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NOISE EXPOSURE FORECASTS: EVOLUTION, EVALUATION, EXTENSIONS, AND LAND USE INTERPRETATIONS

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By

William J. Galloway
Dwight E. Bishop

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

Part I describes the evolution of methods for relating aircraft noise exposure to community response in this country, starting with the original Composite Noise Rating (CNR) concept developed in 1952, and with applications specifically to aircraft noise in 1957 under Air Force sponsorship. The development of CNR procedures for civil and military aircraft in 1962 utilizing perceived noise level contours and the development of Noise Exposure Forecast (NEF) procedures in 1967 utilizing effective perceived noise level data are recounted and compared.

The CNR and NEF procedures are also related to various noise exposure indices developed in several other countries. Cross comparisons of the indices allows the results of various social surveys to be used as verification of the numerical values and descriptors used in the CNR and NEF zones for various acceptable land uses.

Part II interprets the noise exposure due to aircraft operations, as expressed in Noise Exposure Forecast (NEF) values, in terms of estimated impact on land uses. Assessments of the land use compatibility with aircraft noise as a function of NEF values are given for a variety of land uses for the purpose of providing guides in land use planning, zoning and in land use development and building construction. To provide for flexibility in setting descriptor limits to fit particular local conditions, the NEF values of the compatibility descriptors boundaries overlap, providing a range of NEF values where boundary limits may be modified by local considerations.

PREFACE

The concept of Noise Exposure Forecasts (NEF) is a methodology for predicting a single number rating of the cumulative noise intruding into airport communities from aircraft operations. Equal NEF contours result from estimates and generalizations of aircraft categories, mix of aircraft, runway utilizations, number of operations, flight paths, noise levels in EPNdB, and atmospheric conditions. Considering the assumptions, the contours can be considered to have an accuracy of approximately plus or minus five NEF units. In other words, if the contours are plotted at 5 NEF intervals, the limits for any one contour could be considered to be its adjacent contours.

To facilitate the use of these procedures, Part I of this report traces the evolutionary processes leading to the NEF procedures and provides a comparison of NEF to a number of similar procedures developed around the world. Part II of this report provides interpretations of NEF values with respect to community response and to land use compatibility for a wide range of land uses.

Applications of the NEF procedures in describing the current and projected noise environment around selected civil airports in this country, a description of the digital computer program, tradeoff studies, and methodology for noise exposure forecasts can be found in the following reports prepared in performance of Contract FA68WA-1900: FAA-NO-69-2, FAA-NO-70-6, FAA-NO-70-7, and FAA-NO-70-8.

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NOISE EXPOSURE FORECASTS: EVOLUTION, EVALUATION AND EXTENSIONS

By
William J. Galloway

PART I

NOISE EXPOSURE FORECASTS: EVOLUTION, EVALUATION, AND EXTENSIONS

I. INTRODUCTION

For almost two decades the increasing magnitude of aircraft operations has brought increased concern over the noise aircraft produce in communities surrounding airports. In the United States, concern over aircraft noise on the part of the Federal Government goes back to studies performed under the auspices of the Air Force and the National Advisory Committee for Aeronautics (the predecessor of NASA) almost twenty years ago. During most of the decade of the 1950's almost all jet aircraft were operated by the military agencies. Concern over aircraft noise led the Air Force to conduct a series of major investigations of the noise properties of jets, methods of noise control for test operations, and the effect of noise from aircraft operations on communities surrounding air bases. These studies established an operational framework of investigation and identified the basic parameters affecting community response to noise. Many variations and refinements in technique have evolved since these studies, yet essentially all existing models of aircraft-community relationships relate directly to this work.

In the late 1950's and the early 1960's the introduction of commercial jet aircraft in large numbers greatly expanded concern over aircraft noise. Whereas most jet aircraft operations were previously restricted to military bases, now most large metropolitan areas, and an ever increasing number of smaller communities, received noise from jet aircraft in increasing numbers. The comfort, speed, and economic potential of commercial jet aircraft resulted in a growth of air travel between 1958 and 1969 of about 2-1/2 times as measured in passenger miles. The fact that jet aircraft are noisier than piston aircraft, that many more are flying from many more airports, has developed into what is now a major international concern over means for assessing the acceptability of aircraft noise in communities.

As aircraft noise problems have increased, methods for assessing the magnitude and effect of these problems have both been refined and proliferated internationally. In the United States there have been three significant revisions to methods for computing noise exposure and community response since 1952, resulting in the present technique termed Noise Exposure Forecasts (NEF). In other countries alternate methods have evolved, all reaching for the same goal of relating noise from aircraft operations to community response.

The development of techniques useful on an engineering or planning basis for estimating community response to noise has two major components:

1) The identification of physical, psychological or socio-economic parameters influencing response and the mathematical expression of their relationships.

2) The identification of intensity of individual and community response and their quantitative relationships to predictable parameters.

The evolution of present procedures has largely been based on initial descriptions of physical parameters that intuition says ought to be pertinent, then examination of the relative importance of these parameters through studies of interviews in communities, studies of complaints, and through laboratory-based psychoacoustical tests. The interview studies in communities also provide insight into significant sociological factors influencing community response which can be quantified on a scale pertinent to the population sampled. However, these factors are, as yet, difficult to include in an engineering model for prediction of response in another community for which no survey data are available.

With few exceptions, the present methods of estimating community response are related primarily to conditions of "acceptability" for residential use. Since residential community reaction is the source of complaints and community action, it is reasonable that most effort should have been directed to residential problems. On the other hand, if we accept that, for the next decade at least, it is economically not feasible to reduce noise levels at an airport boundary to the point where residential living is entirely acceptable, then we must consider alternate uses for the land that are more compatible with aircraft noise. The determination of "compatability" requires the establishment of noise criteria for different types of land use.

Theoretically, establishing noise criteria for non-residential activities is a simpler process than for residential use. We can make the somewhat arbitrary first order distinction that residential use implies noise criteria for both task interference (e.g. speech, watching TV, sleep) and general underlying undesirability of noise at home, while non-residential use implies only task-interference criteria. Consider that, in most instances, noise interference with speech is the fundamental criterion for non-residential use. We can then establish classes of non-residential use on the basis of our knowledge of speech interference by noise. In the practical sense, this is not so straight forward since aircraft operations tend to provide intermittantly high noise signals with substantially lower noise levels in between the "peaks." Factors such as the importance of non-interruption of speech as a percentage of time for given occupations must be considered in the development of these noise criteria.

II. EVOLUTIONARY STEPS IN THE DEVELOPMENT OF NOISE EXPOSURE FORECASTS

There are four basic development points leading to the current version of the Noise Exposure Forecasts. These phases go back to a beginning in 1952 with the initial publication of the concept of Composite Noise Rating (CNR) by Rosenblith and Stevens.[1]* Subsequent to that publication a slightly modified form became available in the general literature in a paper by Stevens, Rosenblith and Bolt published in January 1955.[2] In these two publications, the concepts relating noise stimulus to expected community response were established. In all of the refinements introduced since that time, no major element has been brought into the discussion of community response, in any of the engineering models, that was not at first envisioned in these papers. It is also worth noting that the description of noise stimulus used in these publications was essentially based upon measurement or specification of the noise level spectrum for a single noise source. The anticipated community reaction to this particular source was then predicted.

The next major step in relating these concepts to the specific case of predicting the response of a community to the noise produced by a series of jet aircraft operations was described by Stevens and Pietrasanta in 1957.[3] This procedure proposed two changes from the previous discussions. The first was a simplification of the noise source description to specialize it to noise produced by a turbojet aircraft. The second step introduced in this document was the concept of predicting the noise from a number of separate operations and then combining them to obtain a single number rating for the noise environment produced by the complex of operations. The concepts relating individual noise levels to anticipated response were retained in much the same form as the earlier two publications.

In 1963 and 1964, Galloway and Pietrasanta[4] revised the previous work to include operations for both military and commercial aircraft. The concept of perceived noise level was introduced as a measure of the noise produced by a given aircraft. In

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* References are listed together at the end of Part I text.

1967 further modifications to the techniques were employed by Bishop and Horonjeff[5] and separately by a research committee of the Society of Automotive Engineers[6], to produce a new set of procedures described as Noise Exposure Forecasts (NEF). Essential differences between the NEF and the CNR calculations were in the transition from perceived noise level in CNR to the effective perceived noise level in the NEF studies and in certain adjustments of constants so that the numerical quantities resulting from the computations would be sufficiently different that no confusion would exist between the two separate methods of prediction.

In the following discussion, we shall outline the evolution of each of these procedures and trace the changes from one procedue to the next as well as the reasons for the adoption of new procedures.

A. Composite Noise Rating - 1952

Exposition of the concept of a community noise rating scheme was presented by Rosenblith and Stevens in 1952.[1] In this procedure the term "effective stimulus" was employed to describe the physically measurable and other identifiable characteristics associated with the noise source and the community environment which would affect the response of the community to the noise. On the basis of these factors, and on the examination of 11 different cases of a noise/community problem, a scale of rating, CNR, was identified numerically with a scale of 6 descriptive responses. The response scale ranged from "no reaction" to "vigorous community reaction." Items entering into the determination of the Composite Noise Rating were the following:

1) A measure of the average noise level spectrum in octave frequency band for the noise source in question.

2) The presence or absence of discrete frequency components.

3) The impulsive or non-impulsive nature of the sounds.

4) Repetition of the sound.

5) Background noise level in the community.

6) The time of day during which the noise source operates.

7) An adjustment for adaptation of the community through previous exposure to the noise.

One should observe that items 1 through 4 above are descriptors related to the physical properties of the noise source itself. Items 5, 6 and 7 have to do with other attributes introduced because of the location of the receiver of the noise. Thus, the first four might be described as the physical descriptors of the source itself, while the second set of three factors are adjustment considerations to change from the physical description of the stimulus to an "effective" description of the stimulus and relate specifically to a given community.

In their discussion Rosenblith and Stevens recognize that factors other than those listed above influence the response of a community to noise. They specifically indicate that the connotation of the noise in terms of its meaning to people, the possible effect of public relations activities related to the noise, the question of whether job dependency was related to the source of the noise, and possible seasonal influences could all affect the degree of community response to noise.

The quantitative measure describing the noise source was the determination of the average sound pressure level (SPL) in octave frequency bands covering the audible range. The band spectrum level was overlaid against a series of curves termed "level rank" curves as shown in Fig. 1. These curves approximate a set of equal loudness curves separated by 5 dB intervals. The level rank into which the highest octave band SPL protruded was selected as the primary descriptor of the magnitude of noise in the CNR calculation procedure. The arguments for this approach were based upon preliminary earlier experiments by Kryter[7] which showed that subjects tend to judge equally loud stimuli to be equally annoying. It is interesting that this concept eventually evolved into the perceived noise level developed by Kryter.[8]

The rationale for categorizing the noise levels in five decibel increments was based primarily on experience indicating that "the range of variation normally encountered in the reaction of residents of a community to a given noise is sufficiently wide that a change of noise level of less than 5 dB would not produce a significant change in the general pattern of reaction to the noise." The authors believed that an attempt to specify a noise environment of a community to a precision greater than 5 dB was unrealistic.

The presence or absence of discrete frequencies, defined as "audible", was intuitively felt to be of importance in the qualities of the noise. The proposal made in this scheme was

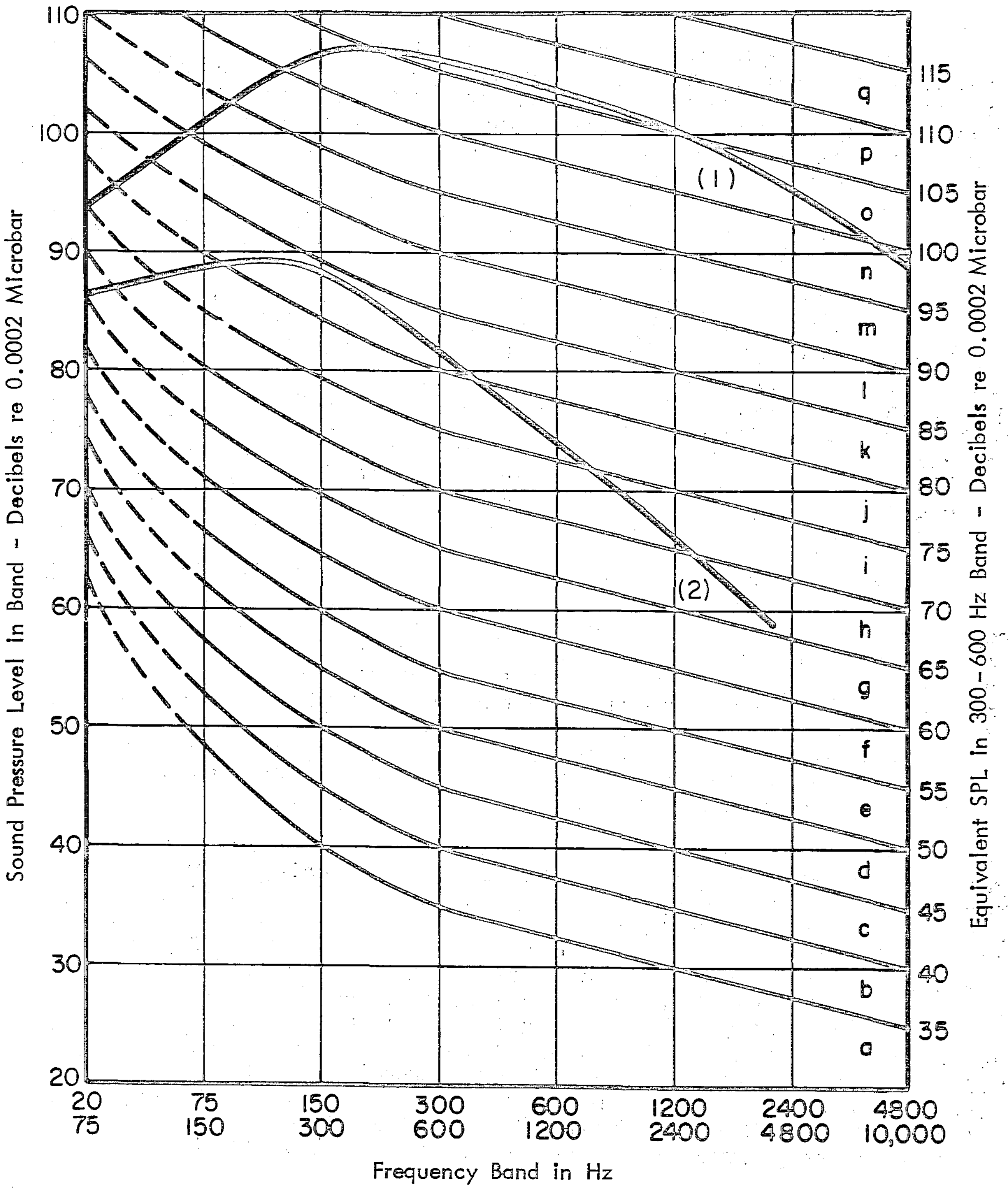


FIGURE 1. DETERMINATION OF EQUIVALENT SPL IN 300-600 Hz BAND FOR TWO TYPICAL SPECTRA. VALUES ARE 105 dB FOR SPECTRUM (1) AND 80 dB FOR SPECTRUM (2) TO THE NEAREST 5 dB. (From WADC TN 57-10)

that, when audible frequency components were present, the "effective stimulus" was essentially 5 dB higher than if the discrete frequencies were not present. It is interesting to note that this factor dropped out of the succeeding schemes to be described later until the latest version in which the effect of discrete frequency components is included in the basic noise measure, the effective perceived noise level. The magnitude of these adjustments now turns out to be between 0 and 6 dB, depending upon the protrusion of the tone above the surrounding broadband levels.

