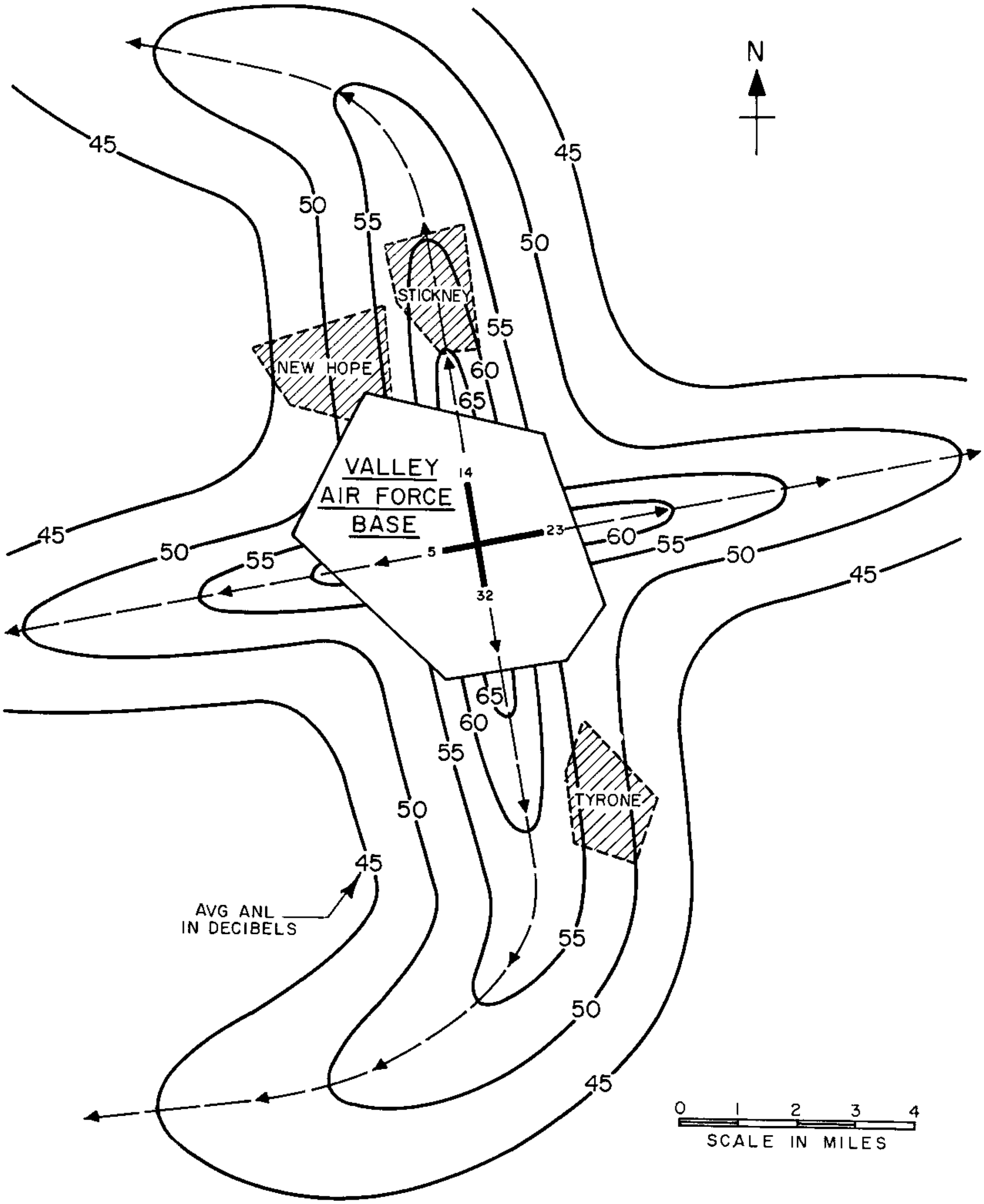


FIG. 33 AVERAGE ANL CONTOURS FOR "PRESENT" TAKEOFF OPERATIONS AT VALLEY AIR FORCE BASE.

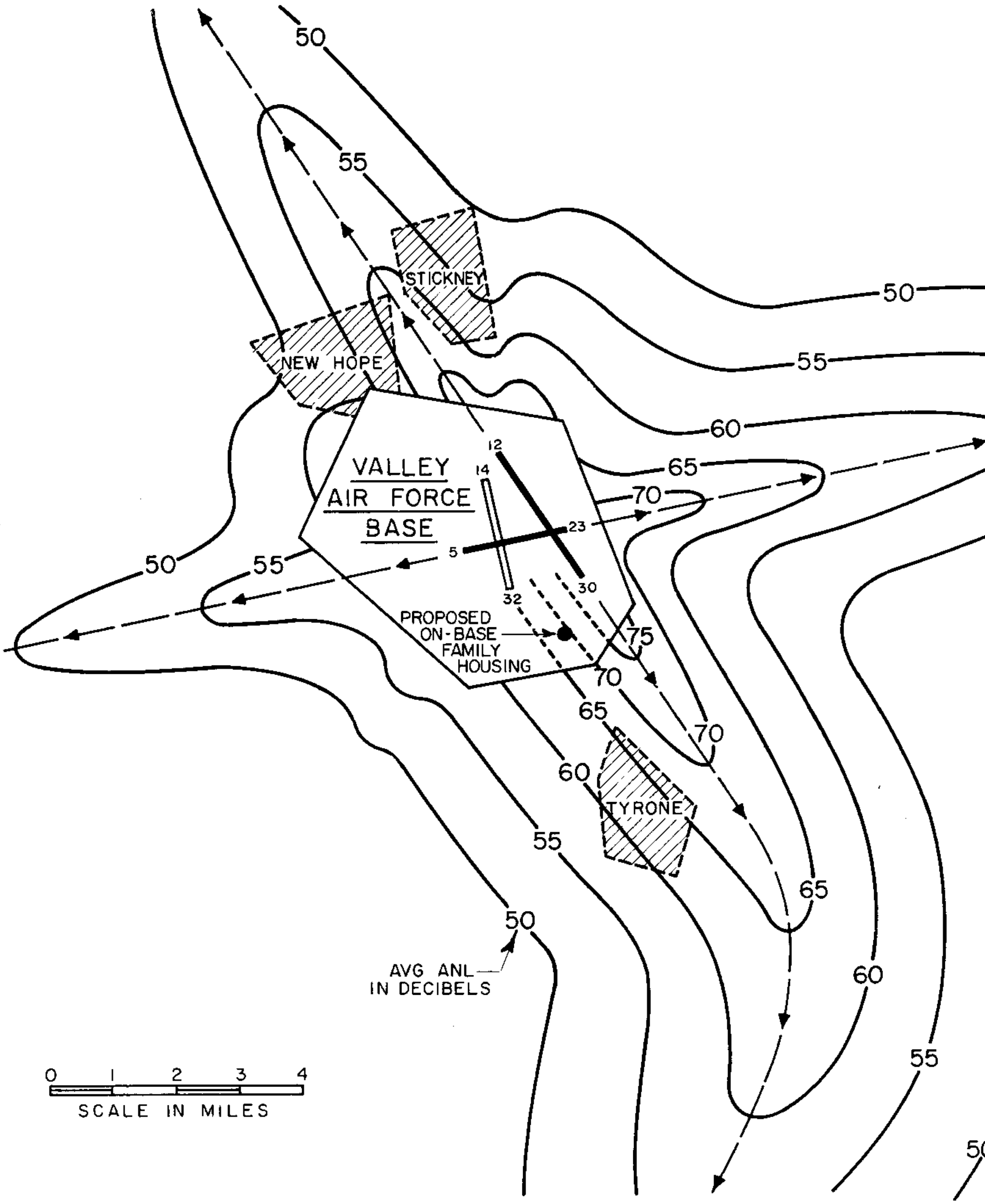


FIG. 34 AVERAGE ANL CONTOURS FOR "FUTURE" TAKEOFF OPERATIONS AT VALLEY AIR FORCE BASE.

combined. The resulting composite contours for present and future operations are given in Figs 33 and 34, respectively.

These contours present a complete picture of the noise in surrounding communities arising from jet takeoff operations at Valley Air Force Base. (Run-up operations, although they have been considered, have not been included since they would only affect the noise contours to the east of the base where there are no communities.) A study of the "present" contours shows that the AVG ANL's in the three communities adjacent to the base are as given below:

Community	Average ANL - db	
	Present	Future
Tyrone	50-55	60-65
Stickney	60-65	50-60
New Hope	45-55	50-60

If one assumes that the corrections to apply to the AVG ANL to obtain the CNR are the same as those suggested in Section IV (page 42), then the AVG ANL that should not be exceeded in a community (for daytime operations) is 60 db. This condition is met in both Tyrone and New Hope, but there are some parts of Stickney where this AVG ANL is exceeded. This result explains the complaint activity in this area.

For future operations the AVG ANL's are as given in the last column of the above table. In Stickney the exposure will decrease to an acceptable value of less than 60 db, in spite of the increased activity and newer aircraft. The reason for the exposure decreasing is primarily the change in flight path in that area occasioned by the closing down of Runway 14-32, and the opening of Runway 12-30. For these same reasons the noise exposure in Tyrone will increase, and the expected AVG ANL is about 60 to 65 db, which indicates that complaints can be expected from that area. The AVG ANL in New Hope will also increase, but the expected value is between 50 and 60 db, which is still acceptable.