In the initial development of CNR, there were some cases where impulsive noise sources were part of the case histories used in evolving the community reaction scheme. An intuitive correction factor for "impulsive" sounds was introduced. The definition of impulse was not advanced and was left to the interpreter of the system to decide whether or not he wanted to make an additional correction for this parameter. The suggested parameter was that if "impulsive" characteristics were associated with the noise source in question, the effective stimulus was increased by 5 dB over the steady state noise level of the source.

The repetition of the source was considered as a significant factor. In the first version of CNR, a direct formulation for the repetitiveness, or what we now refer to as the duration effects of a noise, was introduced by providing a table which gave correction numbers related to the number of times during the day that the individual source was present. Since the typical noise source considered was expected to be 20 to 30 seconds in duration, i.e., related to a typical aircraft flyover at the time, the repetitive nature was in terms of how many of these events occurred per minute per hour or per day.

Background noise level in the community was expected to be a significant element in the determination of community response. Allowance was made for background noise having one of a series of octave band spectra provided in a chart. Associated with the typical background spectra were descriptors of the neighborhood in which these might be encountered. These range from "very quiet suburban" through "suburban, residential urban, urban near some industry", to "area of heavy industry". Over this range, a correction to the effective stimulus of +5 decibels to a -15 decibels was applied in the order of the names just described. Thus the presence of a noise source in an "area of heavy industry" would have an effective stimulus as much as 20 dB less than if that noise source were found in a "very quiet suburban area".

The next concern was whether or not the noise source was present during the day and night, or whether it was present only during the daytime. If the source were not in a continuous nature, then for daytime only operations, a reduction in the effective stimulus of 5 dB was proposed.

Finally, the last quantitative adjustment advanced was a consideration of the adaptation of the community to the noise. The corrections implied that a value of -5 to -10 dB in the effect of the stimulus could be utilized depending upon how well the community had adjusted to repeated exposures of the noise in question. It was suggested, however, that if the intruding noise were a new one, no correction should be applied and that only under extreme conditions ("such as emergency or wartime") should a correction number of -10 dB be applied.

Utilizing the above series of adjustments, the authors derived the effective stimulus for a series of 11 case histories in which measures of noise level and its operation could be coordinated with a measure of community response. The resulting calculations were expressed against a six element scale of response which used the descriptors:

no annoyance
mild annoyance
mild complaints
strong complaints
threats of legal action
vigorous legal action.

It was stated that the number of case histories did not substantiate the proposed scheme in great detail, and that, indeed, some of the proposed correction values for the effect of stimulus were based more on experience than on measured results from case histories. Thus the scheme advanced was a preliminary proposal for relating the physical elements of a noise source and some measures of the noise-related attributes in the community to an identifiable response.

B. <u>Composite Noise Rating - 1955</u>

A slightly modified form of the previous scheme was published by Stevens, Rosenblith, and Bolt in January 1955.[2] Modifications consisted of an extension of the range of consideration of background noise levels over a range of +10 to -15 decibels, a statement of the repetitiveness of the noise source on the basis of the percentage of time it operated in an 8-hour period, and a quantification that allowed for an adjustment for summertime and wintertime operation or a wintertime only case. In this case if the source operated only in the wintertime, a reduction of -5 dB in the effective noise stimulus was permitted.

In addition to the cases described in the first publication, an additional case of aircraft operation was mentioned in detail, and five new cases of community response were plotted on the scale of stimulus vs. response. One significant difference in the two publications, however, is a change in the description of response. In the previous publication six descriptors were utilized and the words such as annoyance and legal action were employed. In the 1955 publication the scale of response was reduced to five descriptors of the following nature:

no observed reaction
sporadic complaints
widespread complaints
threats of community reaction
vigorous community reaction

Examining this set of response against the first set, for the same cases, shows that change was made only in the lowest scale factors where the previous descriptors "mild annoyance" and "no annoyance" were now basically treated as "no observed reaction," and the range from "mild annoyance" to "mild complaints" was collapsed into "sporadic complaints." It is interesting to note that, as future prediction schemes were evolved, the uncertainties in response continues to be greater at the lower ranges of response than at the higher.

This proposed scheme, with slight modification, has survived over the years in a number of publications. It is cited in acoustical manuals, produced by Broch in 1967[9] and Peterson and Gross since 1967.[10] It formed the basis for a proposed International Standards Organization rating scheme for community response to noise of all types. Although it has not received a systematic validity examination, it has, on an empirical basis, been used in many noise control cases of a practical nature.

One of the observations that can be made is that, in starting from scratch to predict community response to a specified noise source, the expected level of community response may be lesser or greater than predicted by the scheme. However, when a noise source exists in a community, and a calibration of the point in the response scale which is produced by the noise source in that community is available, then changes in the operating conditions or modifications to the noise source and their changed effect upon resultant community response are predicted quite well by the procedure.

Thus, on an absolute basis, a substantial variance in response may result from the application of this procedure. However, on a relative basis, moving from one set of conditions to another, moving along the prediction scale works very well.

C. The Application of Composite Noise Rating Directly to Aircraft Noise - 1957

Both ground and airborne operations of military jet aircraft were of significant concern to the Air Force. To better predict the effect of these operations and to analyze the resultant effect on community to changes in these operations, the Air Force sponsored investigations of the physical properties of aircraft noise, noise propagation, and community response. Recognizing that an acceptably valid measure of community response could only be obtained through widespread surveys in communities exposed to noise, the Air Force pursued two paths. One was the acquisition of physical measurements of the noise produced by the aircraft operated by the Air Force and the evolution of engineering techniques for predicting the resultant noise exposure from these operations in the community. In parallel with these studies it supported the preliminary development of investigative techniques for exploring communities' response on a wide scale, Borsky[11]. Since the results of the community investigations were subject to funding limitations and time, the Air Force desired a planning guide which would utilize the previous CNR procedures for estimating response, but which would have more sophisticated input information in terms of the physical measurements of aircraft. Further, it wished to take the concept from the measurement of the noise from a single source to the prediction of the effect of a large number of separate operations, combining the result in a single noise rating number scale which could be related to community response.

The publication by Stevens and Pietrasanta in 1957[3] was a significant step in achieving the above two goals. It was also the first in a series of modifications to the CNR concepts which accounted for the specific nature of the sources involved and disregarded some of the adjustments to the "effective stimulus" proposed by Rosenblith and Stevens because they did not apply in the case of the aircraft noises considered at that time. (It is interesting to note, however, that fan jet engines and sonic booms bring back some of the attributes dropped in the early scheme.)

The major change in this procedure from the previous approaches was in the method of describing the physical nature of the noise sources themselves. It was observed from field measurements that most military turbojet noise spectra, at distances of interest in the solution of air base noise problems, had spectral shapes such that in most instances the level in the 300 to 600 Hz frequency band controlled the level rank in the previous CNR approach. For those spectra (e.g., flyover noise at some distance from the flight path) in which the 300 to 600 Hz octave band levels did not directly control the level rank, an equivalent level for the 300 to 600 Hz band could be selected. While the original loudness-weighted level rank curves were used in deriving the magnitude describing each of the sound sources in this procedure, the simplification was in using only the sound pressure level in the 300 to 600 Hz band instead of all eight octave bands as used previously. An example of this description is shown in Fig. 1.

Adjustments for discrete frequencies and the impulsive nature of sounds were eliminated in the 1957 document. These two factors were dropped from the procedure not because they were considered unimportant but simply since they were not present in the noise produced by most military turbojets of the time. (For some afterburning engines the starting transient did provide a slight starting impulse which might have called for a corrective factor. Since the number of such incidences were small, and the relative reaction to the starting transient of the afterburner was not of major significance, an impulse correction was not considered.)

Repetitiveness or the effect of duration was next considered by assuming an averaging of the time-varying signals from the aircraft operations to determine the "equivalent continuous sound pressure level." This value was determined from the following equation:

$$L(eq) = L_{max} + 10 \log_{10} \left(\frac{\delta t}{3600}\right)$$

The L(eq) was the maximum SPL in the 300 to 600 Hz band plus a correction for the effective duration of this signal (δt) in seconds. Note that the correction for the duration of the signal is a strict energy summation. The L(eq) is therefore an energy-weighted equivalent sound pressure level.

The procedure next made adjustments to L(eq) in a similar manner to that done in the previous CNR descriptions. The correction factors included were a seasonal correction and a correction for time-of-day which now split the daytime-nighttime cycle into three periods. Daytime was described as 0600 to 1800, evening, from 1800 to 2300, and nighttime, from 2300 to 0600. The reference condition was the evening where a 0 correction was provided. Daytime only operations took a -5 dB correction, while nighttime operations took a +5 dB correction. Background noise corrections followed the same pattern as used previously, ranging from a +5 dB correction for very quiet suburban or rural communities to a -10 correction for a noisy urban community.

At this point in time there was some evidence from the studies being performed by Borsky[11] that community attitudes and public relations around an air base tended to improve the reception by the community of the noise produced from the air base. On the basis of some of these preliminary findings, adjustments for previous exposure and community attitudes were applied in this procedure. Thus, where Rosenblith and Stevens had indicated some factors such as community attitudes were important, and that some allowances for previous exposure could be incorporated in the CNR adjustment factors, in this document Stevens and Pietrasanta attempted to quantify these more specifically. In the procedure they provided the following descriptions to go with the "correction" (adjustment) factors:

> "Community has had some previous exposure to noise from air base operations, but little effort is made to foster good public relations; correction may also be applied in a situation where the community has not been exposed to noise from air base operation previously, but some effort has been made to foster good public relations. -5 dB
>
> "Community has had considerable previous exposure to noise from air base operations, and air base-community relations are good. -10 dB
>
> "With good public relations, the correction can be applied for an operation of limited duration: it cannot be applied for an indefinite period. -15 dB"

The resulting comparison of the adjusted L(eq) was translated into a community response table in a similar manner to that in the previous CNR computations. In this particular use, however, the descriptors for community response were again reduced, now, to only three categories. In essence the range of response was chosen to define a band 10 decibels wide, below which it was expected that no serious problems would occur, and above which it was expected that concerted group action would take place. The 10 dB band in the center covered the expected range of variance in individual and community attitudes. Thus the previous 5 dB step descriptors employed in the general CNR scheme were now reduced to three regions of interest. These of course were "no concern," "an area of uncertainty," and "unquestionably unacceptable." The words employed by Stevens and Pietrasanta were the following:

"Description of Community Response	Equivalent Continuous SPL in 300-600 Hz Octave, Plus Corrections
Essentially no complaints are reported: the noise may, however, interfere occasionally with activities of the residents.	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.	45 to 55 dB
Concerted group action is brought against the authorities. The community action may vary from strong threats to vigorous action.	Greater than 55 dB"

Up to this point in the procedure the development related primarily to a simplified means for determining the physical attributes of sound and allowance for the various adjustment factors to derive an "effective stimulus" which could be related to community response. The next major step outlined in this document, however, was the development of a series of techniques to allow the user to proceed directly from a series of operational characteristics of aircraft to derive a noise rating and expected community response.

A number of new steps were involved. One was the development of a set of basic contours for ground runup operations and a table which would allow the modification of these contours for the specific aircraft of concern. The contours were based on an engine of known acoustic power level. A table was provided for all military aircraft in operation at the time which would account for the differences in power levels of the different aircraft and allow for adjustments to be made to the contours provided to account for the differences in power levels of the individual aircraft.

The data presented for ground run-up operations were based on a large number of measurements performed on many aircraft.[12] The data for the basic set of noise levels were presented in the form of contours of equal L(eq). The contours could then be overlaid on a map of the air base to determine the L(eq) at any point on the base.

During the course of the studies leading up to this procedure, various ways of presenting the noise exposure from an aircraft in flight were considered. The procedure used here was described by Stevens, Galloway, and Pietrasanta[13] in 1956. Measurements of the noise produced on the ground by a large number of aircraft flying overhead at different air speeds and heights above terrain had been obtained. Examination of the data indicated that the complex time pattern of SPL produced during a flyover could be replaced, on an equal energy basis, by an equivalent square time pattern whose magnitude had the same SPL as the maximum in the original signal and whose duration was that obtained from the original time pattern by observing the duration between the points at which the SPL was 5 dB below the maximum. An example is shown in Fig. 2.

Next, generalized profiles of height as a function of distance from start of take-off roll were developed for two classes of aircraft; one for fighters and light bombers, and the other for heavy bombers. It was assumed that the fighters would accelerate at a rate of 5 ft./sec.^{2} to a speed of 300 knots, and that the bombers would accelerate at a speed of 4 ft./sec.^{2}. A directivity pattern derived from the measurements having a maximum occurring about 40° from the jet axis was used. Corrections for atmospheric absorption of sound were developed from a combination of measured data and existing theory. Combining these factors, contours of L(eq) in the 300 to 600 Hz band were computed, using a single sound power level of 170 dB re 10^{-13} watt for the source of sound.

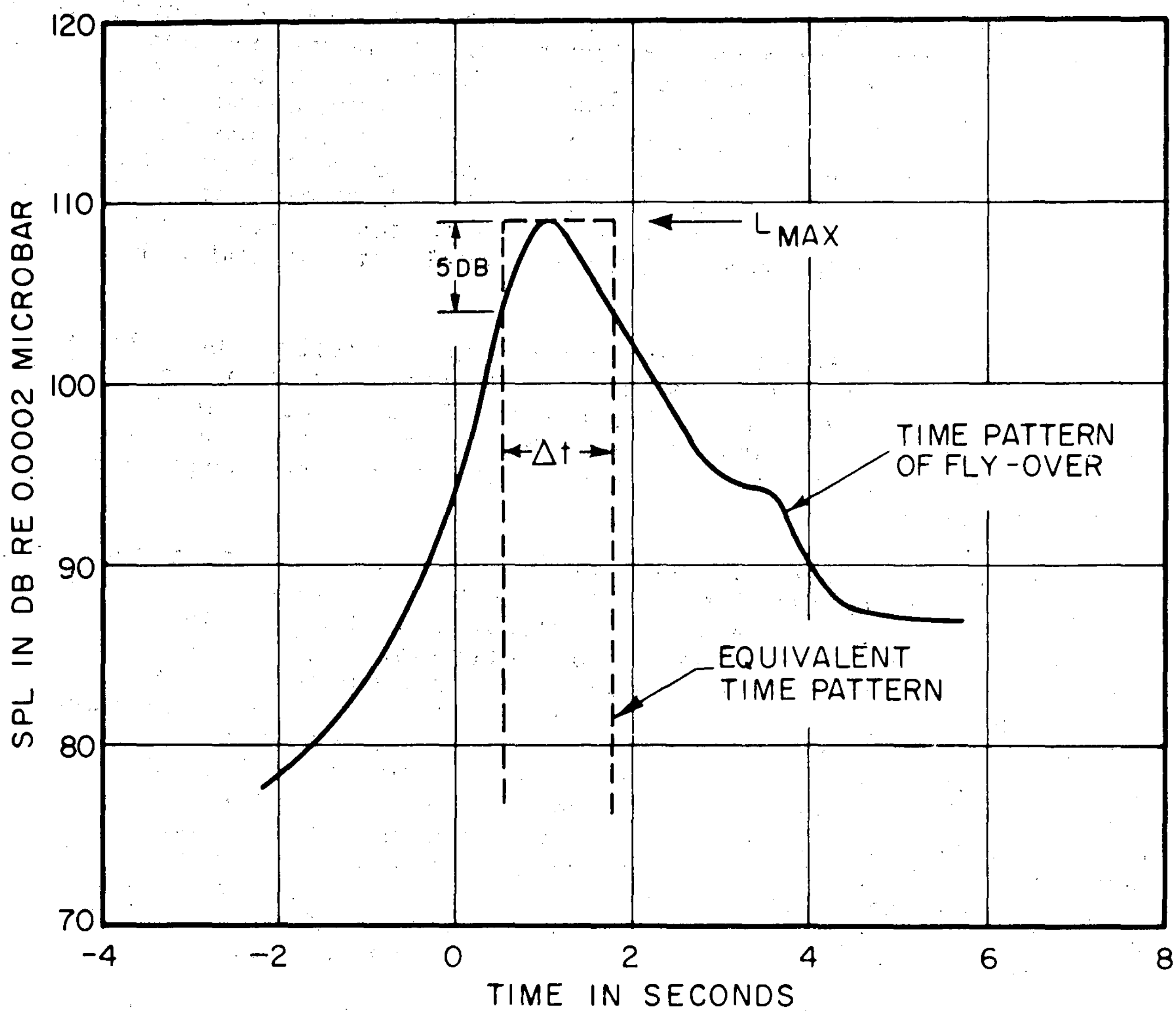


FIGURE 2. TYPICAL TIME PATTERN OF SPL IN 300-600 Hz BAND FOR FLYOVER OF JET AIRCRAFT. THE DASHED LINES SHOW AN EQUIVALENT TIME PATTERN FOR WHICH THE TOTAL ENERGY AND THE MAXIMUM SPL ARE THE SAME AS THOSE OF THE ORIGINAL TIME PATTERN.
(From WADC TN 57-10)

Correction charts were supplied to adjust the numerical values of the contours for different aircraft having higher or lower engine power levels. An example of these contours is shown in Fig. 3.

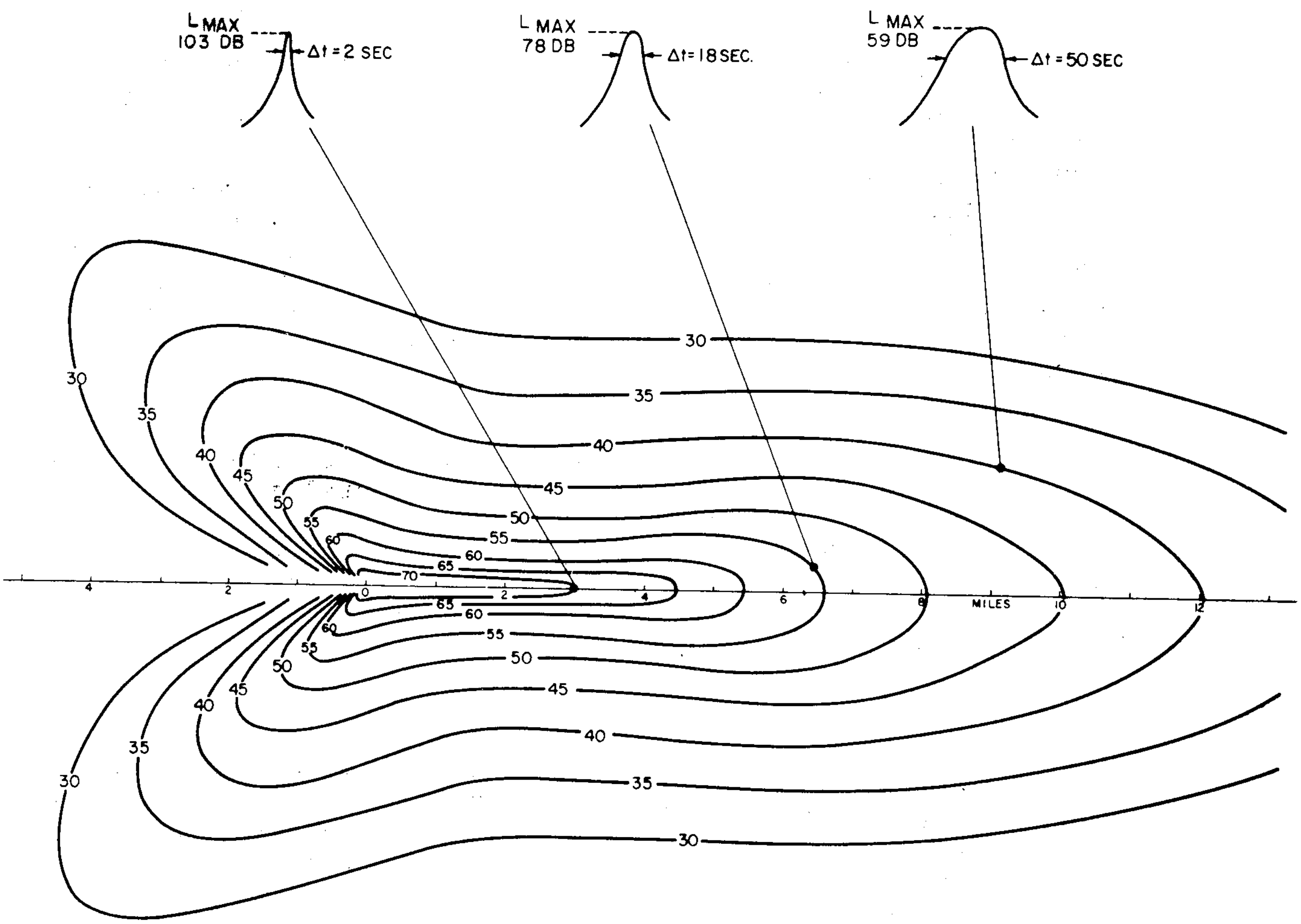
The resulting flyover contours thus contained all the elements of the engine source characteristics, the time varying elements associated with acceleration and distance from the source, and the effects of directivity, distance, and air absorption in the propagation of the sound to the ground. These contours could be overlaid on the airbase map to obtain the L(eq) of any point on the ground. By summing the number, N, of such operations in the chosen time period on an energy basis, i.e., $10 \log_{(10)} N$, for each type of aircraft operation, and adjusting the L(eq) for source power, the total L(eq) for a set of operations could be obtained at any point on the ground.

Examples were provided to show how the results of both ground run-ups and flight operations could be combined to develop a composite set of contours of L(eq) for a totality of operations on an airbase. The numerical values on these contours were then related to the community response scale derived earlier. This procedure was adopted by the Air Force and was widely used as a planning tool in the analysis of military airbase noise problems throughout the world.

D. Composite Noise Rating - 1963-1964

By 1962 several developments had taken place which led to the preparation of a new planning document. The most significant factor was the psychoacoustic development by Kryter[8], of the perceived noise level (PNL), reported in PNdB, as a single number measure relating the physical measure of noise to subjection judgments of the annoyance of that noise. The PNL concept was developed directly as a result of the introduction of the Boeing 707-120 commercial jet transport aircraft. In the initial statements concerning the noise output of the aircraft, Boeing claimed that it would be no more noisy than existing propellor-driven aircraft. Their interpretation of this statement was that the overall sound pressure level produced under comparable operating conditions would be no greater for the jet than was then produced by the propellor aircraft. During the flight test program, however, observors noted that the jet sounded much noisier than a propellor aircraft of equivalent overall SPL. The answer was clearly in the differences in the spectral distribution of the two different sounds.

EXAMPLES OF TIME PATTERNS IN 300 - 600 Hz BAND



Contours of Equivalent Continuous SPL in 300 - 600 Hz Octave Band for Take-Off of One Jet Fighter Aircraft Per Hour With An Overall PWL of 170 dB Re 10^{-13} Watt. It is Assumed That There is No Pre-Takeoff Run-Up, Acceleration of 5 ft/sec^2 Up to a Speed of 300 Knots. Typical Time Patterns Are Shown for Three Locations.

FIGURE 3. NOISE CONTOURS FOR FIGHTER TAKE-OFFS (From WADC TN 57-10)

This observation prompted the management of the Port of New York Authority to support research on the development of a single number description of a sound which would allow two sounds of different spectral shape to be equated in a judged annoyance or noisiness basis if the single number descriptors of the two sounds were numerically equal. Kryter, recalling his earlier work on this subject[7], and building upon the recent work of Stevens on the loudness of bands of noise [14], developed a set of equal noisiness functions for sound pressure levels in the various frequency bands. Using these functions, and the Stevens summation procedure, a single number was computed for a complex sound spectrum. The magnitude of this number was termed the perceived noise level in PNdB.

It is interesting to note that had the aircraft industry accepted the initial concept of CNR, the PNL might never have been developed. If one superposes a typical propellor spectrum and a typical turbojet spectrum on the original level rank curves of Rosenblith and Stevens, he finds that, in order to achieve the same level rank value, the overall SPL of the jet spectrum must be lower than that of the propellor spectrum by essentially the same amount as would be required for the two spectra to have the same PNL value. See Fig. 4.

The second factor entering into the decision to produce a new planning document was a general dissatisfaction with the planning document then in use by the FAA[15] for depicting noise around an airport. This document provided contours of the maximum noise level on takeoff for a single aircraft and did not take into consideration such variables as frequency of operations, runway utilizations, variations in aircraft performance with load and other factors related to noise exposure from a series of operations.

As a result of these two elements, a subcommittee of the Committee on Hearing and Bioacoustics of the National Academy of Sciences/National Research Council was asked to review the situation. Their recommendation was to rewrite the Air Force document TN 57-10 to incorporate descriptions of noise in PNdB and to incorporate data for both military and civil aircraft in a single planning document for joint civil and military use. This document was also to include as much as possible of the findings obtained from the sociological surveys completed by Borsky[11], as interpreted in an analysis by Clark[16]. Further, simplifying steps were to be introduced wherever possible so that complications such as logarithmic addition of decibel quantities would not be required of the acoustically-naive user.

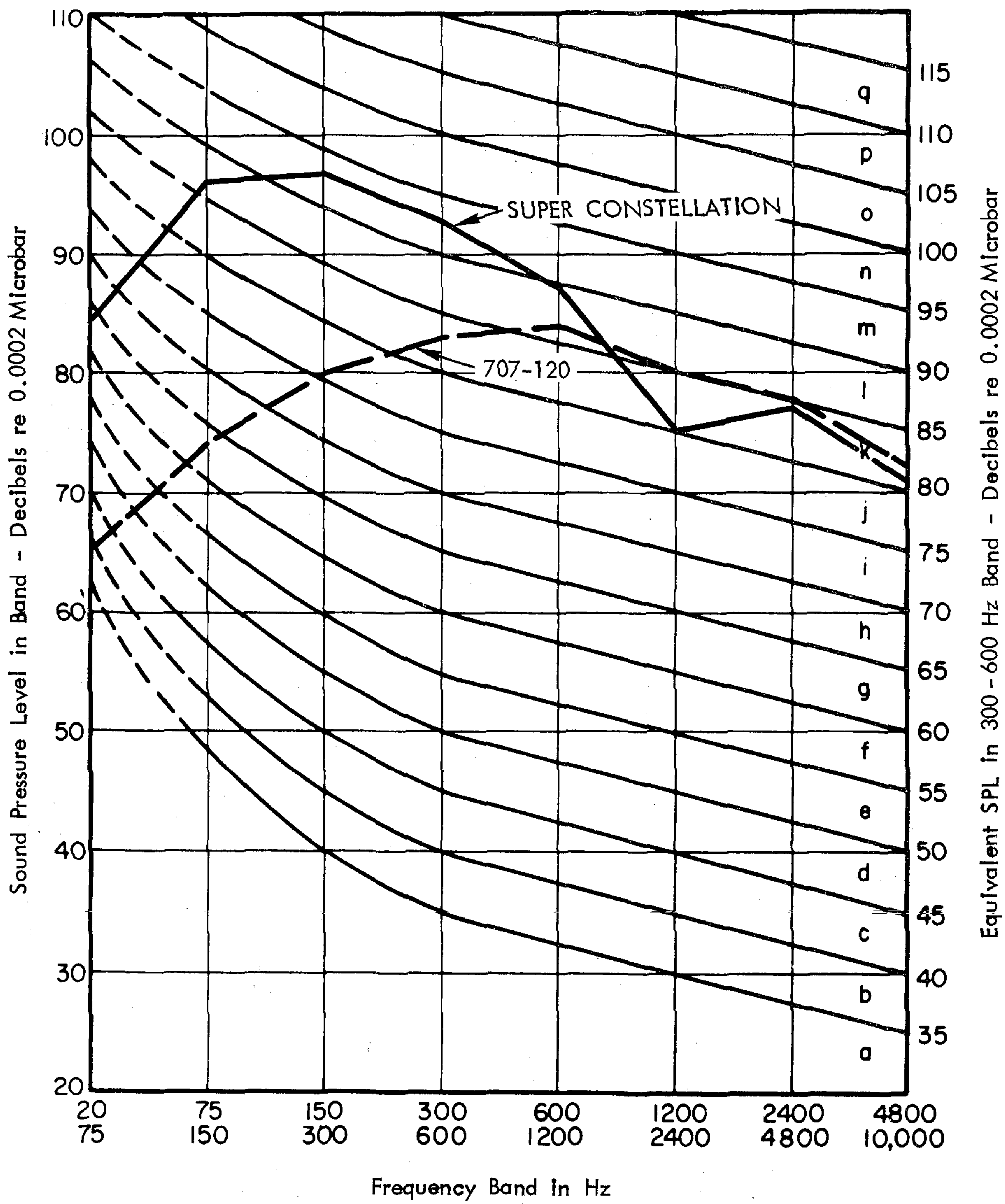
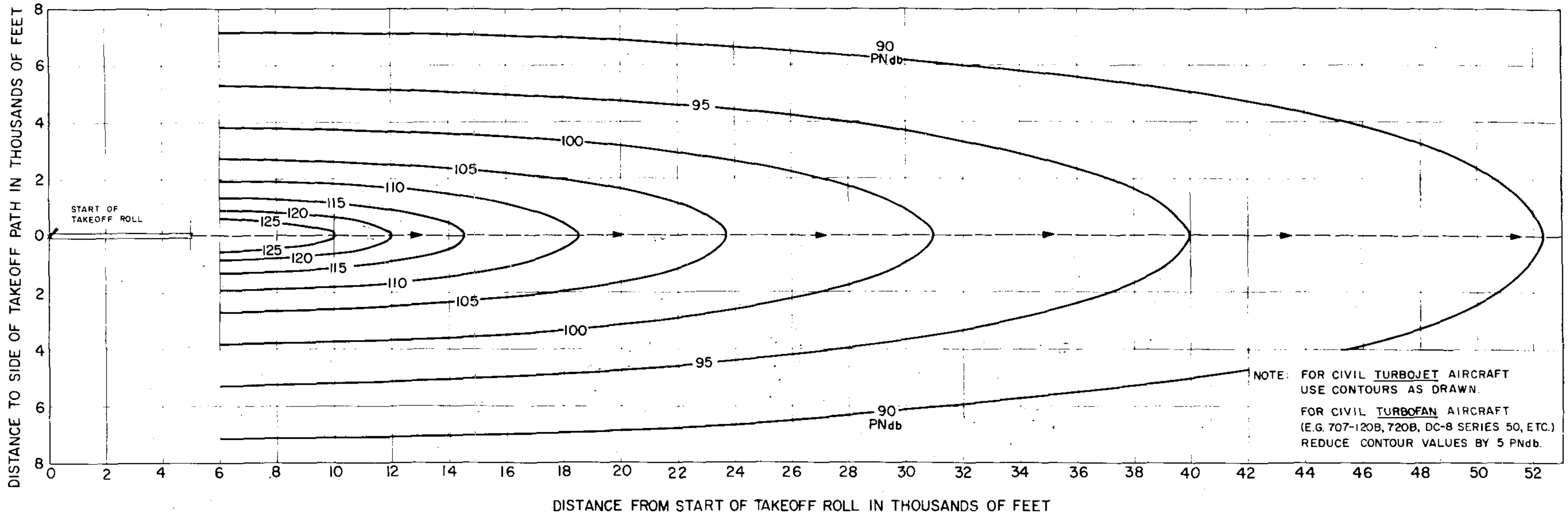