In summary, the present unacceptable conditions in Stickney will be alleviated by the closing down of Runway 14-32 and the opening of Runway 12-30. For both present and future operations, the noise exposure in New Hope falls below the criterion value. In Tyrone, however, the conditions will very likely be unacceptable for "future" operations. A close study of the contours reveals that the noise exposure in Tyrone will be caused by takeoffs on Runway 12. One way to alleviate this condition is to reduce the very high percentage utilization on Runway 12, if possible.

6. Proposed On-Base Housing. The proposed site for the on-base family housing area is shown in Fig 34. One readily notes from the contours that the AVG ANL resulting from future air base operations will be about 70 db at this site. Again assuming the same corrections as before for background noise, previous exposure, etc., the acceptable AVG ANL is 60 db. This value will be exceeded by 10 db which, from a noise exposure point of view, renders the site unacceptable.

In this section several noise problems at one air base have been studied and analyzed, and solutions have been suggested. It has been shown that air base noise problems are sometimes interrelated, and that one must study the total noise situation at a base, rather than confine the analysis to one isolated problem. A solution to one problem (for example, rebuilding a control tower) may be rendered unnecessary in the light of measures that are taken to solve another problem (utilizing noise suppressors, for instance). Further, once the noise analysis has been completed, one must also consider other factors, such as the relative practicality of various solutions, the economics of the situation, etc., before deciding on a solution.

SECTION VII

MASTER PLANNING OF NEW AIR BASES

Nearly all air base noise problems can be avoided through careful planning before work is started on the actual construction of the new base. Air base noise problems are generally the result of poor planning of base layout, inadequate building construction, undesirable base location, or of failure to foresee and allow for more powerful aircraft and resulting jet noise. The foregoing Sections of the Guide have presented data and engineering procedures relative to noise control. This material is equally applicable to considerations of possible noise problems and their avoidance when planning new bases. Clearly the most economical method of handling noise problems on new bases is to recognize the continual possibilities of such problems and, through a thorough acquaintance with the nature of aircraft noise and its control, to analyze and solve such problems before they occur.

Air base planning to avoid noise problems may be divided into two categories: 1) base layout (noise control on the base), and, 2) base location and orientation (noise control outside of the base). With the base requirements and uses in mind (number, length, and orientation of runways, quantity and type of aircraft, number of run-up areas, etc.), the problem may be attacked either by first locating noise sources and then planning the base according to acoustical criteria, or by laying out the base and then determining how much the initial plan must be altered in order to avoid on- and off-base noise problems. The most practical approach is usually a combination of these two methods.

Section VI of the Guide has presented an analysis of the sort of future situation planning that must be undertaken in order to successfully minimize or eliminate noise problems before they occur on a new air base. Of course, the data available will be "programmed" or estimated operational data rather than actual data, and therefore the results will be best estimates. Nevertheless, such procedures will give a generally good picture of the total noise situation to be expected, and the base planners will have at their disposal useful data which will prevent expensive and time consuming modifications after the base is in operation.

On-Base Planning. Figures 31 through 34 in Section VI illustrate the various paper analyses used to determine the noise situation on an air base. Review of these diagrams and their accompanying text will provide the planner with methods for determining noise conditions on new bases. Layout of work and office areas, vital communication centers, base housing, hospitals, etc. are thoroughly discussed in Sections IV and VI for existing and hypothetical bases, and the engineering procedures described are easily applicable to new bases.

Base Location (Off-base or community noise problems). While aircraft run-ups must, of course, be considered, generally community noise problems will be determined by takeoffs and flight patterns around the base. Consideration of noise contours around proposed runways, flight paths and profiles, types of aircraft to be handled, runway utilization, etc. will give a total picture of the effect of flight operations on surrounding areas. The base planners can utilize this information together with data pertaining to land areas required, local zoning ordinances, existing suburban developments, etc. to locate the base so as to best avoid future problems with nearby communities.

Summary

The principles and engineering procedures for noise control presented in the Guide should be carefully studied before attempting to plan a new air base. A thorough knowledge of the material presented in the foregoing sections will enable air base planners to avoid noise problems on new bases by extending the procedures of noise control both on and off base to the layout and planning of the new base.

REFERENCES

1. Hazardous Noise Exposure, Air Force Regulation No. 163-3, 29 October 1956.

2. Eldred, K.M., W.J. Gannon, H.E. von Gierke, Criteria for Short Time Exposure of Personnel to High Intensity Jet Aircraft Noise, WADC Technical Note 55-355, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, September 1955.

3. Clark, W.E., A.C. Pietrasanta, W.J. Galloway, and the Staff of Bolt Beranek and Newman Inc., Noise Produced by Aircraft During Ground Run-up Operations, WADC Technical Note 56-60, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, June 1957.

4. Eldred, K.M., and D.T. Kyrazis, Noise Characteristics of Air Force Turbojet Aircraft, WADC Technical Note 56-280, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1956.

5. von Gierke, H.E., and A.C. Pietrasanta, Acoustical Criteria for Work Spaces, Living Quarters, and Other Areas on Air Bases, WADC Technical Note 57-248, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, November 1957.

6. Stevens, K.N., A.C. Pietrasanta, and the Staff of Bolt Beranek and Newman Inc., Procedures for Estimating Noise Exposure and Resulting Community Reaction from Air Base Operations, WADC Technical Note 57-10, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, April 1957.

7. Beranek, L.L., "Revised Criteria for Noise in Buildings," Noise Control, Vol 3, No 1, pp 19-27, January 1957.

8. Beranek, L.L., and the Staff of Bolt Beranek and Newman Inc., Office Noise Studies at Hill Air Force Base, WADC Technical Note 56-58, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, August 1956.

9. Beranek, L.L., Acoustics, McGraw-Hill Book Company, Inc., N.Y., N.Y., 1954.

10. Doelling, N., R.H. Bolt, and the Staff of Bolt Beranek and Newman Inc., Noise Control for Aircraft Engine Test Cell and Ground Run-up Suppressors, Vol. 2 - Design and Planning for Noise Control, WADC 58-202 (2), Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, November 1961.

11. Pietrasanta, A.C., "Aircraft Noise and Building Design," Noise Control, Vol 3, No 2, pp 11-18, March 1957.

REFERENCES (CONT'D)

12. Nyborg, W.L., and D. Mintzer, Review of Sound Propagation in the Lower Atmosphere, WADC Technical Report 54-602, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1954.

13. Stevens, K.N., W.A. Rosenblith, and R.N. Bolt, "A Community's Reaction to Noise; Can it be Forecast?" Noise Control, Vol 1, No 1, pp 63-71, January 1955.

SUGGESTED ADDITIONAL READINGS

General

1. Harris, C. M.(Editor), Handbook of Noise Control, McGraw-Hill Book Company, Inc., 1957.

   Chapter 33. "Aircraft Noise Sources" by von Gierke, H.E., Aero Medical Laboratory, WADC.

   Chapter 34. "Aircraft Noise Control" by von Gierke, H.E., Aero Medical Laboratory, WADC.

   Chapter 35. "Community Noise and City Planning" by Stevens, K.N., MIT, and Baruch, J.J., Bolt Beranek and Newman Inc.

   Chapter 36. "Community Reaction to Noise" by Parrack, H.O., Wright Air Development Center.

   Chapter 37. "Legal Aspects of the Aircraft Noise Problem" by Lucey, K.J., Attorney, New York Telephone Co.

2. Noise Guide for Air Base Commanders, Air Force Pamphlet No. 32-2-1, 15 July 1957.

3. Doelling, N., R.H. Bolt, and the Staff of Bolt Beranek and Newman Inc., Noise Control for Aircraft Test Cells and Ground Runup Suppressors, Vol 1, - Measurement and Analysis of Acoustical Performance, Vol 2 - Design and Planning for Noise Control, Vol 3 - An Engineering Analysis of Measurement Procedures and of Design Data, WADC Technical Report 58-202, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

Noise Suppressors

1. Doelling N., and the Staff of Bolt Beranek and Newman Inc., An Acoustical Evaluation of Two Durastack Ground Run-up Noise Suppressors, WADC Technical Note 57-392, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, November 1961.

SUGGESTED ADDITIONAL READINGS (CONT'D)

Noise Suppressors(cont'd)

2. Hoover, R.M., and the Staff of Bolt Beranek and Newman Inc., Acoustical Evaluation of General Sound Control Model N-400 Jet Aircraft Noise Suppressor, WADC Technical Note 57-391, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, April 1958.

3. Doelling, N., K.S. Pearsons, and the Staff of Bolt Beranek and Newman Inc., Acoustical Evaluation of a B-58 Run-up Pen at Convair-Fort Worth, WADC Technical Note 57-389, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, October 1958.

4. Keast, D.N., and the Staff of Bolt Beranek and Newman Inc., Acoustical Evaluation of F-102 Production Silencer, Convair, San Diego, WADC Technical Note 57-390, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, November 1961.

5. Hoeft, L.O., Acoustical Evaluation of the F4D Noise Suppression Run-up Hangar at Douglas, El Segundo, WADC Technical Note 58-112, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, September 1958.