FIGURE 4. COMPARISON OF PROPELLER AND TURBOJET TRANSPORT AIRCRAFT SPECTRA FOR JUDGED EQUALITY IN NOISINESS

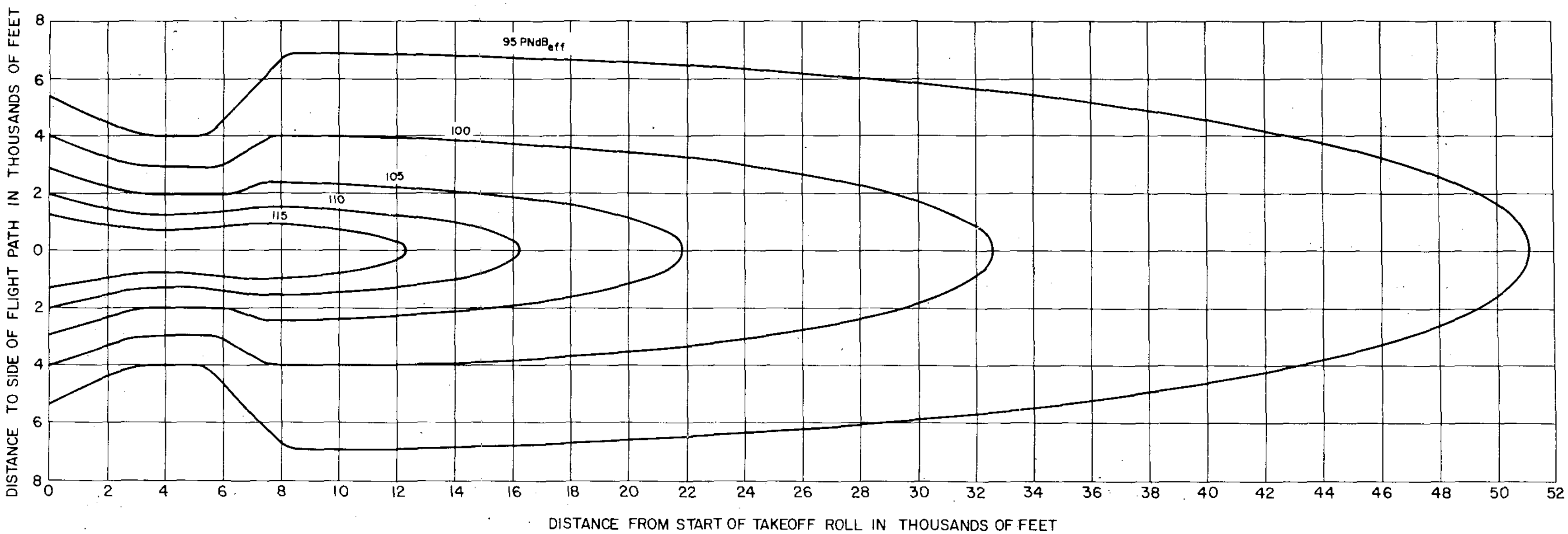
A completed draft of the document "Land Use Planning with Respect to Aircraft Noise" was submitted by Galloway and Pietrasanta in July 1963.[4] This document incorporated the following features. First, the noise from different aircraft operations were described in contours of maximum PNL. In order to cover the large number of aircraft considered in the study, the aircraft were grouped into classes on the basis of aircraft type, engine type, and performance. Since the introduction of commercial jets, noise from landing operations had become of concern, so noise contours for landings were also provided. In all, fourteen sets of contours were required to cover the variety of aircraft considered. An example of these contours is shown in Fig. 5.

The effects of the duration of a flyover signal were also treated differently. An examination was made of the variation in time patterns of the noise produced by civil aircraft in the vicinity of airports. It was found that the distribution of durations, as measured at levels of 5 dB or 10 dB below the maximum level and evaluated on a 10 log duration basis, did not vary more than ±3 dB from the average. In order to simplify the calculations, and because the final results were to be considered only in 5 dB increments, it was decided to exclude the individual time history effects of each aircraft explicitly, and to consider that the duration of an individual flyover was considered implicitly by the average duration of the distribution considered in developing the procedure.

The PNL contours described above were the counterpart of the L(eq) contours used in TN 57-10. The next step was to develop adjustments which would account for the factors required to relate the description of a single event to the community response produced by the total operations from an airport. Repetitiveness, or the total duration of noise over a given time period was considered by applying a correction factor for the number of aircraft operations of each class of aircraft on each runway. Two steps were employed in obtaining this factor. Since most airports report aircraft movements as a total, and then provide an annual runway percent utilization, these values were multiplied to obtain the number of aircraft of each type using a given runway within a given time period. Second, to avoid logarithmic summations, the number of operations were broken into numerical ranges which, on an equal energy basis, would provide 5 dB increments in total energy. The corrections were normalized so that a zero dB correction would exist if the average number of movements on a specific runway were between 10 to 30 during daytime hours.



Perceived Noise Level Contour



Effective Perceived Noise Level Contour

FIGURE 5. COMPARISON OF PERCEIVED NOISE LEVEL AND EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS FOR TAKEOFF OF LARGE CIVIL TURBOJET TRANSPORTS (Trip Length Less Than 2000 Miles)

Previous case histories and information from the sociological surveys in this country and in Britain indicated that, all other things being equal, noise exposure from night operations needed to be from 10 to 17 dB lower than daytime operations to achieve a comparable response in the community. A compromise correction factor requiring nighttime noise exposure to be 10 dB less than daytime exposure was used in this procedure. Only two time periods were employed, 0700-2200, and 2200-0700, to simplify computations. At the time of release of the document, few airports had sufficient night operations to have night operations control the resulting CNR.

The results of the Borsky studies[11] had shown that background noise levels, per se, had essentially no effect on the community response to noise from aircraft operations. As a result, background noise was dropped from the adjustments in this document. Similarly, no explicit adjustment for previous exposure, public information programs, or other intervening factors were explicitly considered for flyover operations because of the difficulty in obtaining such information for any arbitrary airport, and because no explicit means for quantifying such relationships could be agreed upon by the agencies sponsoring the development of the document.

The final step of relating the CNR values obtained by applying the above adjustment factors to the PNdB values employed a different approach from that of the previous document. In TN 57-10, the numerical value of L(eq) with its adjustment factors was translated to what its level rank value in the original CNR scheme would have been to determine the numerical values which were to be correlated to expected community response. In essence, the original case histories, with a few more judgments of their validity, were used to establish the translation of adjusted L(eq) to response. In the new document it was assumed that all the available operational and noise factors were included in the procedural computation of CNR. The procedures were then used to compute the CNR values for 21 specific case histories which included both civil and military airports, where the operations were well known and an assessment of community response could be made.

The measure of response was strictly on the basis of individual complaints, group complaints, and overt community action. It was recognized that Borsky's results had indicated complaints were not a good measure of the attitude of the community. This approach was selected, however, on the basis that the severity

of complaints provided an operational measure of how well the community would tolerate the operations regardless of other feelings the community might hold about the noise.

On the basis of the case histories it was found that, retaining the basic zones of response used in TN 57-10, e.g. a lower zone of little concern, a "grey" area of mixed individual and community action, and an upper zone of high probability that the community would take vigorous action against the airport, numerical boundaries for these zones could be identified. For daytime operations, the boundary between the lower two zones was provided when the quantity $\overline{PNdB}_{max} + 10 \log_{10} N$ equalled 112. In this expression $\overline{PNdB}_{max}$ was the average maximum PNdB for the operations considered, and N was the number of operations.* Similarly, the separation between the middle and upper zones could be identified by the value of 122. In both instances a standard deviation of the order of 5 dB was estimated. In order to give the airports the benefit of the doubt it was finally decided that the middle zone be increased to a value of 127 because of this variance in response.

Both the numbers 112 and 127 had a connotation of precision and a lack of nicety in their values. It was decided at this point that normalizing the number of operations at the 10-30 level to provide a zero adjustment to the number of operations would allow the zonal separators to be designated as 100 and 115 respectively. These were then defined arbitrarily as CNR values of 100 and 115. See Fig. 6 for the distributions of level with community response.

The case histories for ground-runup operations provided a different story. It was found that, from the limited data available, an equivalent community response to that for flight operations required a 20 dB lower CNR. This rather startling displacement is probably due to a series of confounding conditions in the cases examined. Most of the operations occurred at night. The background levels in the communities were some 10 dB lower than in daytime. The case locations were in suburban residential areas of medium economic status.

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* The fact that the number 112 is also the number set by the Port of New York Authority for the maximum permissible PNdB at certain ground positions for takeoffs from John F. Kennedy International Airport is pure coincidence, there being no relationship whatsoever between these situations.

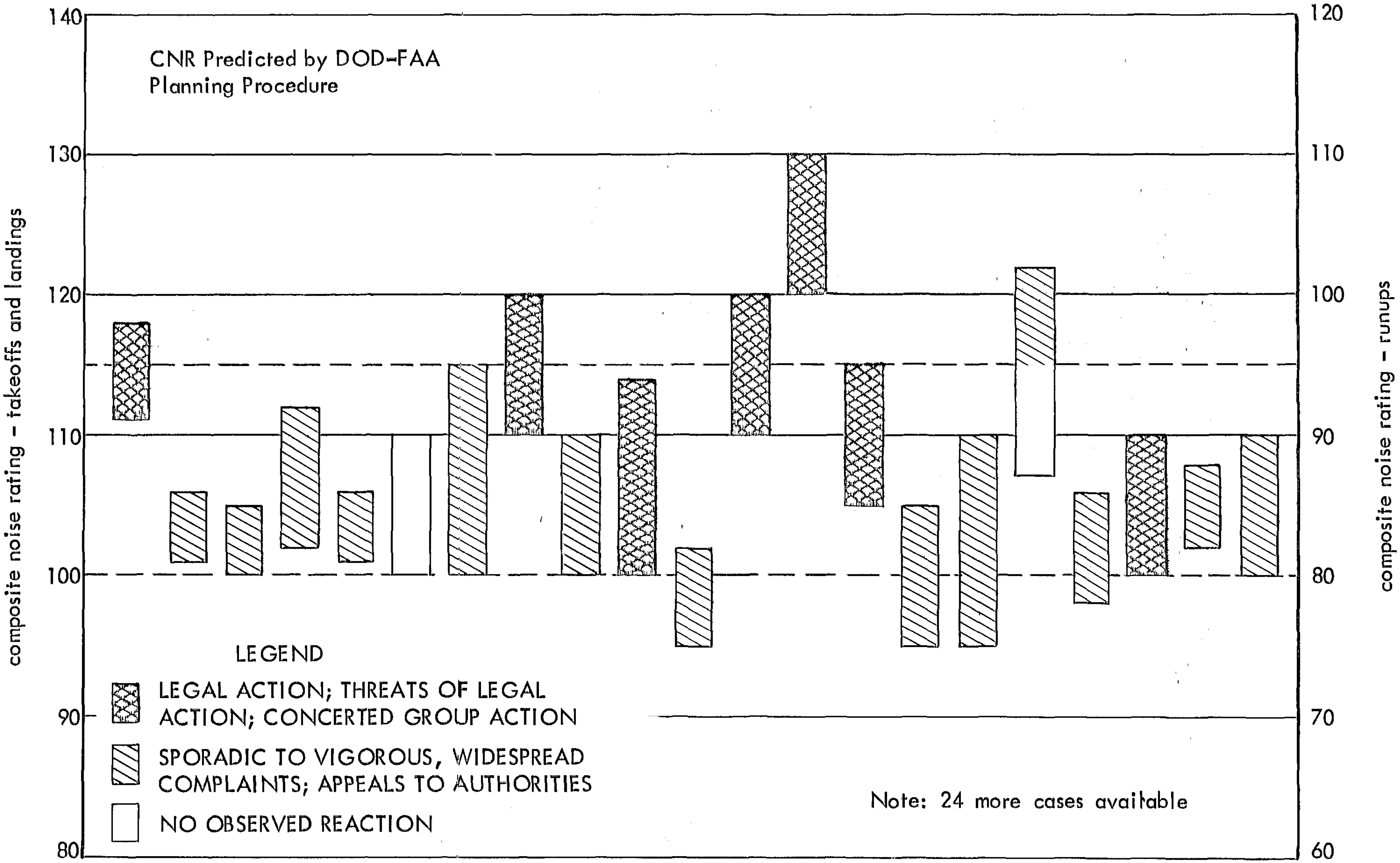


FIGURE 6. CORRELATION OF CASE HISTORIES OF OVERT COMMUNITY RESPONSE WITH COMPOSITE NOISE RATINGS

Few flight operations were happening at the time of the runups. And finally, the complainants expressed the feeling that the airport could control the runup operations whereas they believed the airport operators when they said they had no control over flight operations. Thus, there is nothing inherently different in noise produced by ground versus flight operations in terms of physical descriptions of the noise (with duration effects taken into account), yet the other intervening factors take on great significance in determining community response. Since ground runup operations which cause community complaints are very small in number compared to flight operations, this difference in relative acceptability has received little attention.

Subsequent to the issuance of the draft document a meeting was held by FAA with representatives of airlines, airports, and aircraft and engine manufacturers. While the military services accepted the document, the civil aviation segment raised violent objections. Some of the objections were of a technical nature, some were on choices of words, but most were on the basic policy. After protracted discussions with industry spokesmen, the FAA released the document in October 1964 as a contractor's technical report assuming no responsibility for its representations. The military services issued the document on a tri-service basis for use in airport/land use planning.

As finally issued, the words describing the expected response associated with the three CNR zones were changed from those of TN 57-10 to the following:

Composite Noise Rating			
Takeoffs and Landings	Runups	Zone	Description of Expected Response
Less than 100	Less than 80	1	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the resident.
100 to 115	80 to 95	2	Individuals may complain, perhaps vigorously. Concerted group action is possible.
Greater than 115	Greater than 95	3	Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected.

At the present time, the document has not been endorsed by the civil aviation community. However, since issuance, it has been used by many airports, communities, airport planners and engineers, and land use planners for a variety of planning purposes. It is also used by the Federal Housing Administration in considering the guarantee of loans for new residential tract construction near airports.

An Appendix to the CNR document was published in 1965 providing additional PNL contours covering the newer smaller jet transports and business jet aircraft[17]. Additional PNL contours for helicopter operations were also published in 1965 by the FAA[18].

In 1964, Bishop interpreted the CNR values in terms of land use compatibility for a wide range of non-residential land uses[19]. Major emphasis was placed on speech communication requirements for different activities, and the importance of freedom from noise intrusions for special buildings such as concert halls.

E. Noise Exposure Forecasts - 1967-1969

Technical criticisms of the 1964 CNR procedure were based primarily on three features:

a) The discreteness of the 5 dB steps in summing the number of events through two steps (average number of movements and runway utilization) could cause ambiguities in the borderline cases where a change of one operation would place the results in the next class, increasing the CNR value by 5 dB.

b) The step approximations in summing the noise contributions by different classes of aircraft, or by different types of operations could lead to sizable over- or under-estimation of the effects on CNR values of changes in operations or changes in types of aircraft.

c) The continued evolution of the PNL concept to include duration factors and corrections for discrete frequencies was receiving gradual acceptance by the aircraft community. The effective perceived noise level (EPNL) which includes these factors was likely to be the unit used in certification of aircraft for noise. It was thus considered desirable to evaluate the noise exposure in communities using this unit as the basic descriptor of aircraft noise.

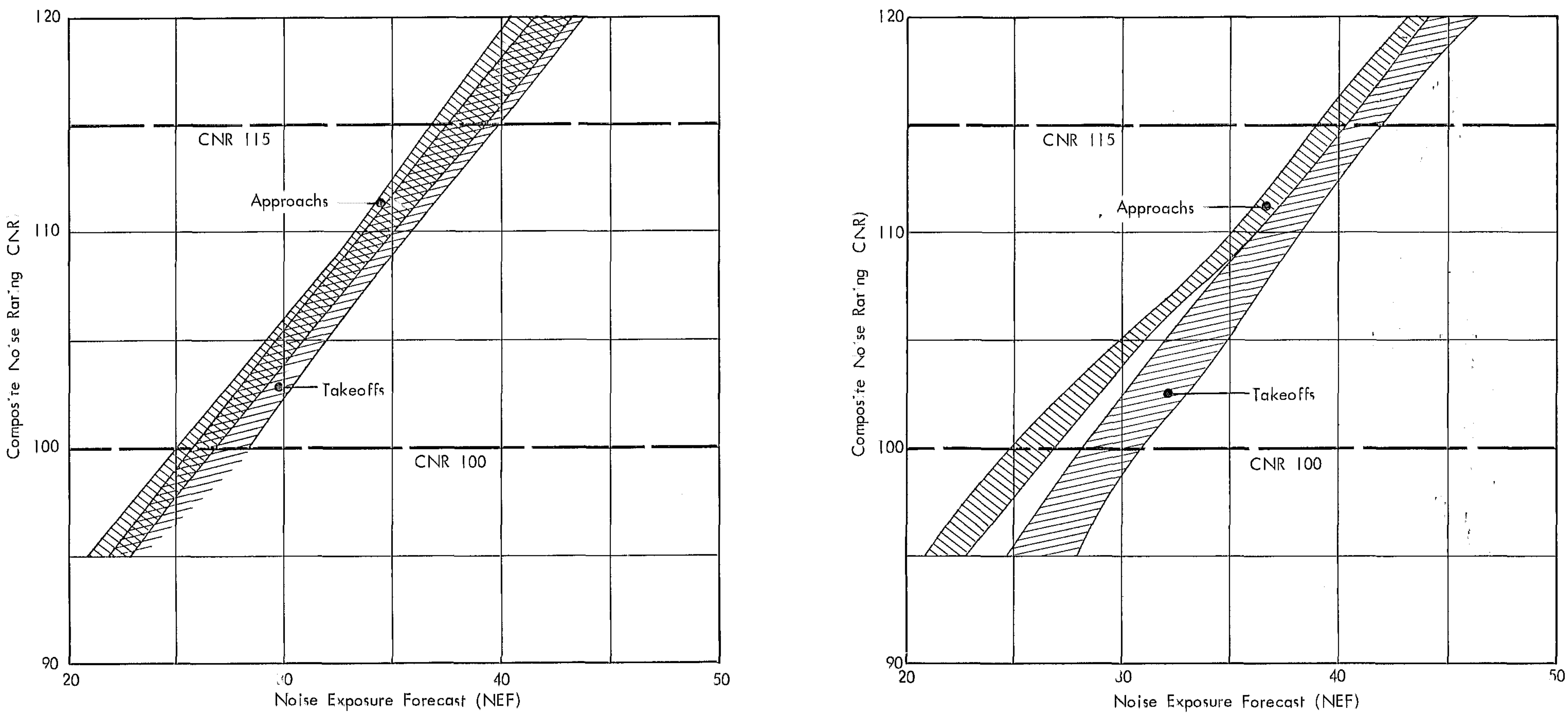
A secondary consideration was the impression that somewhat better expressions of aircraft classification and performance could be developed. Further, it would be desirable to have a new unit whose numerical values would be substantially different from CNR values or PNL values so that no confusion would result.

As a consequence of these considerations, FAA funded two independent studies [5,6] to develop Noise Exposure Forecast (NEF) procedures which would incorporate these refinements. The development was restricted solely to civil jet aircraft for which noise data was available to compute EPNdB.

EPNL computation requires a much more complicated procedure than the previous PNL computation. One-third octave sound pressure levels are used instead of octave data, and further, computations are required for each one-half second of the flyover time pattern in order to determine the discrete tone and duration corrections. An EPNL contour for turbojet aircraft takeoff is shown on Fig. 5 where it can be compared with the equivalent PNL contour.

Refinements on aircraft classes and operating characteristics were developed by industry representatives[6]. The adjustments to EPNL values to obtain the "effective" stimulus were the same as those used on the previous CNR studies. An arbitrary numerical factor was subtracted from the summation of EPNL and $10 \log_{10} N$ value to obtain the final numerical NEF value.

No new information on community response was applied in these studies. The zonal concept of responses in the CNR development was retained intact since Galloway and Von Gierke[20] had evaluated some additional 25 cases which appeared to validate the reasonableness of the zones selected previously. The identification of numerical values for NEF to be used in describing the zonal separations was performed by mapping the NEF values for a series of operations against the CNR values computed for the same set of operations as indicated in Fig. 7. The zone boundaries were then selected so that the NEF values would correspond approximately to the CNR values of 100 and 115.



A. LARGE TURBOJET TRANSPORT AIRCRAFT

B. LARGE TURBOFAN TRANSPORT AIRCRAFT

FIGURE 7. COMPARISON OF CNR AND NEF VALUES

III. COMPARISON OF VARIOUS METHODS FOR RATING AIRCRAFT NOISE EXPOSURE

In the previous sections we have indicated that there are two parts to the question of relating noise exposure to community response: 1) how the noise exposure is calculated, and 2) how response is correlated with the computed noise exposure. A number of different approaches to these two issues have been proposed throughout the world. Most have focused on the first part only, using different measures for noise level representations and different normalizing approaches to consider time patterns of the noise. There are several significant studies, however, in which both aspects of the problem have been considered. It is these studies in which independent assessments of community response have been evaluated that we now compare to the CNR/NEF procedures.

A. Noise and Number Index - United Kingdom

The present method for assessing noise exposure and community response in the United Kingdom is the Noise and Number Index (NNI) expressed by the following equation:

$$NNI = \overline{PNdB}_{max} + 15 \log_{10} N - 80$$

Where: $\overline{PNdB}_{max}$ is the average maximum noise level in PNdB for the aircraft flyovers, N is the number of aircraft in a specified period, e.g. one day or one night.

The NNI was derived from a combined experiment during which physical measurements were made of aircraft noise at 85 locations within 10 miles of London (Heathrow) Airport and approximately 2000 people living in the same area were interviewed concerning their general satisfaction or dissatisfaction with their living environment [23]. The physical measurements covered about 100 successive flyovers at each location and were used to define statistical distributions of level and time. The interviews probed 42 questions related to the respondents evaluation of his living environment.

The combined studies identified 14 variables related to the noise environment and 58 socio-psychological variables. The physical variables were intercorrelated and found to be reducible to two parameters, average maximum noise level in PNdB and the number of aircraft heard. The socio-psychological variables were used to derive a Guttman scale depicting a continuous measure of annoyance. Finally, the annoyance scale was correlated to the physical measures. In the derivation of these correlations it was estimated that doubling the number of events was equivalent to raising the noise levels by 4-1/2 dB, hence the 15 $\log_{10}N$ term in NNI. The constant of 80 was subtracted from the total noise exposure figures on the basis that the derived annoyance scale was zero at about 80 PNdB.

In addition to the derivation of an overall annoyance scale, the British study examined a number of separate indirect effects of noise, all considered to be components of annoyance, against noise exposure. Graphs of these relationships are provided in Ref. 23. These results were used to reach (among many similar findings) the following conclusions:

1) The number of people disliking aircraft noise exceeds those disliking all other factors (spontaneously mentioned) affecting their living conditions when NNI reaches 48.

2) Those who would change aircraft noise outnumber those who would change all other factors (spontaneously mentioned) of their environment put together when NNI reaches 48.

3) When asked to rate their area as poor or very poor for a variety of reasons, aircraft noise becomes predominant at an NNI of 50 to 54.

This evaluation is summarized as follows: "29. Taking into account all the inevitable uncertainties of the above comparisons, we consider that exposure to aircraft noise reaches an unreasonable level in the range 50-60 NNI."

The measurement of noise levels in PNdB and inclusions of number of events in determining noise exposure, the same elements used in computing CNR, allows a direct comparison of the London survey annoyance scale with the CNR computed for the reported noise exposures. This result is shown in Figure 8. It should be observed that the line is directly computed from the CNR equation and is <u>not</u> a fit to the data points. The correlation of CNR to average annoyance values is strikingly good. It can also be argued that a consideration of numbers of events on an energy basis, i.e. 10 $\log_{10}N$, gives as statistically significant a fit to the annoyance data as does

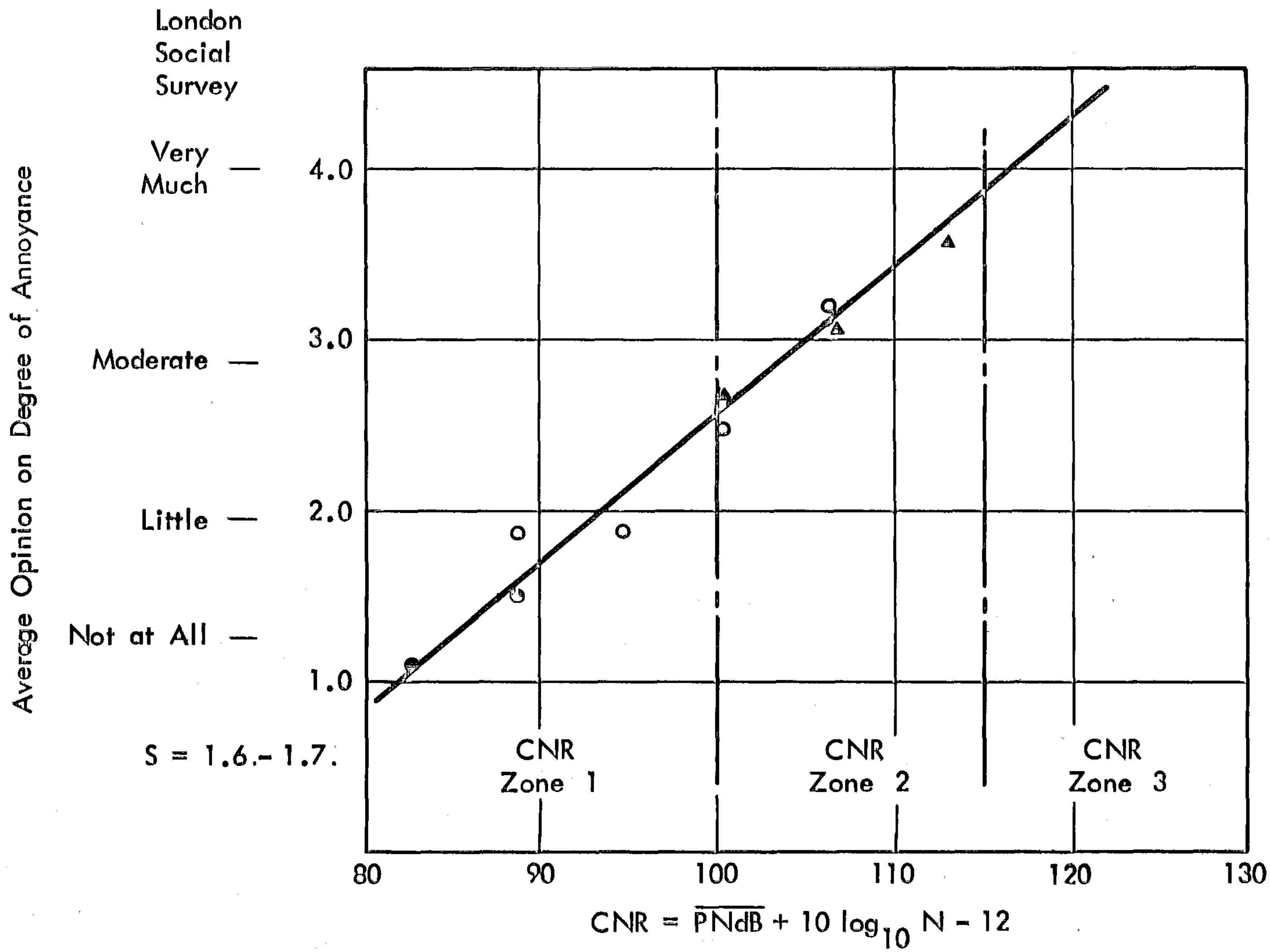


FIGURE 8. CALCULATED CNR AS A FUNCTION OF SOCIAL SURVEY ANNOYANCE SCALE - LONDON SURVEY DATA (1961)

$15 \log_{10} N$, and provides a considerably more palatable physical description of noise exposure.

B. Isopsophic Index - France

The representation of total noise exposure from aircraft operations employed by the French Ministry of Transport is called the Isopsophic Index, symbolized by $\mathcal{N}$, and computed (for daytime operations) from the following equation[24]:

$$\mathcal{N} = \overline{PNdB}max + 10 \log_{10} N - 30$$

where the symbols are the same as used in CNR or NNI. The constant in this expression, 30, is derived from the consideration that each aircraft movement causes a disturbing noise for 30 seconds and assumes that aircraft movements can occur at a maximum rate of one per minute. Considering daytime hours only, from 0600 to 2200 hours, then a maximum of 960 movements per day will result. Since $10 \log 960 \doteq 30$, the total noise exposure is approximated by subtracting 30 from $PNdB_{max} + 10 \log_{10} N$. In this formulation one observes that $\mathcal{N}$= CNR-18 exactly.

The treatment of night operations in the Isopsophic Index is considerably more complicated than that in other procedures. Nighttime is considered in two time intervals, 2000 to 0200, and 0200 to 0600 hours. Operations in the first period are treated as three times more significant than in the second. Further, a 10 log summation is no longer employed, being replaced by $6 \log_{10}(3n_1+n_2)-1$, where n_1 and n_2 are the numbers of operations in the two nighttime periods. This expression is ignored if $3n_1+n_2 < 64$, and a straight 10 log summation is then used.

Identification of exposure levels with community response is primarily derived from a survey of approximately 2000 respondents living in 20 survey areas contained in the vicinity of four airports: Orly, Le Bourget, Marseilles, and Lyons. The results of the survey were used to derive two attitude scales, one a nuisance scale related to aircraft noise, and the other a general satisfaction scale related to the district of residence. The structure of survey and resultant analyses was such that the progressive emergence of nuisance due to aircraft noise could be correlated with the degree of noise exposure, and that discrimination was made regarding aircraft noise as compared to other sources of dissatisfaction as a direct function of noise exposure. It is claimed that the Isopsophic Index had a 0.93 correlation with the area averaged rating of nuisance.

Again, because of the simple linear translation of   to CNR, it is of interest to compare the French survey results with the equivalent CNR values for the noise exposures considered. Several of the interview results are plotted as a function of CNR on Figure 9. The figure shows the percent of responses, as a function of CNR, for the following questions:

1) Are you dissatisfied with noise? (As compared to distance from work, public transport, entertainment, shopping, neighbors)

2) What would you most like to change?

3) Are you considerably disturbed by aircraft noise? (A choice of considerably, somewhat, a little, or not at all)

4) General impression of disturbance derived from percentages of "sometimes" and "fairly often" in response to: radio/TV, kept from going to sleep, house vibrates, awakened, startled, concentration disturbed.

As a result of this work, the French have established various zones for various land uses, on the basis of noise exposure, as follows:

| AREA A | $\mathcal{N} > 96$ | (CNR > 114) |

All buildings prohibited except those corresponding to activities associated with the vicinity of the airport, providing soundproofing provisions are made such as living conditions are at least equal to what they would be if the buildings were located in area C.