APPENDIX A

PROCEDURES FOR ESTIMATING NOISE LEVELS AROUND JET AIRCRAFT DURING STATIC OPERATION 3,6,11/

This Appendix describes engineering procedures for estimating noise levels around jet aircraft during static operation. By means of the information in Tables I and II on pages 14 and 15, and Figures A-1, A-2 and A-3, one can estimate the sound pressure level (SPL) as a function of octave bands of frequency and angular location around the aircraft at distances beyond 100 feet from the aircraft. This procedure applies for engine operation from 70% rpm up through afterburner operation.

The first step in the procedure is to determine the acoustic power level (PWL) in db re 10^{-13} watt. For military power and afterburner operation of all operational USAF aircraft and turbo-jet engines, the PWL to the nearest 5 db can be obtained from the data in Table I on page 14 by noting that all Group I aircraft have a PWL of 170 db re 10^{-13} watt. The PWL of Group II aircraft and engines is 5 db greater, or 175 db, etc. For operation of aircraft or engines between 80% rpm and military power, the appropriate correction to the PWL at military operation is given in Table II on page 15. By use of these tables one finds, for example, that a B-58 operating with all engines at military power has a PWL of 180 db re 10^{-13} watt. If all engines on the B-58 were operating at 90% rpm, the PWL would be equal to 180 minus 5 db, or 175 db re 10^{-13} watt.

The next step in the procedure is to convert the PWL to the overall (OA) space average SPL* at 100 ft by use of the following expression:

$$\text{Space Average OA SPL}_{100} = \text{PWL} - 48 \text{ db}$$

Knowing the space average OA SPL, one can then find the OA SPL at any angle around the aircraft from Fig A-1. To find the octave band SPL at that angle, one selects the appropriate curve in Fig A-2 and reads from the graph the value by which the OA SPL should be reduced to give the octave band SPL at 100 ft.

For example, the SPL in the 1200-2400 cps octave band at 100 ft and 140° for an aircraft with a PWL of 170 db is 113 db, as calculated below:

Space Average OA SPL	= 170 - 48 = 122 db
OA SPL at 140°	= 122 + 7 = 129 db
SPL in 1200-2400 cps band	= 129 - 16 = 113 db

* The space average SPL is equal to the SPL that would be measured at a fixed distance from a non-directive source radiating the same acoustic power.

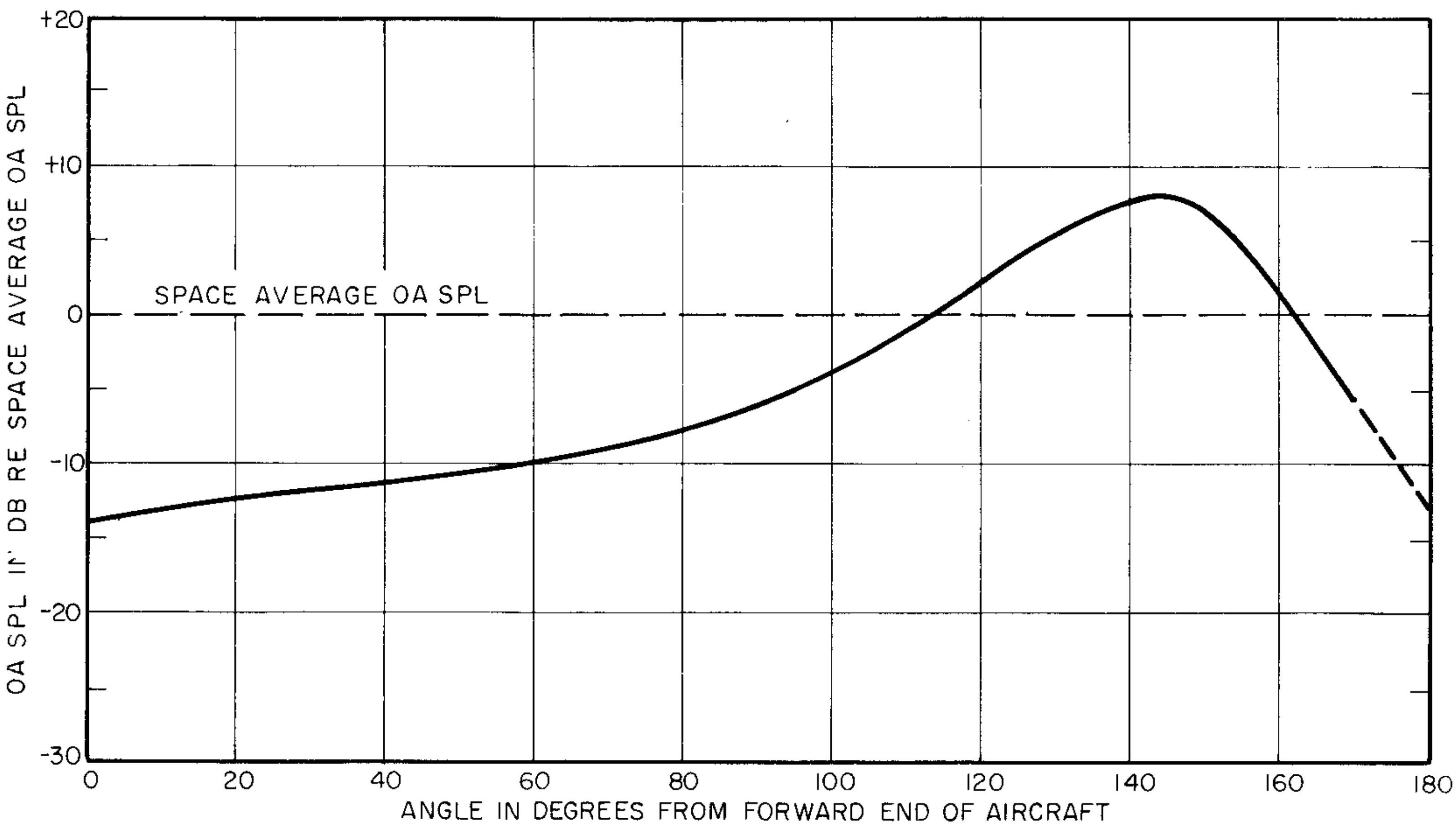


FIG. A1 OA SPL VERSUS ANGLE FOR NOISE FIELD AROUND JET AIRCRAFT OPERATING ON THE GROUND. CURVE IS APPLICABLE FOR ENGINE OPERATION ABOVE 80% RPM, INCLUDING AFTERBURNER OPERATION.