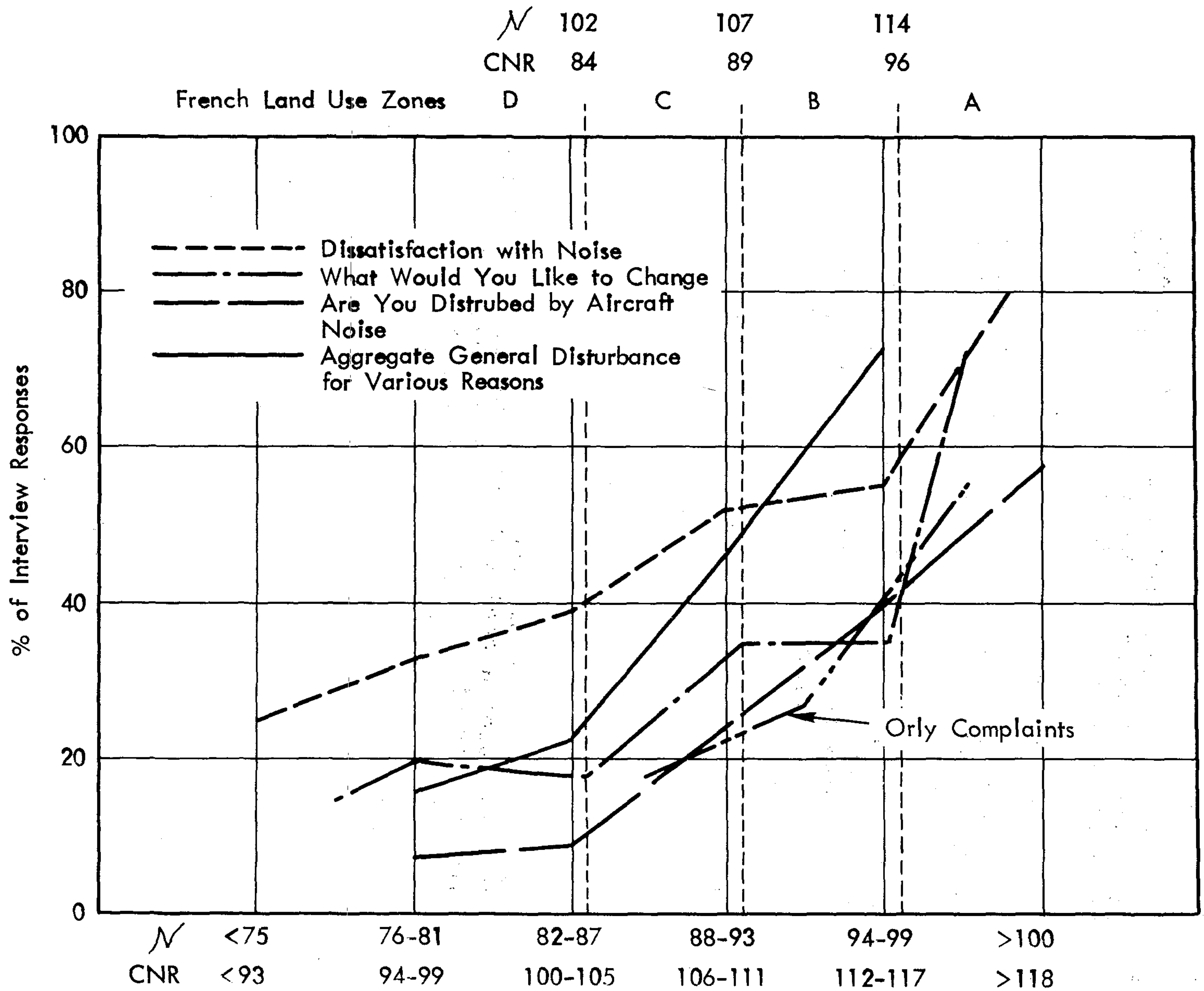


FIGURE 9. COMPARISON OF FRENCH SURVEY RESULTS WITH EQUIVALENT CNR VALUES

AREA B $89 < \mathcal{N} < 96$ $(107 < \text{CNR} < 114)$

Development of existing communities to be restricted to areas located within the smallest possible perimeters. Construction for residential purposes will be authorized subject to adequate soundproofing (with a particular value to be established). Density limitations (number of inhabitants to the hectare) will also be established for this type of residential area.

Erection of public buildings (i.e. schools, hospitals, etc.) and residential buildings should be avoided. Should the erection of such public buildings be considered essential, soundproofing should conform to at least a certain given value and each case should be studied specifically.

AREA C $84 < \mathcal{N} < 89$ $(102 < \text{CNR} < 107)$

New residential developments to be avoided. Density limitations (number of inhabitants to the hectare) will be established for all residential buildings and it will be recommended that such residential buildings as well as public buildings be provided with adequate soundproofing, each case being studied specifically.

AREA D $\mathcal{N} < 84$ $(\text{CNR} < 102)$

No building restrictions.

Areas B and C are seen to be comparable in noise exposure to the CNR region between 100 and 115, or the NEF region between 30 and 40.

As an additional comparison, one can examine the distribution of complaints received at Orly airport in 1965 concerning aircraft noise with noise exposure. The complaints have been segregated into percentage of the total which originate in the various zones of noise exposure. These data indicate that 55% of the complaints originated in locations where the CNR was greater than 114, 27% where the CNR was between 107 and 114, and 18% in the CNR range from 102 to 107. Only a few isolated complaints originated in areas where the CNR was less than 102.

C. Total Noise Load - Netherlands

The advisory Committee on Noise Nuisance appointed by the Netherlands Minister of Public Works has specified a series of investigations concerning the response to aircraft noise produced by operations at Schiphol Airport, Amsterdam, in communities surrounding the airport. Interviews were obtained with 1000 respondents located in eight communities surrounding the airport[25]. The interview process followed basically the approach used in previous English, American, and Swedish surveys. Physical measurements of noise produced by about 1000 aircraft flyovers were also obtained to establish the noise exposure in the communities.

The results of the interview was used to derive a "mean relative nuisance score" which was a composite of the individual attributes of disturbance or dissatisfaction comparable to those derived in the British and French surveys. These results were then correlated to a measure of noise exposure. The correlation with NNI was 0.94. It was the opinion of the Dutch technical group, however, that it would be most desirable to obtain a noise exposure measure in which noise levels were expressed in dB(A) so that simple direct measurements could be used for noise exposure due to aircraft. The resulting expression derived was the "total noise load," symbolized by the letter B, and specified by the following equation:

$$B = 20 \log_{10} \Sigma n \, 10^{\frac{L_A}{15}} - 157$$

where L is the maximum sound level in dB(A) for aircraft flyovers and n is the distribution factor for aircraft movements in 24 hours. This formula permitted a one-to-one map of noise exposure to "mean relative nuisance score," e.g. where B equals 30, the percentage of nuisance score is 30%.

As was true in other studies, the individual percentage nuisance score for separate attributes of disturbance varied with the attribute and with the community. For example, several attributes such as fear, speech, sleep and occupational interferences are plotted in Fig. 10. The percentages of "mean

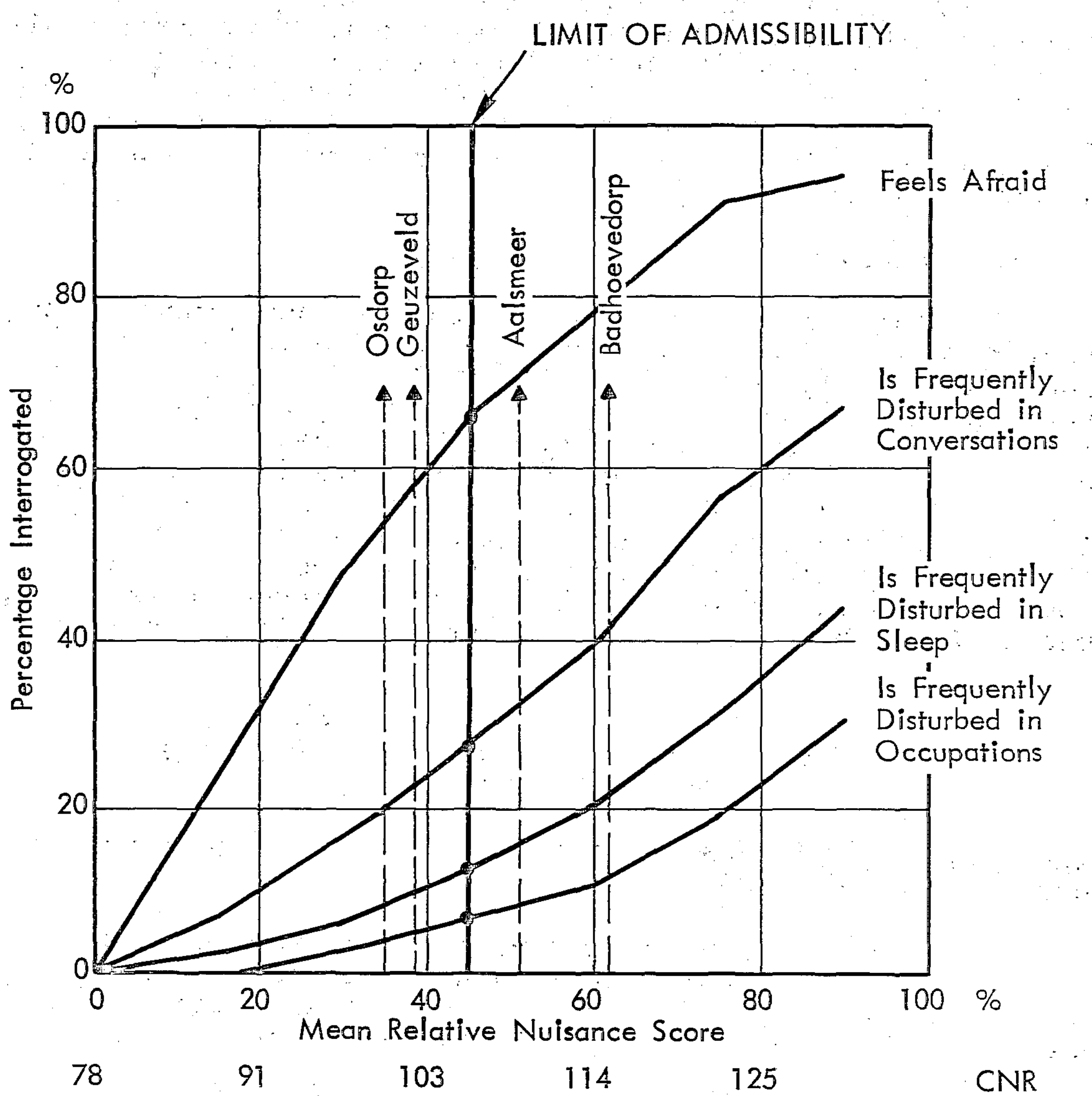


FIGURE 10. PERCENTAGE OF INHABITANTS WHO FEEL TO BE FREQUENTL DISTURBED IN CONVERSATION, SLEEP OR OCCUPATIONS, OR WHO FEEL AFRAID, PLOTTED AS A FUNCTION OF THE MEAN NUISANCE SCORE IN THE RESIDENTIAL AREA CONCERNED

relative nuisance" are equal numerically to the "total noise load," B. An equivalence to CNR or NNI can be derived to compare these results to other work. Using the transformations shown in Fig. 11, we have shown the equivalent CNR values for the "total noise load" in Fig. 10. The Dutch authorities have chosen a "total noise load" of 45 as the "limit of admissibility" for aircraft noise. This corresponds to a CNR of about 105, or an NEF of about 30 to 35.

D. Mean Annoyance Level, $\overline{Q}$ - Germany

In addition to the exposure measures described before, another measure has been developed for use in Germany, the "mean annoyance level," $\overline{Q}$. This quantity is obtained by summation of various noise levels times their duration, averaged over a specified time, times a constant. If the constant is 10, the process is an energy average of noise level. Instead of energy average, the constant 13.3 has been used in Germany, corresponding to 4 dB increase per doubling of duration. The choice of this value is somewhat obscure, but appears to be based on a combined consideration of the results of psychoacoustic experiments.[26] The expression for computing $\overline{Q}$ is as follows:

$$\overline{Q} = 13.3 \log_{10} \{ \frac{1}{T} \Sigma \, 10^{\frac{L_A}{13.3}} \cdot \tau_k \}$$

where L_A is the sound level in dBA (or PNdB) and τ is the duration at that level.

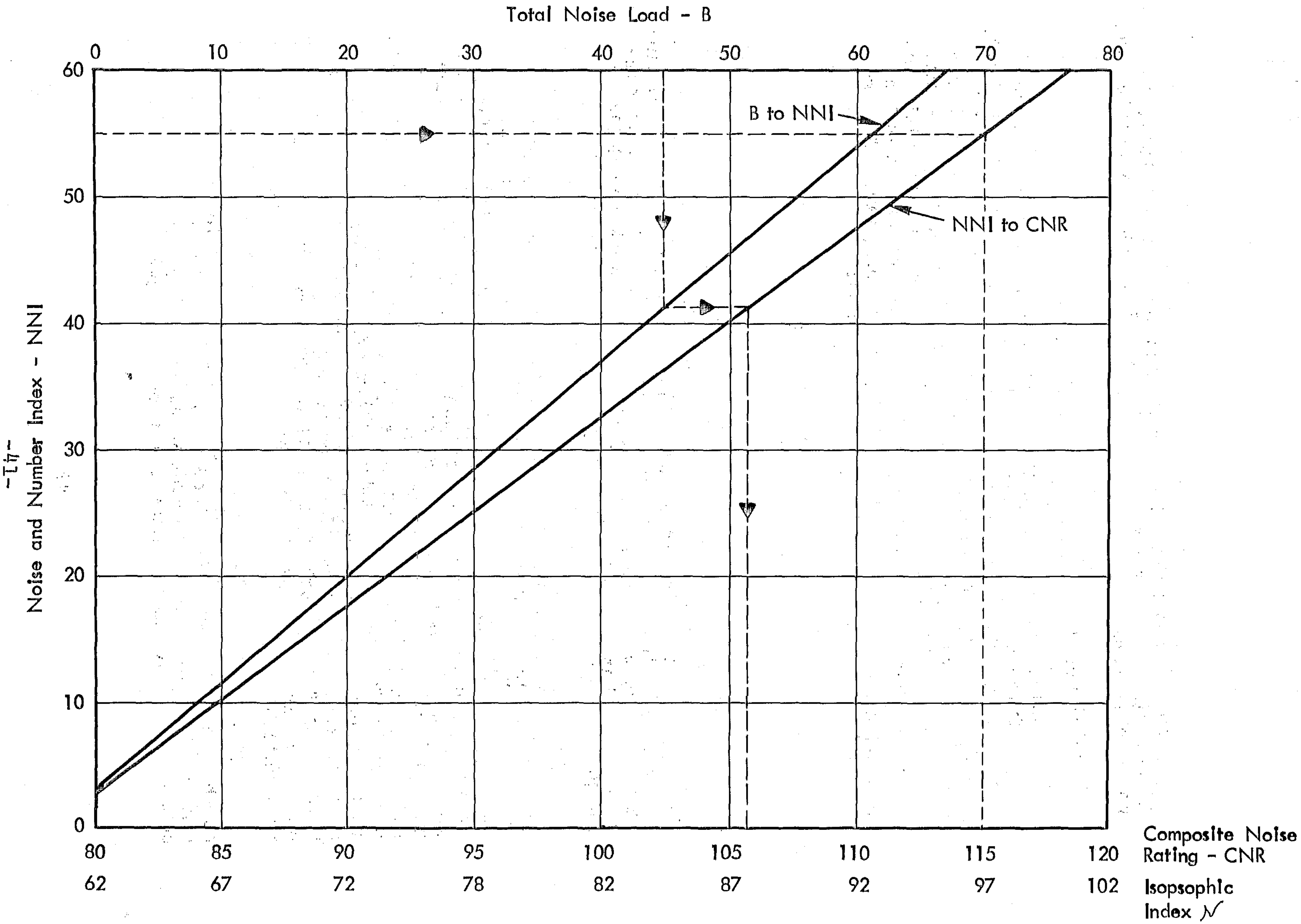
The $\overline{Q}$ index is used in Germany to define four zones of aircraft noise exposure for land use. If the noise levels are specified in PNdB, the zones are deduced as follows, where $\overline{Q}_c$= 82 PNdB is termed the "critical" value of $\overline{Q}$:

Zone I $\overline{Q} \geq \overline{Q}_c$. No residential building.

Zone II $\overline{Q}_c - 5$ dB $\leq \overline{Q} \leq \overline{Q}_c$. Residential building only in urgent cases. Strong sound suppression measures are required.

Zone III $\overline{Q}_c - 10$ dB $\leq \overline{Q} < \overline{Q}_c - 5$ dB. Sound suppression measures are indicated.

Zone IV $\overline{Q} < \overline{Q}_c - 10$ dB. No restrictions, but no new hospitals in the vicinity of the boundary to Zone III.



TRANSFORMATION NOMOGRAM FOR VARIOUS NOISE EXPOSURE INDICES

Since $\overline{Q}$ considers the duration of noise explicitly, it is not directly comparable to CNR or NEF unless a specific time pattern is considered.

E. Noisiness Index, $\overline{NI}$ - South Africa

Studies of noise exposure from aircraft operations in South Africa have been reported by van Niekerk and Muller [27]. They express the value of $\overline{NI}$ as an energy summation over a twenty-four hour period maximum tone-corrected sound pressure level for each flight, weighted with the A-weighting network, and an effective duration at that level. Appropriate additional constants may also be introduced to adjust for day, evening, or night hours, or for various seasons of the year. The basic daytime expression for computing $\overline{NI}$ is thus:

$$\overline{NI} = 10 \log_{10} \sum \frac{t}{t_o} 10^{\frac{L_A}{10}}$$

where t_o is 8.64×10^4 seconds. It is interesting to note that the standard practice in South Africa is to perform measurements and analysis in one-third octave frequency bands, then to compute the dBA value from these data. van Niekerk and Muller also point out that any other quantity, such as perceived noise level or dBD, can also be used in their analysis.

A preliminary social survey was conducted by the National Institute for Personnel Research of the South African Council for Scientific and Industrial Research to relate community response to aircraft noise exposure. The survey was conducted to ascertain the resident's attitudes towards living conditions in the area, with particular regard to undesirable factors. The survey was designed so as not to reveal its primary purpose, but did reveal that aircraft noise became a significantly disturbing factor at the higher noise exposure levels. The results indicated that about 13% of the people were disturbed by aircraft noise at an $\overline{NI}$ value of 60, about 18% at $\overline{NI}$ of 65, with about 45% disturbed at an $\overline{NI}$ of 70. The $\overline{NI}$ zone between 65 and 70 is thus regarded as the upper limiting region for residential development.

As with $\overline{Q}$ and NEF, there is no unique correlation of $\overline{NI}$ to the other indices described previously since the particular time pattern of the flyover noise signal enters into the computation. An approximate relationship between the indices can be derived if a specific flyover signal is used in the computations. This relationship is developed in sectþpm G for a specified set of occurrences.

F. Weighted Noise Exposure Level, WECPNL - ICAO

The obviously international nature of aircraft noise has led to several international meetings to discuss the subject. In November and December of 1969 a special meeting of the International Civil Aviation Organisation (ICAO) was held in Montreal for the purpose of deriving international agreement on a number of subjects concerning aircraft noise.[28]. One conclusion of this meeting was the adoption of ICAO reference units for total noise exposure from aircraft noise. This result is largely a distillation of the information described in the previous sections. The ICAO formulation is included here for comparison to the other indices.

Three different terms are used by ICAO. The "total noise exposure level," TNEL is defined as:

$$TNEL = 10 \log_{10} \sum_{i}^{n} \text{antilog} \frac{EPNL(i)}{10} + 10 \log_{10} \frac{T_o}{t_o}$$

where EPNL(i) is the effective perceived noise level of the i-th flyover, T_o is 10 seconds, and t_o is one second.

For purposes of intercomparing various noise exposures the term "equivalent continuous perceived noise level," ECPNL, is defined as:

$$ECPNL = TNEL - 10 \log_{10} \frac{T}{t_o}$$

where T is a specified time period, e.g. day, month, or year. It is likely that most users will specify T to be a 24 hour day.

When it is desired that additional weighting factors for the effect of night operations or seasonal variations are to be included the term "weighted equivalent continuous perceived noise level," WECPNL, is defined. Two types of daytime-nighttime weighting are defined, depending on whether the 24 hours are divided into two or three parts. For example, using a two-part division as is used for NEF and CNR, the equation for calculating WECPNL is defined as:

$$WECPNL = 10 \log_{10} \left(\frac{5}{8} \text{ antilog } \frac{ECPNL(D)_2}{10} + \frac{3}{8} \text{ antilog } \frac{ECPNL(N)_2 + 10}{} \right) + S$$

where $ECPNL(D)_2$ is the ECPNL over the hours 0700-2200, $ECPNL(N)_2$ is the ECPNL over the hours 2200-0700, and S is obtained from the following table.

SEASONAL WEIGHTING FACTOR, S, (dB)

Condition	S
Less than 100 hours per month at or above 20°C (68°F)	-5
More than 100 hours per month at or above 20°C and less than 100 hours at or above 25.6°C (78°F)	0
More than 100 hours per month at or above 25.6°C	+5

One may note that at the present time only NEF and WECPNL are specified in terms of effective perceived noise level, although NI is essentially equivalent if the difference between dBA and perceived noise level is assumed constant. Direct comparisons of these indices can be used to obtain an approximate set of criteria in terms of WECPNL. Specific recommendations for criteria are not given by ICAO as yet, since criteria are within the purview of the individual member states. As can be seen in the next section, however, international opinions on acceptable criteria for residential use are not very divergent.

In the following section where the various indices are compared, only daytime operations are assumed, a zero seasonal correction is assumed, and the time period, T, is assumed to be 24 hours. In this instance WECPNL is equal to TNEL.

G. Direct Comparison of NEF, CNR, NNI, $\mathcal{N}$, B, $\overline{Q}$, $\overline{NI}$, WECPNL

One method of comparing the various indices and the response zones they define is to select a single type of aircraft noise level, vary the number of operations, and examine the effect on the indices. The values for these indices, based on different numbers of daytime operations at an average maximum noise level of 110 PNdB (or 110 EPNdB for NEF and WECDNL) and an effective duration of 10 seconds, are plotted in Fig. 12. Where levels are expressed in L_A, it is assumed for this purpose that $L_A = L_{pn} - 13$ dB. The equations used to derive this figure are summarized below:

$$CNR = 10 \log_{10} 10^{\frac{L_{pn}}{10}} + 10 \log_{10} N - 12$$

$$NEF = 10 \log_{10} 10^{\frac{L_{epn}}{10}} + 10 \log_{10} N - 88$$

$$\mathcal{N} = 10 \log_{10} 10^{\frac{L_{pn}}{10}} + 10 \log_{10} N - 30$$

$$NNI = 10 \log_{10} 10^{\frac{L_{pn}}{10}} + 15 \log N - 80$$

$$\overline{Q} = 13.3 \log_{10} 10^{\frac{L_{pn}}{13.3}} + 13.3 \log_{10} N - 52.3$$

$$\overline{NI} = 10 \log_{10} 10^{\frac{L_{pn-13}}{10}} + 10 \log_{10} N - 39.4$$

$$WECPNL = 10 \log_{10} 10^{\frac{L_{epn}}{10}} + 10 \log_{10} N - 39.4$$

$$B = 20 \log_{10} 10^{\frac{L_{pn-13}}{15}} + 20 \log_{10} N - C$$

(The constant C is derived by transform from NNI and CNR since there is some confusion as to the time periods used with the constant, 157, cited previously)

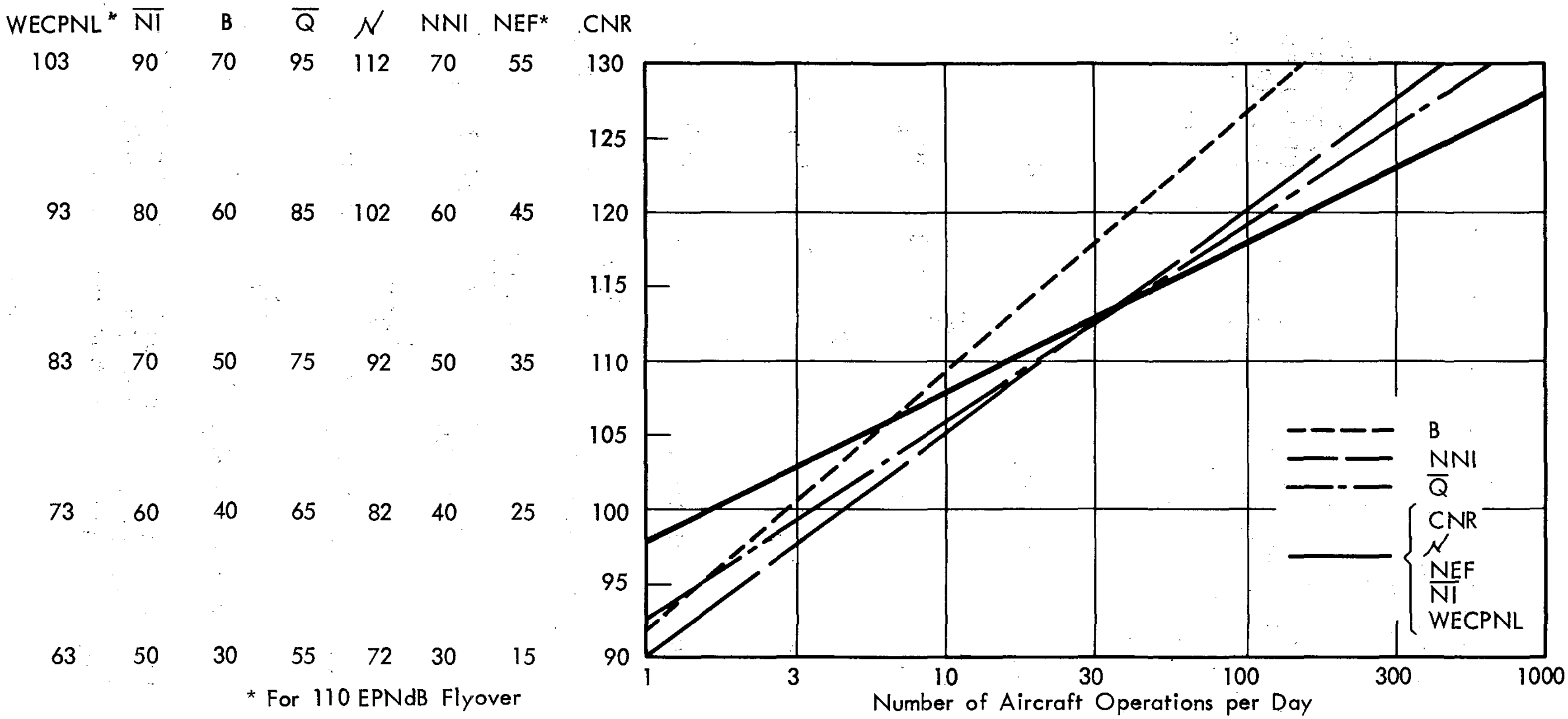


FIGURE 12. COMPARISON OF VARIOUS NOISE EXPOSURE INDICES FOR A FLYOVER NOISE LEVEL OF 110 PNdB, EFFECTIVE DURATION OF 10 SECONDS, AND VARIABLE NUMBER OF OPERATIONS

One should note that if one were to hold the number of operations constant, and instead vary the noise levels (and flyover signal durations) in accord with the way flyover signals characteristically change with distance from an aircraft, the correlations among indices would be somewhat different from those expressed above. An example of this was given earlier in Fig. 7. This figure reflected the fact that as distance from an aircraft is varied, the relationship between EPNL and PNL values change. (In this case, the EPNL, which explicitly includes a duration factor, decreases with distance at a lesser rate than the PNL.)

Utilizing the data in Fig. 7, 11 and 12 we can derive a table of equivalences which allow the zonal boundaries for various response descriptions, or land use restrictions for various indices, to be intercompared. These results are shown in Fig. 13. (The transformation from CNR to NEF is made by using Fig. 7.)

The comparisons shown in Fig. 13 clearly identify an upper boundary of acceptable noise exposure for residential use as being, with the exception of the Dutch limits, between NEF 38 and 42. At the lower levels of noise exposure where no restrictions are required the equivalent NEF values range from 30 to 33. The diversity of conditions, study methods, and noise exposure computational techniques of these studies all provide conclusions which support each other quite closely. The identification of the three NEF zones, less than 30, 30 to 40, and greater than 40, along with their descriptors, seems to be further supported by these other studies.

The community response derivations and comparisons described above have related primarily to suitable environments for residential living. The computation of noise exposure, however, is a function of noise levels and time, and can be correlated with subjective responses other than "acceptability" for residential living. For example, the British, French, and Dutch surveys evaluated speech communication acceptability as a function of noise exposure. One can use the concept of an acceptable environment for speech or other task interference criteria to obtain numerical values of noise exposure for a variety of land uses. Such criteria are developed in Part II of this report.

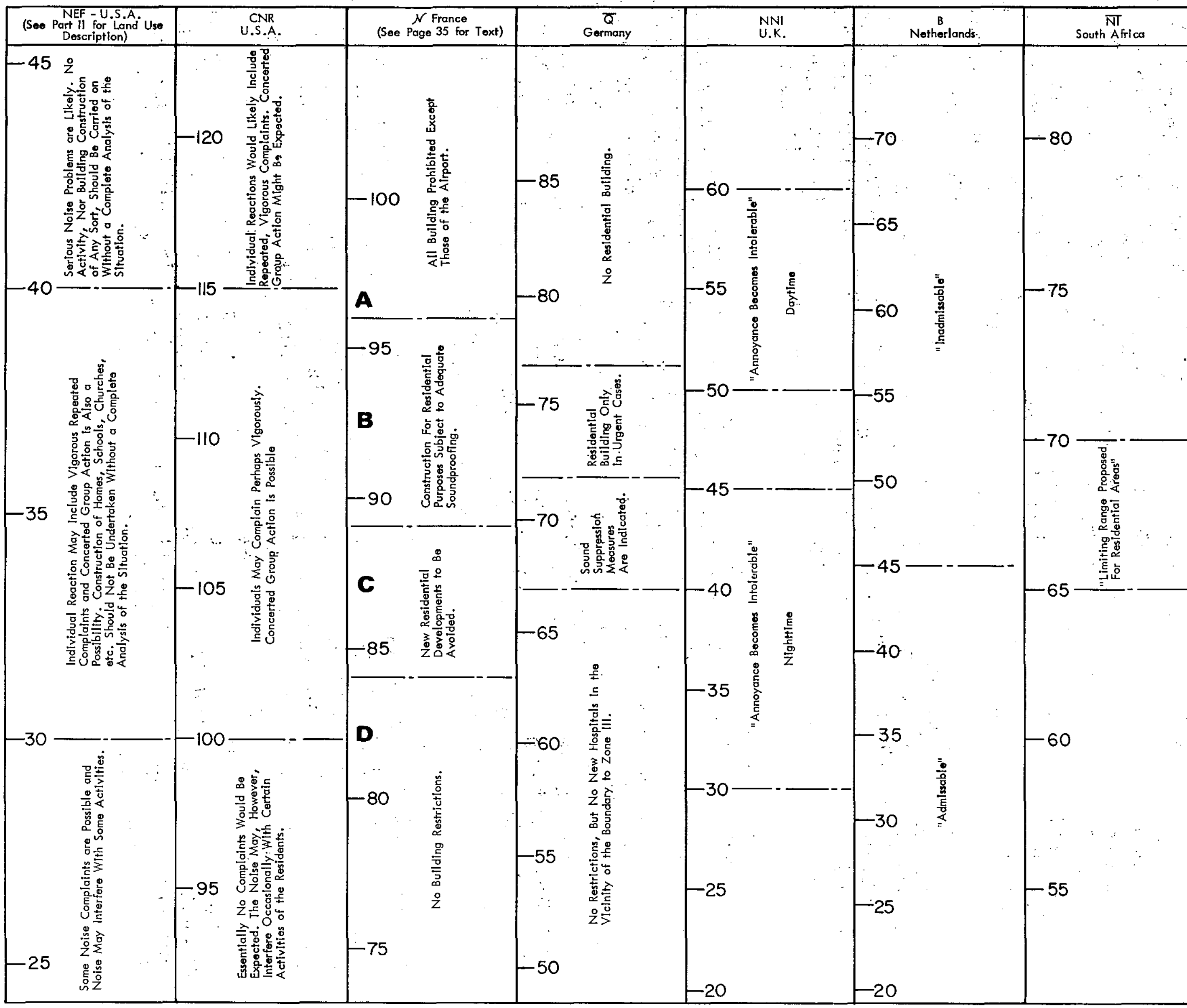


FIGURE 13. APPROXIMATE EQUIVALENCES BETWEEN NOISE EXPOSURE INDICES AND RESPONSE OR LAND USE DESCRIPTIONS

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PART II

NOISE EXPOSURE FORECASTS: LAND USE INTERPRETATIONS

By
Dwight E. Bishop

I. INTRODUCTION

The Noise Exposure Forecast (NEF) value at a ground position provides an estimate of the integrated noise exposure resulting from aircraft operations. The NEF values are calculated from

a. Measures of the aircraft flyover noise described in terms of the effective perceived noise level (EPNL).*

b. The average number of flyovers per day (0700 to 2200) and per night (2200 to 0700) periods.