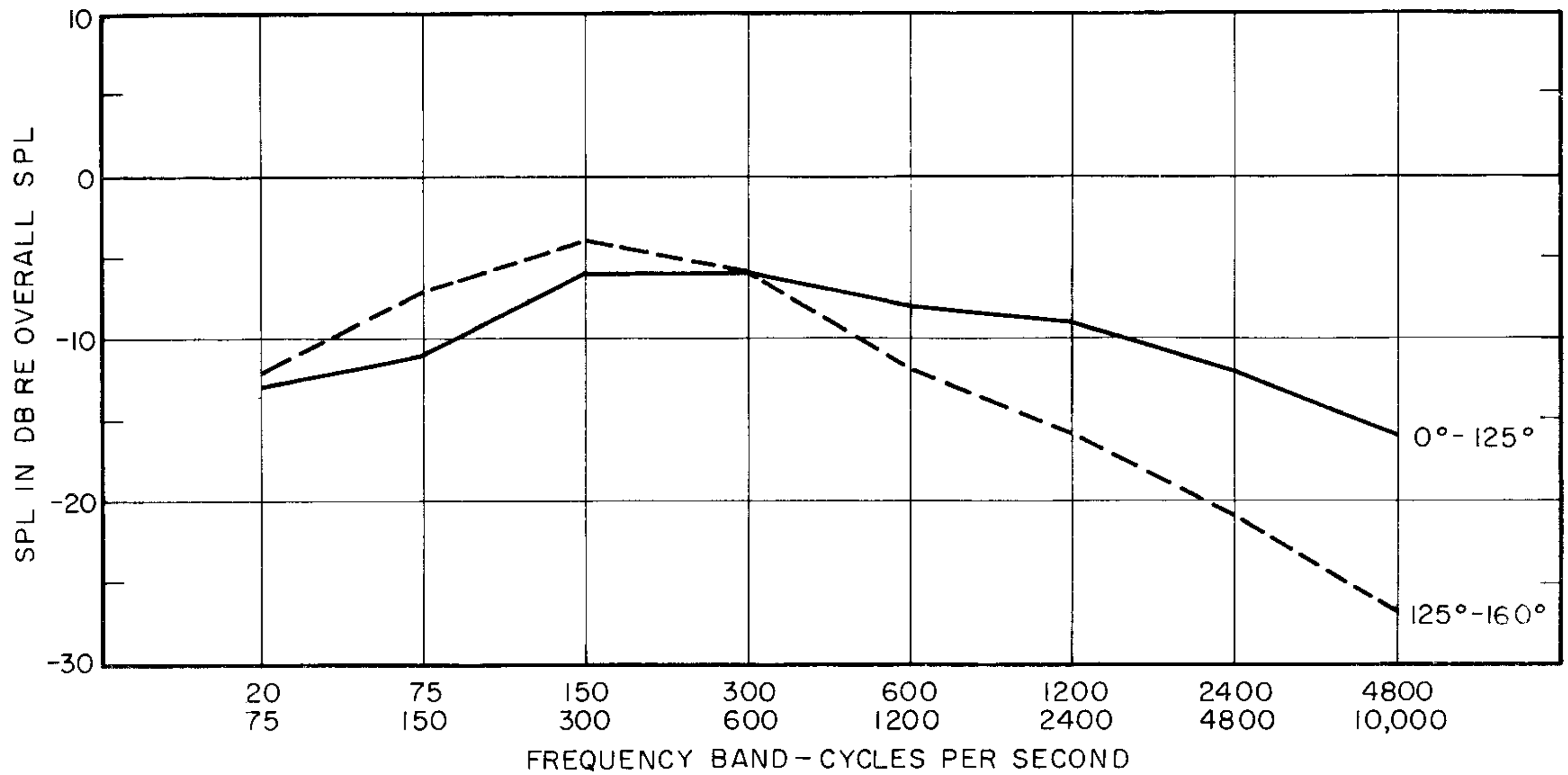


FIG. A-2 GENERALIZED SPECTRA OF NOISE FROM JET AIRCRAFT OPERATING ON THE GROUND. CURVES ARE FOR ENGINE OPERATION ABOVE 80 % RPM, INCLUDING AFTERBURNER, AND FOR A DISTANCE OF 100 FEET (FOR GREATER DISTANCES REFER TO FIGURE A3)

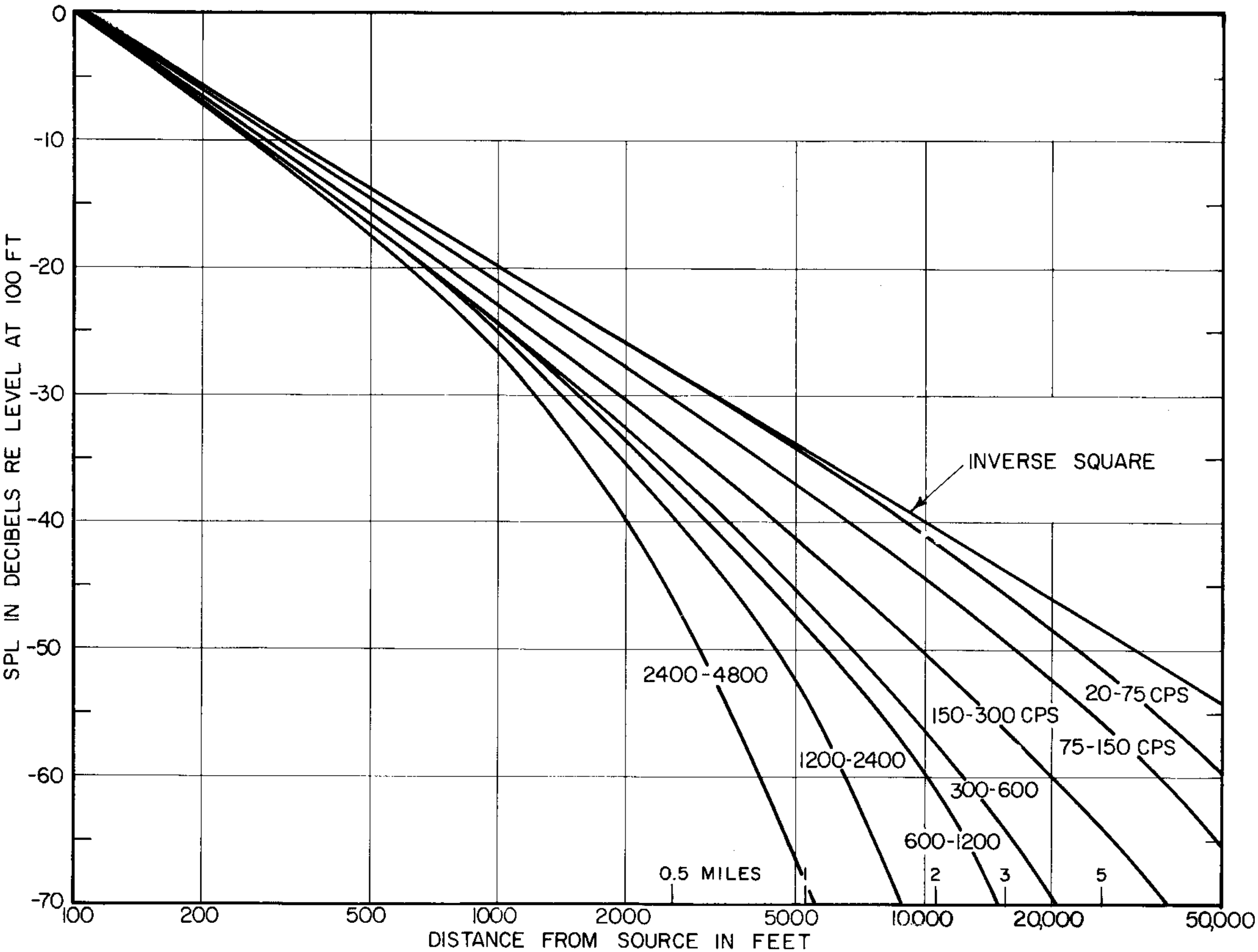


FIG. A-3 CONSERVATIVE VALUES OF REDUCTION OF SOUND PRESSURE LEVEL WITH DISTANCE FOR JET AIRCRAFT OPERATING ON THE GROUND.

For distances beyond 100 ft, corrections must be applied for geometrical spreading of sound and attenuation due to atmospheric affects and terrain 6,12/ In Fig A-3 the combined effect of spreading and ground and air attenuation is given for the various octave bands as a function of distance out to 50,000 ft. These curves have been drawn for a ground cover consisting of grass and bushes up to two ft in height, for normal ranges of temperature and relative humidity, and for a wind velocity of about four mph or less. As such, the values shown by these curves are considered conservative. Higher wind velocities and certain temperature gradient conditions would cause considerably higher losses in some of the octave bands than shown.

If the example worked out above is extended to determine the SPL in the 1200-2400 cps band at 1000 ft, Fig A-3 indicates that it is 25 db less than the calculated value at 100 ft, or 88 db.

APPENDIX B

NOISE SPECTRA FOR JET RUN-UP AND TAKEOFF OPERATIONS

A prerequisite for developing the simplified analysis procedures employed in this Guide is a knowledge of the range of noise spectra that will be encountered on and near air bases from both ground run-up and takeoff operations of jet aircraft. Representative spectra indicating this range are given in this Appendix for both types of operations.

A. Run-ups

From the procedures described in Appendix A, octave band spectra have been calculated for various distances from 200 ft to 5000 ft, and for each of the two angular ranges noted in Fig A-2. These spectra are given in Fig B-1, one family of curves for an angle of 60°, and a similar set of curves for an angle of 145°. (Angles are measured from the forward end of the aircraft.) The sound pressure levels in Fig B-1 are based on the assumption of a power level of 170 db re 10^{-13} watt.

The most important characteristic of these two sets of curves is the change in spectrum shape with both distance and angle. The variation in spectrum shape with angle and with distance was a very important factor in developing the simplified procedures used in this Guide for treating problems involving ground run-up operations, as is illustrated by the discussion in Appendices E and F.

B. Takeoffs

In developing simplified procedures for treating problems involving takeoff operations, it is also necessary to know the range of noise spectra from these operations. However, the problem is somewhat more complicated than for run-up operations since a number of different flight profiles are involved. For purposes of illustration, some representative spectra of maximum SPL's are given in Fig B-2 where the distances noted on the curves are equal to the perpendicular distance from the aircraft flight path to the observer. For overhead flyovers, these distances equal the altitudes.

The spectrum for the 400 ft distance was obtained from an average of several field measurements. The data at 1600 and 4000 ft have been extrapolated from the 400 ft data. The actual distances from the aircraft to the observer at the time the SPL on the ground reaches its maximum value are, of course, somewhat greater than those noted.

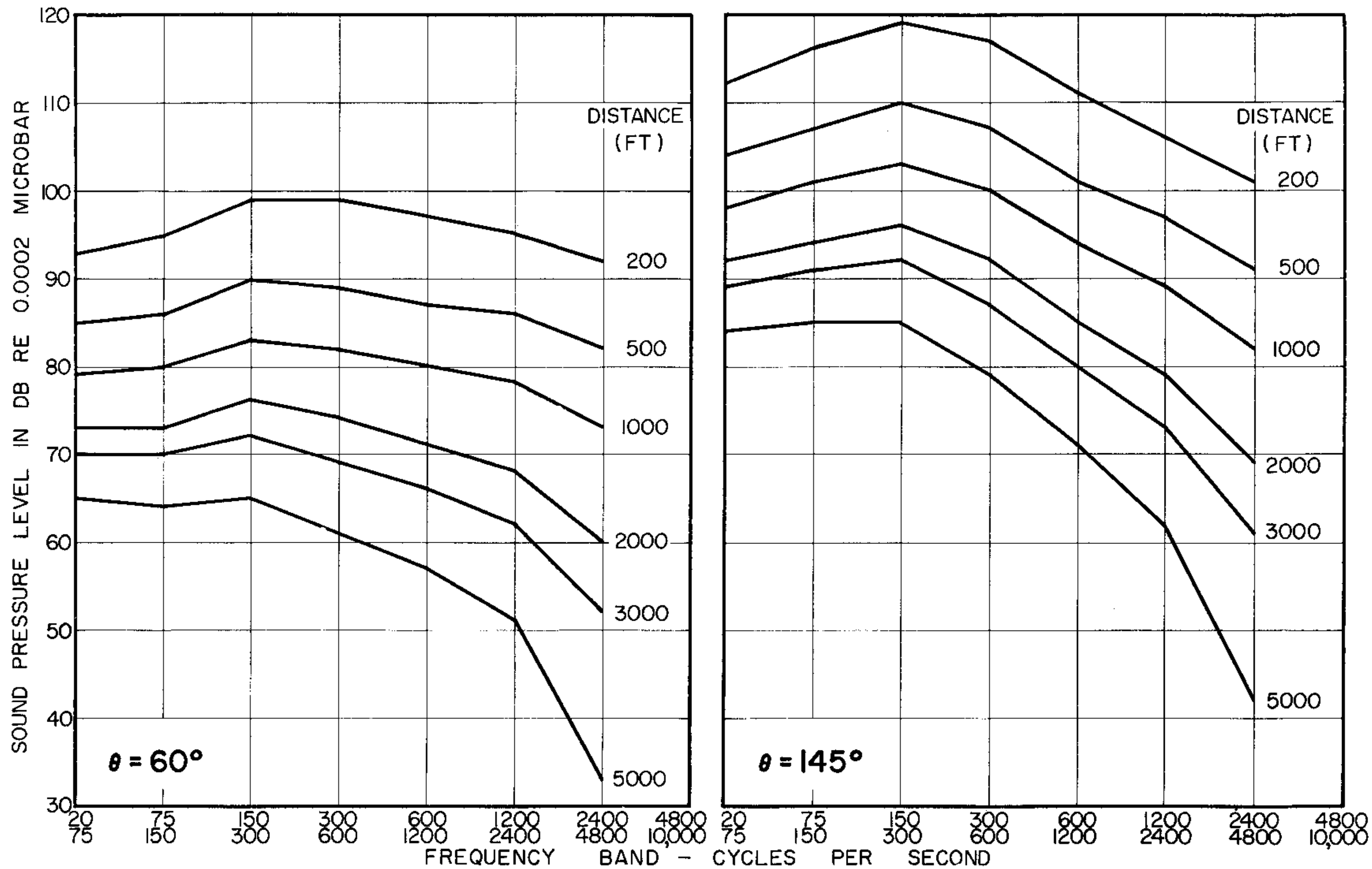


FIG. B-1 ESTIMATED NOISE SPECTRA AT VARIOUS DISTANCES FROM GROUND RUN-UP OF JET AIRCRAFT WITH PWL=170 DB RE 10^{-13} WATT

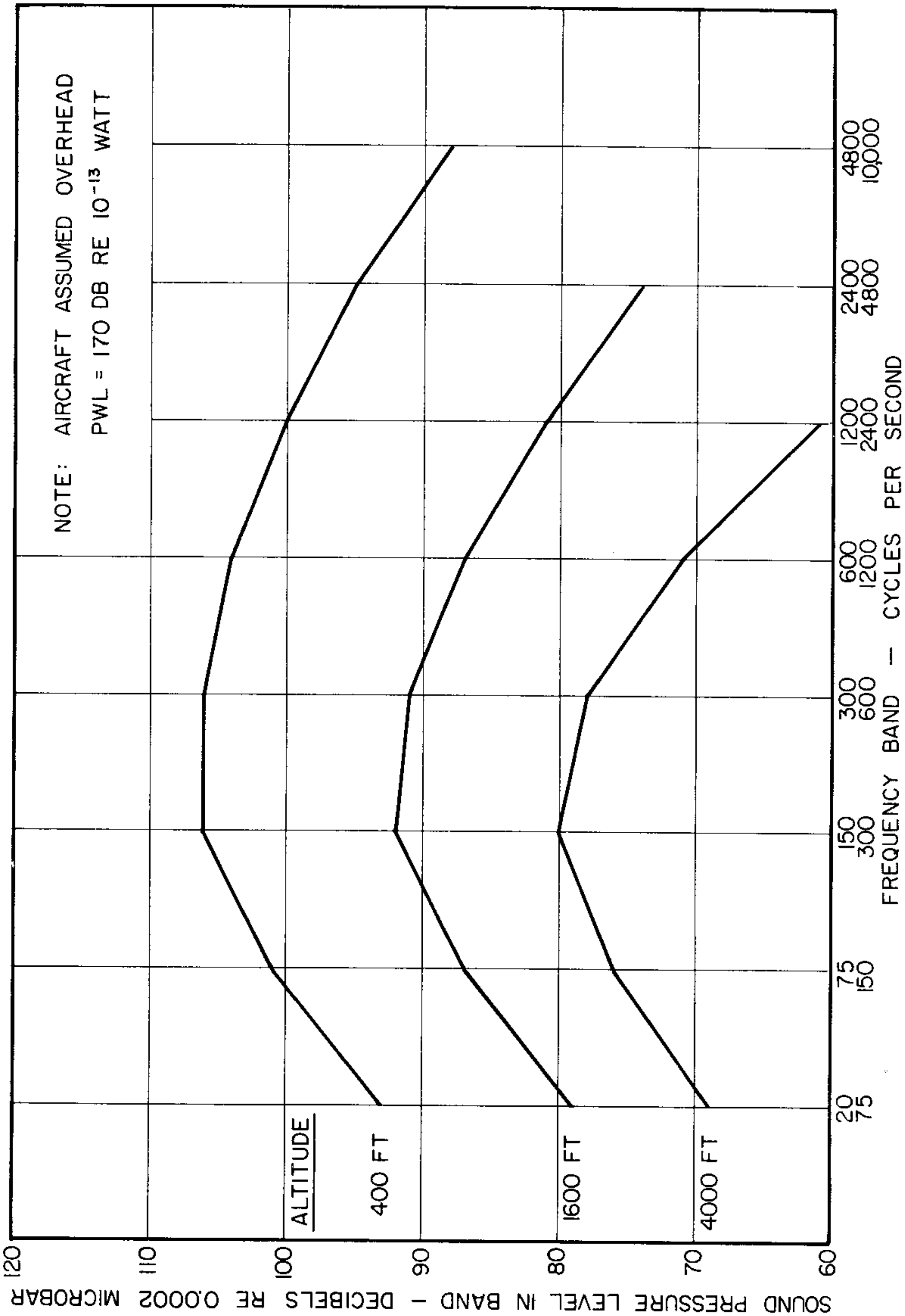


FIG. B-2 REPRESENTATIVE NOISE SPECTRA FOR JET TAKEOFF OPERATIONS.

APPENDIX C

THE ANL CONTOURS

To develop reasonably simple engineering procedures for analyzing air base noise problems, it is necessary to simplify the description of the intruding noise. The manner in which this has been accomplished was described in detail in WADC Technical Note 57-10[6]. Essentially the same approach has been used in this Guide except that some terms have been given different names.

As described in WADC TN 57-10, the frequency dependence of the intruding noise is simplified by equating the jet noise spectrum to a single number called the "Equivalent SPL in the 300-600 cps octave band", or the Aircraft Noise Level (ANL) as it is called in this Guide. The time dependence of the noise is simplified by equating the time varying noise to a value of SPL which, over a given period of time, yields the same total energy as the time varying noise. By means of these two simplifications, the noise exposure at any point can be expressed in terms of the "equivalent continuous SPL in a 300-600 cps octave band (Leq)", or the Average Aircraft Noise Level (AVG ANL), as it is called in this Guide. Procedures for determining these values are described below.

The Aircraft Noise Level is determined by use of the grid lines, or "level rank" contours as they have been called[13] shown in Fig C-1. The noise spectrum, either from a flyover or a run-up, is superimposed on the grid lines, and the highest grid line (to the nearest 5 db) reached by the spectrum is noted. The number along the right hand scale associated with this grid line gives the ANL in db for this spectrum.

The simplification of the time dependence of the noise is accomplished in the following manner: For a simple intermittent noise that rises to a value of ANL for a period of ΔT seconds once during each one-hour period, the average ANL is given by

$$\text{AVG ANL} = \text{ANL} + 10 \log_{10}\left(\frac{\Delta T}{3600}\right) \text{ db.}$$

For example, if the ANL at some location due to a jet run-up operation rises to 90 db for six minutes each hour, the AVG ANL is equal to 90 minus 10, or 80 db.

The ground run-up contours of Fig 4 are given in terms of ANL for a PWL of 170 db re 10^{-13} watt. For the time durations involved in a particular problem, the above equation is used to convert these ANL values into AVG ANL's.

For takeoff operations, both the noise levels and the time durations have been considered in specifying the noise exposure,

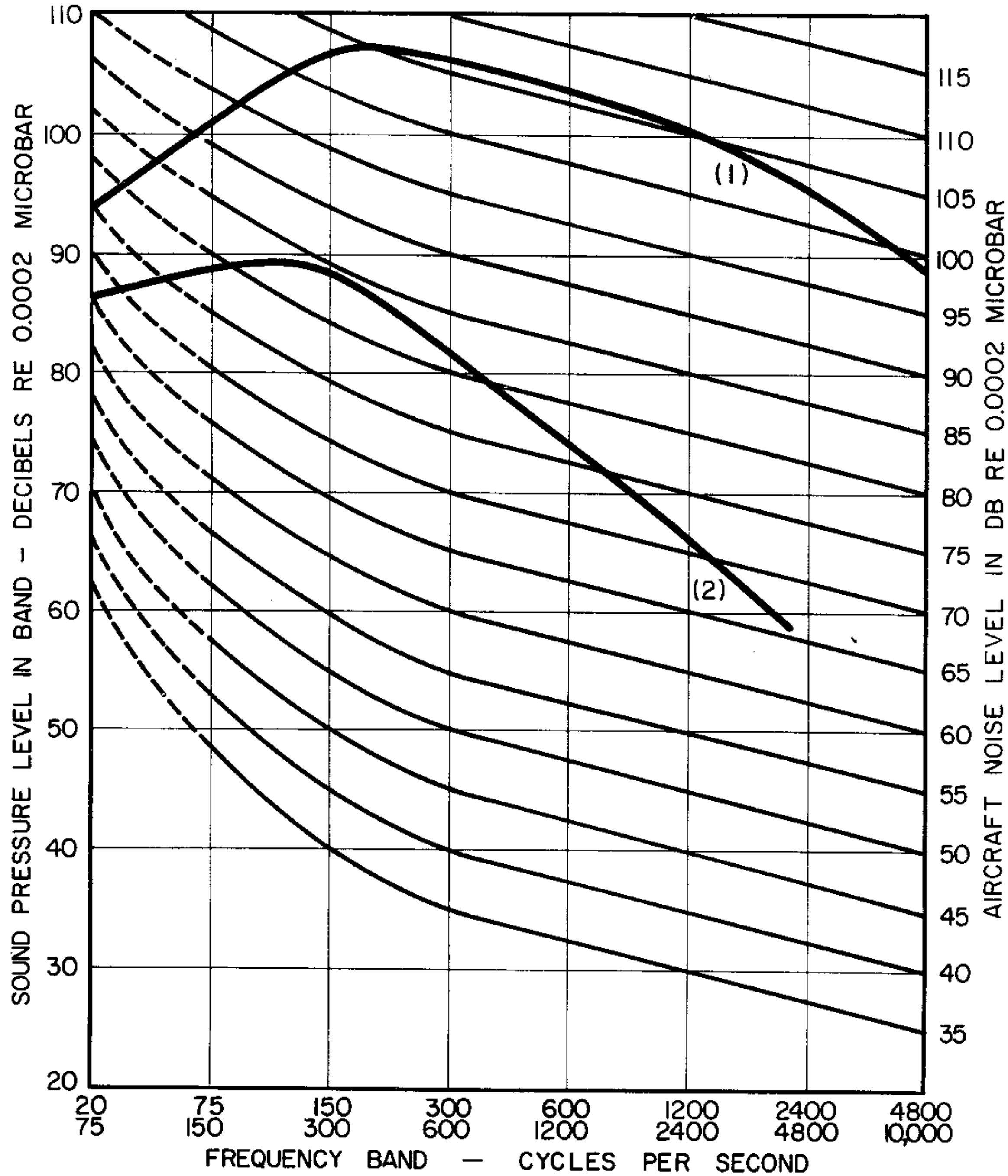


FIG. C-1 FAMILY OF CURVES USED TO DETERMINE AIRCRAFT NOISE LEVEL. FOR SPECTRA SHOWN THE ANL'S ARE 105 DB FOR SPECTRUM (1) AND 85 DB FOR SPECTRUM (2), TO THE NEAREST 5 DB.

and consequently noise contours for takeoff operations have been specified in terms of the AVG ANL's (Fig 10).

AVG ANL's are used primarily in analyzing a base-community noise problem where the community may be either on or off the base. This approach has been extended in this Guide to include the use of MAX ANL's in analyzing noise problems in offices and work spaces on air bases, as discussed in Appendix D.

APPENDIX D

USE OF MAX ANL'S FOR OFFICE AND WORK SPACE NOISE PROBLEMS

In offices, work spaces, and other similar areas, the appropriate criteria[5] are given in Table XI on page 67 and plotted in Fig D-1. Superimposed on the NC curves[7] in Fig D-1 are the "level rank" curves of Fig C-1. One notes that they are very similar in shape, i.e., essentially interchangeable. Therefore, for purposes of simplification, the "level rank" curves have been used in this Guide as engineering approximations to the NC curves. The errors associated with this approximation are negligible when compared with the procedural simplicity achieved. In particular, this approximation permits use of the ANL contours (actually MAX ANL contours, as described below); otherwise different contours would have been required for analysis of this type of noise problem. (The five db correction factor which occurs, for example, because the NC-40 curve overlays the ANL 45 curve, has been taken into account in developing the specific procedures used in the text.)

Besides the use of contours, additional simplification is necessary in describing the intruding noise in offices and work spaces. If the intruding noise does not vary appreciably throughout the working day (ventilating noise, office equipment noise, etc.), then the problem is simply one of comparing these noise levels with the appropriate criterion to determine the extent of the problem. However, if the noise is intermittent (as it is in many spaces on air bases), it can be permitted to rise above the applicable criterion levels for short periods of time, such as during takeoffs and flyovers, and during intermittent ground run-up operations. For these spaces it is recommended that the mean, or average SPL in each octave band over the working day not exceed the NC criterion curve associated with the desired communication environment given in Table XI on page 67[8,11].

Translating the concept of mean SPL's into a procedure permitting the use of noise contours is extremely difficult. Therefore, a technique has been developed whereby the mean SPL in any given situation can be related to the maximum SPL and, in turn, to the MAX ANL. It is then possible to utilize contours of MAX ANL's in analyzing office and work space noise problems.

The essence of this technique is summarized in Table XII on page 68. For run-up operations, for example, one calculates the amount of time in minutes per hour during which the ANL is within ten db of the maximum value. For the desired NC criterion one can then determine the allowable MAX ANL in the particular space in question.

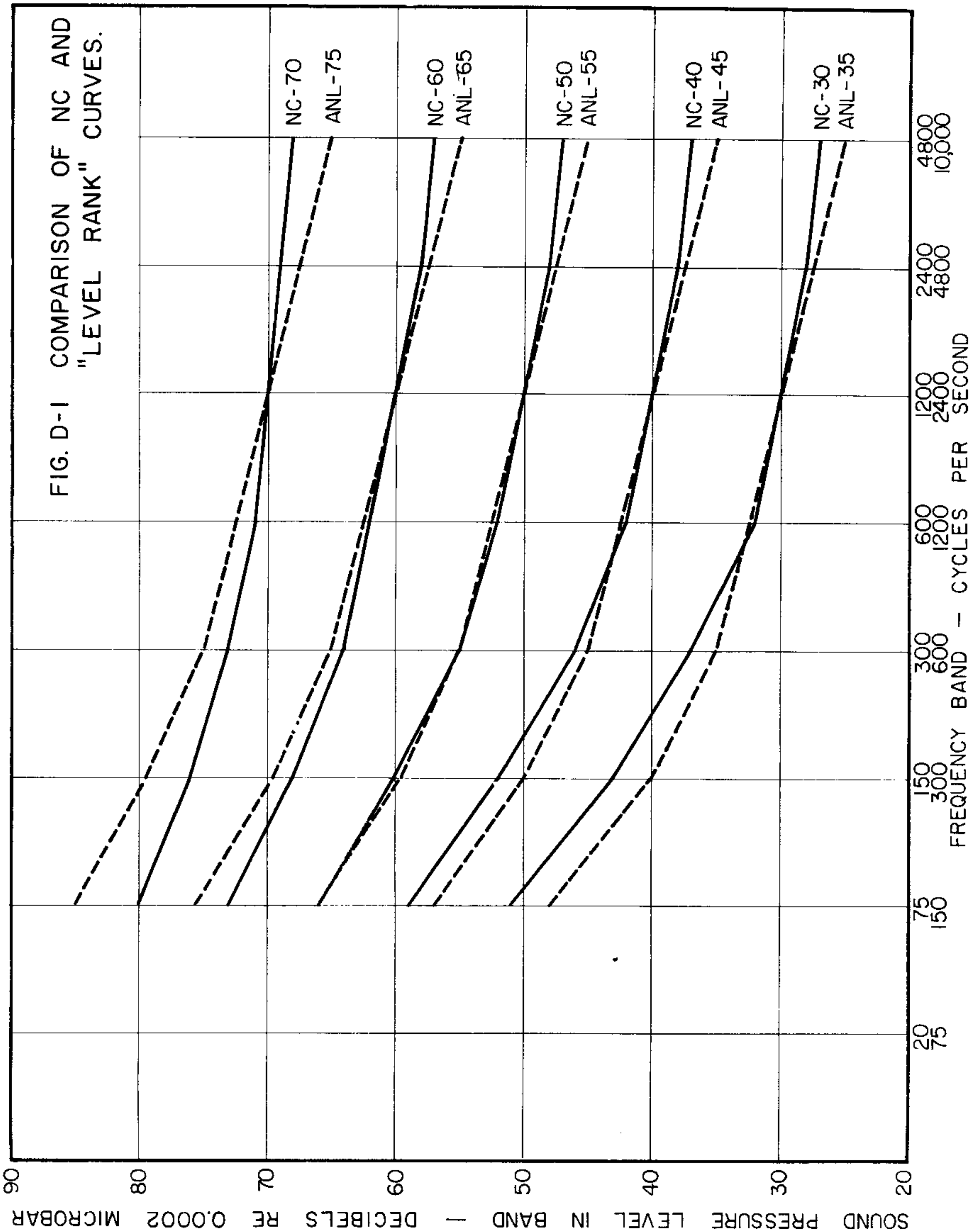


FIG. D-1 COMPARISON OF NC AND "LEVEL RANK" CURVES.

For any combination of run-up times and MAX ANL's given in Table XII, the mean NC values will be equal to or less than the corresponding NC criterion provided one assumes that the background noise in the absence of intruding jet noise is from zero to five db less than the NC criterion in question. Take, for example, the following illustration: Assume that run-up operations produce noise levels within ten db of the MAX ANL value for an average of 15 minutes each hour. During this 15 minutes the noise levels are at the MAX ANL value for two minutes, at the MAX ANL value minus five db for three minutes, and at the MAX ANL value minus ten db for ten minutes. Further, assume that the desired NC criterion is NC-45. Table XII indicates that the MAX ANL value should not exceed 60 db. If this condition is met, what is the actual mean NC value in db for this example?

The mean NC value has been calculated in the following manner and is equal to approximately 42 db.

Min		NC Value in DB		DB - Min
2	x	55(ANL = 60)	=	110
3	x	50(ANL = 55)	=	150
10	x	45(ANL = 50)	=	450
45	x	40(ANL = 45)	=	1800
		Total	=	2510 DB - Min

$$\text{MEAN NC VALUE} = \frac{2510}{60} \simeq 42 \text{ db}$$

These calculations have been made assuming that the background noise was equal to NC-40, or five db less than the desired criterion value, and also keeping in mind that the NC values are five db less than the corresponding ANL values. If the background noise had been assumed equal to NC-45, the mean NC value over the entire hour would have been equal to about 46 db, or less than one db greater than the desired criterion.

For intruding noise levels of very short duration, the mean SPL concept would allow the MAX ANL's to rise to very high values. In the construction of Table XII this has not been permitted, and an upper limit, which varies depending upon the desired criterion, has been placed on the MAX ANL values. For example, if the desired criterion is NC-25, the MAX ANL, regardless of the duration, is not allowed to rise above 65 db. These upper limits on the MAX ANL's have been based upon a consideration of the degree of telephone communication possible at various noise levels.

By making certain simplifying and practical assumptions, therefore, such as utilizing the "level rank" contours as an engineering approximation to the NC criterion curves, and assuming that the intruding noise levels from run-up and takeoff operations bear some known relation to the MAX ANL's, it is possible to utilize the MAX ANL contours in the analysis of office and work space noise problems.

APPENDIX E

CONVERSION OF ANL'S TO SIL'S

Criteria for "important communication areas" (see Section IV-E) are given in terms of Speech Intereference Levels (SIL's). Analysis of noise problems involving these spaces could be performed by the use of SIL contours, just as other on-base problems are handled by use of ANL contours. However, to minimize the number of noise contours used in this Guide, a procedure has been developed whereby the ANL contours can be used to compute SIL's.

The results of this procedure, in terms of a set of correction numbers used to convert ANL's to SIL's, are given in Fig 28 on page 103. This Appendix describes how those correction numbers were derived.

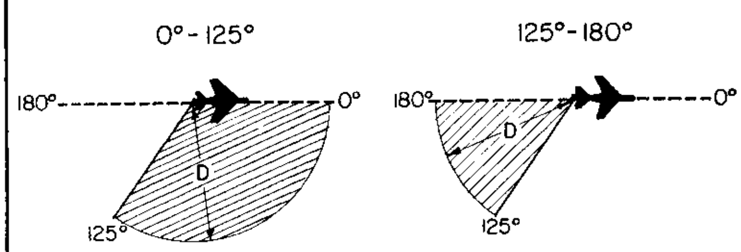
For run-up operations the procedure was to calculate the corresponding values of ANL and SIL for each of the spectra given in Fig B-1. The ANL value was obtained by the technique described in Appendix C. The SIL value is simply the average of the sound pressure levels in the 600-1200, 1200-2400, and the 2400-4800 cps octave bands. The difference in db between ANL and SIL value for each curve was plotted as a function of distance from the ground run-up, as shown in Fig E-1. Separate curves have been plotted for the two angular regions around the aircraft.

From these curves one could obtain the actual correction in db at any specified distance from 200 ft up to about 6,000 ft. However, for the sake of simplicity, corrections have been determined to the nearest five db (which means that any one correction value is not in error by more than two db). For example, in the 0^{o}-125^{o} angular range, the stated correction for the range of 1500 ft to 4000 ft is -10 db and the actual correction values vary from about -8 db to -12 db.

Corrections for takeoff operations have been determined in a somewhat similar manner. However, the technique is not as straightforward as it is for run-up operations. The basic reason for this is that, at a given distance D from a runway, or from its centerline extension, the actual distance to the aircraft (and hence the noise spectrum) will vary depending upon the flight profile. Further, the noise spectrum will vary for a given distance D depending upon whether the aircraft is on the ground (during the ground roll) or in flight.

Consequently, the differences between the ANL and SIL values for a given distance D will vary over a range of values, as indicated by the correction curve shown in Fig E-1. The shaded area represents the spread in correction values due to the differences in flight profile (see Fig 8). The points plotted within the

GROUND RUN-UPS



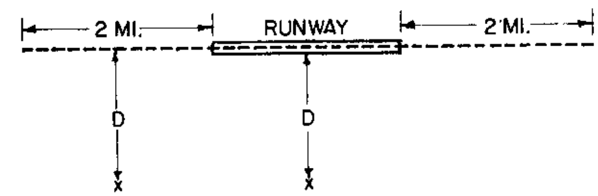
0° - 125°

DISTANCE (D)-FT	CORRECTION-DB
UP TO 1500	-5
1500 TO 4000	-10
BEYOND 4000	-15

125° - 180°

DISTANCE (D)-FT	CORRECTION-DB
UP TO 1000	-10
1000 TO 3500	-15
BEYOND 3500	-20

TAKEOFFS



DISTANCE (D)-FT	CORRECTION-DB
UP TO 1000	-10
1000 TO 2000	-15
2000 TO 4000	-20
BEYOND 4000	-25

NOTE: APPROXIMATIONS GOOD UP TO 2 MILES FROM END OF RUNWAY.

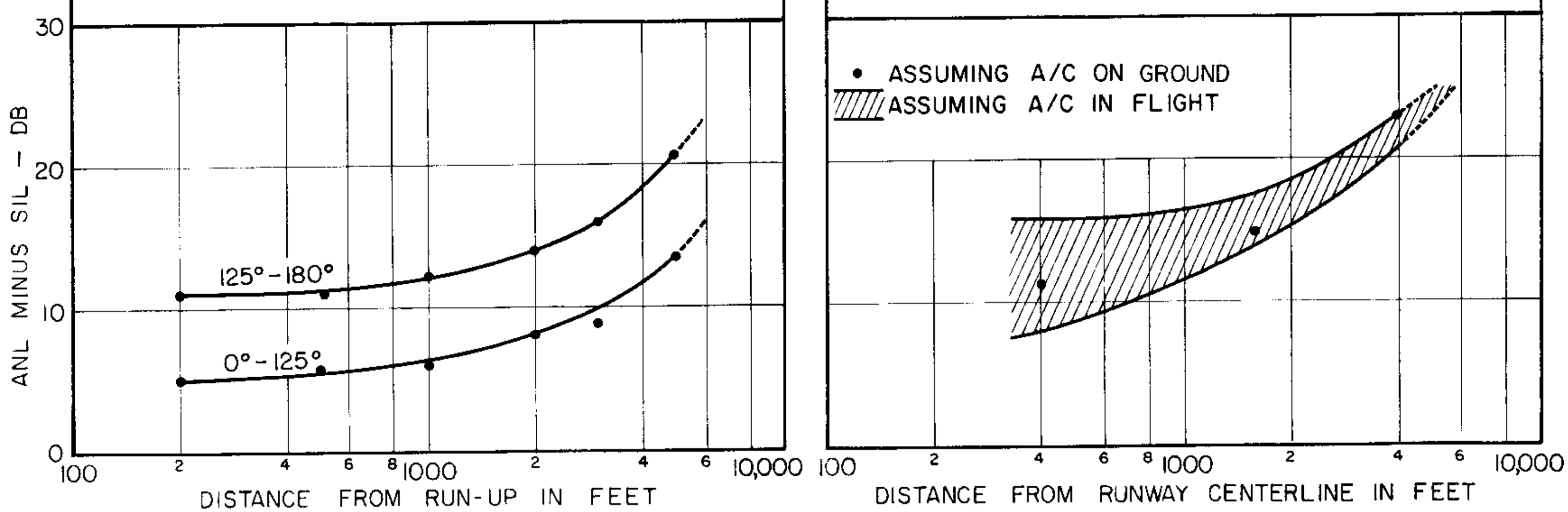


FIG. E-1 DETERMINATION OF CORRECTIONS TO BE APPLIED TO ANL (OR MAX ANL) TO OBTAIN SIL (OR MAX SIL) shaded region represent the correction values for the noise spectra produced during the ground roll.

At first glance, the tabulated correction values permit errors, in some cases, more than the two db mentioned for the run-up correction numbers. This would be true mostly for lower values of D. However, further explanation of the derivation of this correction curve will show that the errors in practice will be much less than suggested by the spread of values shown by the shaded area. As noted on the graph, the correction curve applies for distances out to about two miles from either end of the runway. The upper edge of the shaded area represents the corrections that would apply at a distance of two miles from the runway where the differences in altitudes of the different types of aircraft would be the greatest. Since most air base buildings are usually located in an area opposite the runway, the actual correction values would probably be closer to those represented by the lower edge of the shaded area and by the plotted points. In these instances, therefore, the tabulated correction numbers should be correct to within two db.

APPENDIX F

ANL AND SIL REDUCTION OF WALL STRUCTURES

In Tables XIII and XVI the noise reduction (NR) of wall structures is presented in terms of the "ANL reduction" and "SIL reduction", respectively. The techniques whereby the NR of a structure can be expressed in "single numbers" are explained in this Appendix.

In the analysis of problems involving "office and work areas", "group meeting, study, and rest and relaxation areas" and "hospitals", one compares the intruding noise from aircraft operations with the appropriate NC criterion. In this Guide the intruding noise levels are characterized by the MAX ANL's (see Appendix D). The MAX ANL inside a structure depends on the MAX ANL outside the structure and the noise reduction characteristic of the structure.

If a wall structure could be described as having a certain ANL reduction, then the MAX ANL inside would be simply equal to the outside MAX ANL less the ANL reduction. The problem then is one of determining the ANL reduction of a wall structure. This is done simply by first calculating the ANL of a noise spectrum outside a building by means of the procedure outlined in Appendix C. Next, this noise spectrum is reduced by the characteristics of the wall structure in each of the octave bands. The resulting noise spectrum, which now exists inside the building, also has a certain ANL. The difference between the inside and outside ANL's is the ANL reduction of the structure.

This entire problem is complicated by the fact that the ANL reduction varies with the shape of the outside noise spectrum and also with the shape of the noise reduction characteristics of wall structures. What approximations can be made? This question can be answered by calculating the actual ANL reductions for wall structures having various noise reduction characteristics and for the actual noise spectra that might be encountered in air base noise problems, such as those shown in Appendix B.

Three arbitrary noise reduction characteristics of wall structures are shown in Fig F-1. The lower curve represents a wall with acoustical "leaks" of one form or another. The middle curve approximates the shape of the noise reduction characteristic of a single wall with no leaks. The upper curve describes a wall that has somewhat better noise reduction than a single wall -- perhaps characteristic of some form of double-wall structure. The choice of the shape and the slope of the curves had been somewhat arbitrary, but the basic intent has been to cover a rather wide range of noise reduction characteristics.

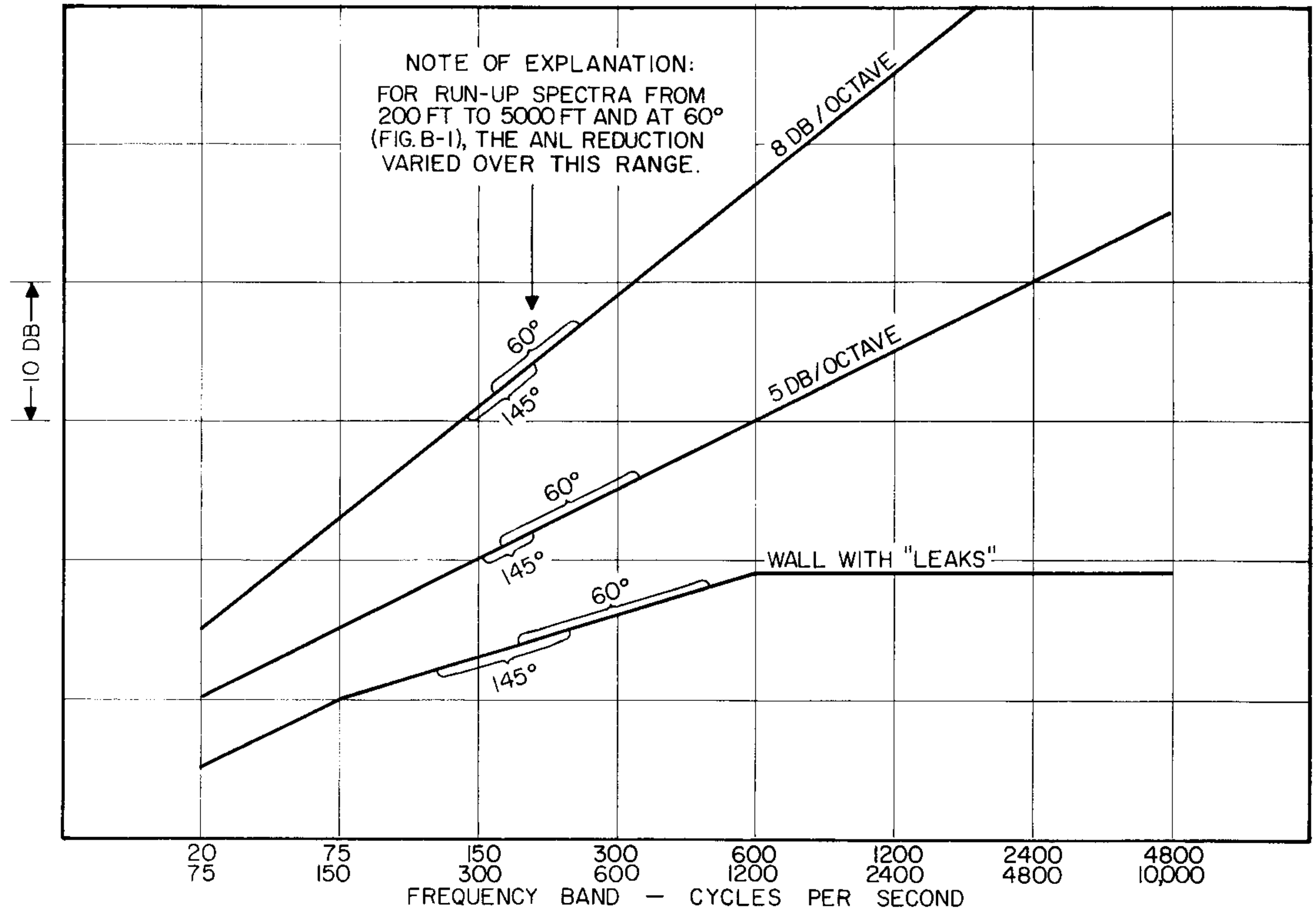


FIG. F-1 NOISE REDUCTION CHARACTERISTICS USED TO DETERMINE ANL REDUCTION OF WALL STRUCTURES.

Each of these three noise reduction curves has been used (on a relative basis) in conjunction with the 12 noise spectra representing ground run-up operations (Appendix C). The outside and inside ANL values have been calculated in each case, and a resultant ANL reduction has been determined. Each of these values of ANL reduction corresponds to a value that would have been given by the noise reduction curve at some frequency. The actual range of values for each of the three curves and for the two angular regions associated with the ground run-up spectra is shown in Fig F-1. For example, for the eight db/octave curve, the ANL reduction for all of the ground run-up spectra at 60° varied over the range indicated by the bracket. Similarly, the ANL reduction for the ground run-up spectra at 145° varied as shown by the other bracket on the same curve. In other words, for a wall structure having a noise reduction characteristic that rises at about eight db per octave, the ANL reduction for intruding noise from ground run-up operations of jet aircraft varies over a range of only seven db and, for engineering purposes, could well be characterized by a value of noise reduction that lies somewhere between the noise reduction for the 150-300 cps and 300-600 cps octave bands.

Similar results are shown for the other two noise reduction curves in Fig F-1. One notes that as the slope of the noise reduction curve decreases, the range of ANL values spreads out over a larger frequency range. However, the actual decibel variation is approximately the same -- six db for both of the lower curves. Incidentally, the values of ANL reduction for typical noise spectra from takeoff operations fall well within the bracketed regions shown in Fig F-1.

On the basis of these results, the ANL reduction of a wall structure has been taken to be equal to the average of the actual noise reduction of the structure in the 150-300 cps and 300-600 cps octave bands. Most commonly encountered air base structures are characterized by the lower two curves in Fig F-1 and for these, this assumption will result in a maximum error of only 3 db. This error is negligible compared to the convenience of being able to describe the acoustical effectiveness of a structure by a single number, the ANL reduction in db.

The SIL reduction of a structure is somewhat easier to determine. It is equal simply to the average noise reduction in the three SIL octave bands, the 600-1200, 1200-2400 and 2400-4800 cps bands. For all practical purposes the SIL reduction is equal to the actual noise reduction in the 1200-2400 cps octave band.