This portion of the report interprets the noise exposure due to aircraft operations, expressed as NEF values, in terms of probable impact upon land uses. Assessments of the land use compatibility are given for a variety of land uses. The major purpose of these interpretations is to provide a guide in land use planning and zoning and in land development and building construction.

The land use interpretations given in this report may be used to assess the impact of aircraft noise, as described by the sets of NEF contours given in Refs. 2 and 3. In Ref. 2, NEF contours resulting from aircraft operations for 1967, 1970 and 1975 are given for 28 airports scattered throughout the United States. In Ref. 3, NEF contours for 1975 operations are presented for three major airports: O'Hare International Airport, Chicago; Los Angeles International Airport; and John F. Kennedy Airport, New York.

The assessments of land use compatibility with respect to aircraft noise given in this report are based upon the following major considerations:

- Accumulated case history experiences of noise complaints near civil and military airports;
- Speech interference criteria;
- Subjective judgment tests of noise acceptability and relative "noisiness";

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* The effective perceived noise level definition employed in this study is that given in Ref. 1. The references are listed together at the end of the text of Part II.

- Need for freedom from noise intrusions;

- Typical noise insulation provided by common types of building construction.

Different considerations are given precedent for the differing land uses. For example, in determining the effects of noise upon residential land use, case history experience, acceptability criteria and speech communication criteria are most important; for concert halls, the need for freedom from noise intrusion is probably most important.

The land use interpretations given herein have evolved from the community response and land use interpretations of Composite Noise Rating (CNR) values, given in Ref. 4 and 5. The interpretations are basically similar to those developed in initial NEF studies (Table II of Ref. 6). However the land use interpretations given herein reflect additional information about land use categories (Ref. 7), aircraft noise impact upon speech communication (Ref. 8), and building noise insulation (Ref. 9).

The interpretations, given in Section II also provide for greater flexibility in interpretation to meet local conditions, and have been extended to cover a larger variety of land uses, keyed to SLUCM land use codes (Ref. 10).

For ease in reference, the basic NEF equations are summarized in Appendix A.

II. LAND USE COMPATIBILITY GUIDES

Figure 1 provides the key to the selection of the appropriate noise compatibility interpretations for differing NEF values. For each land use listed in the figure, several interpretations in Table I are provided. The choice of the appropriate interpretation is governed by the NEF values describing the noise exposure. Also listed in Figure 1 is the appropriate SLUCM land use code (Ref. 10), and a "Noise Sensitivity Code." The noise code provides a gross ranking of the land use in terms of noise sensitivity, with the number 1 indicating the land uses most sensitive to noise and 5, the land use, least sensitive. The approximate relationship between the noise sensitivity code rating and the NEF level at which new construction or development <u>is not</u> desirable is given below:

Noise Sensitivity Code	Approximate Noise Exposure Forecast Value Where New Construction or Development Is Not Desirable
1	30
2	35
3	40
4	45
5	50-55

As an additional aid in relating noise exposure to land use, Table II lists the noise sensitivity code for a number of land use classifications.*

In Fig. 1, one will note that, for most land uses, the compatibility interpretation for the lowest NEF values has the notation "satisfactory with no special noise insulation requirements required for new construction," indicating that there should be no adverse effects from aircraft noise. Corresponding to higher levels of noise exposure, the interpretations generally define a range of noise exposure in which new construction or development should not be undertaken unless an analysis of noise requirements is made and needed noise insulation features are included in the building design and site development. For more extreme noise exposure, many of the land uses are assigned an interpretation saying that new construction or development should not be undertaken.

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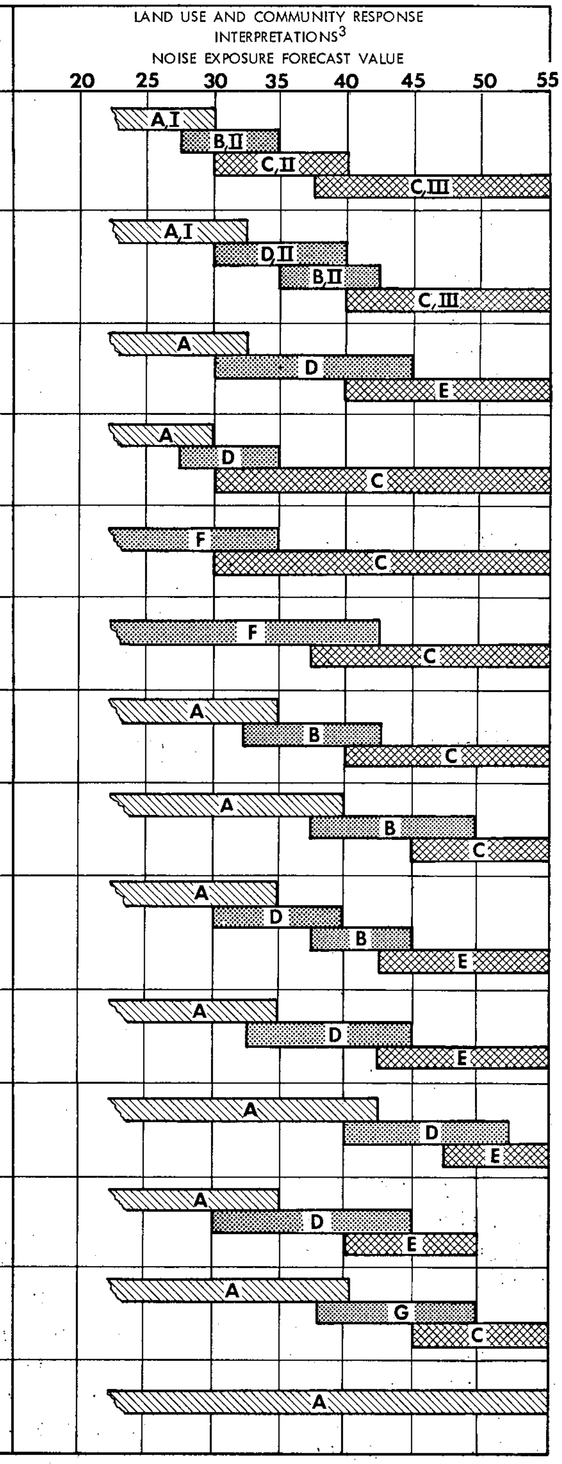
* This table format and land use listing has been adopted from that of Attachment A of Ref. 11.

LAND USE CATEGORY	SLUCM CODE[1]	NOISE SENSITIVITY CODE[2]
RESIDENTIAL - SINGLE AND TWO FAMILY HOMES, MOBILE HOMES	11 x[4], 14	1
RESIDENTIAL - MULTIPLE FAMILY APARTMENTS, DORMITORIES, GROUP QUARTERS, ORPHANAGES, RETIREMENT, HOMES ETC.	11x, 12, 13, 19	2
TRANSIENT LODGING - HOTELS, MOTELS	15	3
SCHOOL CLASSROOMS, LIBRARIES, CHURCHES, HOSPITALS, NURSING HOMES, ETC.	68, 651	1
AUDITORIUMS, CONCERT HALLS, OUTDOOR AMPHITHEATERS, MUSIC SHELLS	721	1
SPORTS ARENAS, OUT-OF-DOOR SPECTATOR SPORTS	722	3
PLAYGROUNDS, NEIGHBORHOOD PARKS	761x	3
GOLF COURSES, RIDING STABLES, WATER-BASED RECREATIONAL AREAS, CEMETERIES	741 x. 743, 744 624	4
OFFICE BUILDINGS, PERSONAL, BUSINESS AND PROFESSIONAL SERVICES	61, 62, 65[5], 69 63	3
COMMERCIAL - RETAIL, MOVIE THEATERS, RESTAURANTS	53, 54, 56, 57, 59,	3
COMMERCIAL - WHOLESALE & SOME RETAIL, INDUSTRIAL / MANUFACTURING, TRANSPORTATION, COMMUNICATIONS & UTILITIES	51, 52, 64 2_xx[6], 3_xx 4_xx	5
MANUFACTURING - NOISE SENSITIVE COMMUNICATIONS - NOISE SENSITIVE	35_[7], 47_[7]	3
LIVESTOCK FARMING, ANIMAL BREEDING	815 - 817	4
AGRICULTURE (EXCEPT LIVESTOCK FARMING) MINING, FISHING	81 NEC[8] 82, 83, 84, 85, 91, 93	5



NOTES
1. STANDARD LAND USE CODING MANUAL, REF. 10
2. RELATIVE RANKING OF LAND USES WITH RESPECT TO NOISE SENSITIVITY. SEE TEXT FOR APPROXIMATE RELATIONSHIPS TO NEF VALUES
3. INTERPRETATIONS ARE LISTED IN TABLE I
4. "x" REPRESENTS A SLUCM CATEGORY BROADER OR NARROWER THAN, BUT GENERALLY INCLUSIVE OF, THE CATEGORY DESCRIBED
5. EXCLUDING HOSPITALS
6. "xx" SOME EXCEPTIONS MAY OCCUR FOR PARTICULAR OR SPECIALIZED NOISE SENSITIVE ACTIVITIES
7. DEPENDENT UPON SPECIFIC TASK REQUIREMENTS
8. NOT ELSEWHERE CLASSIFIED

FIGURE 1. LAND USE COMPATIBILITY CHART FOR AIRCRAFT NOISE

TABLE I

NOISE COMPATIBILITY INTERPRETATIONS FOR USE WITH FIGURE 1

General Land Use Recommendations*
A. Satisfactory, with no special noise insulation requirements for new construction.
B. New construction or development should generally be avoided except as possible infill of already developed areas. In such cases, a detailed analysis of noise reduction requirements should be made, and needed noise insulation features should be included in the building design.
C. New construction or development should not be undertaken.
D. New construction or development should not be undertaken unless a detailed analysis of noise reduction requirements is made and needed noise insulation features included in the design.
E. New construction or development should not be undertaken unless directly related to airport-related activities or services. Conventional construction will generally be inadequate and special noise insulation features must be included. A detailed analysis of noise reduction requirements should be made and needed noise insulation features included in the construction or development.
F. A detailed analysis of the noise environment, considering noise from all urban and transportation sources should be made and needed noise insulation features and/or special requirements for the sound reinforcement systems should be included in the basic design.
G. New development should generally be avoided except as possible expansion of already developed areas.
Community Response Predictions**
I. Some noise complaints may occur, and noise may, occasionally, interfere with some activities.
II. In developed areas, individuals may complain, perhaps vigorously, and group action is possible.
III. In developed areas, repeated vigorous complaints and concerted group action might be expected.

* Land use recommendations are based upon experience and judgmental factors without regard to specific variations in construction (such as air conditioning and building insulation) or in other physical conditions (such as the terrain and the atmosphere). These features and others involving social, economic, and political conditions must be considered in recommending individual use and density construction combinations in specific locations.

** Community response predictions are generalizations based upon experience resulting from the evolutionary development of various national and international noise exposure units, in particular, the Composite Noise Rating (CNR). For specific locations, considerations must also be given to the background noise levels and the social, economic, and political conditions that exist.

TABLE II

LAND USE - AIRCRAFT NOISE COMPATIBILITY CLASSIFICATION

SLUCM Code[2]	Category	Noise Sensitivity Code[1]
1	RESIDENTIAL	
11x[3]	Single family	1
11x	2-4 family	1
11x	Multi-family apartments	2
12	Group quarters	2
13	Residential hotels	2
14	Mobile home parks or courts	1
15	Transient lodging	3
19	Other residential, NEC[4]	2
2	INDUSTRIAL/MANUFACTURING	
21	Food and kindred products	4
22	Textile mill products	5
23	Apparel	4
24	Lumber and wood products	5
25	Furniture and fixtures	4
26	Paper and allied products	5
27	Printing, publishing	5
28	Chemicals and allied products	5
29	Petroleum refining and related ind.	5
3	INDUSTRIAL/MANUFACTURING	
31	Rubber and misc. plastic goods	5
32	Stone, clay and glass	5
33	Primary metals	5
34	Fabricated metals	5
35	Professional, scientific and controlling instruments	3
39	Misc. Mfg. NEC	4
4	TRANSPORTATION, COMMUNICATIONS & UTILITIES	
41	Railroad, rapid rail transit	5
42	Motor vehicle transport	5
43	Aircraft transport	5
44	Marine craft transport	5
45	Highway and street ROW	5
46	Auto parking	5
47	Communication	3
48	Utilities	5
49	Other trans. communications & utilities NEC.	5

TABLE II (Con't)

SLUCM Code	Category	Noise Sensitivity Code
o[5]	COMMERCIAL/RETAIL TRADE	
51	Wholesale trade	5
52	Building materials retail	5
53	General merchandise retail	3
54	Food retail	3
55	Automotive retail	4
56	Apparel and accessories retail	3
57	Eating and drinking places	3
59	Other retail NEC.	3
o	PERSONAL AND BUSINESS SERVICES	
61	Finance, insurance and real estate	3
62	Personal services	3
63	Business services	3
64	Auto repair services	5
65	Professional services[6]	3
66	Contract construction services	5
o	Indoor recreation services	3
69	Other services NEC.	3
o	PUBLIC AND QUASI-PUBLIC SERVICES	
67	Government services	2*
68	Education services	1
711	Cultural activities	1
651	Medical and other health services	1
624	Cemeteries	4
69x	Nonprofit organization, incl. churches	2
o	Other p. and qp. services NEC.	2
o	OUTDOOR RECREATION	
761x	Playgrounds and neighborhood parks	3
762x	Community and regional parks	3
712	Nature exhibits	3
722	Sports assembly	3
741x	Golf courses, riding stables	4
743,744	Water based recreation areas	4
75	Resorts and group camps	3
721	Entertainment assembly	2**
o	Other outdoor recreation NEC.	3

TABLE II (Con't)

SLUCM Code	Category	Noise Sensitivity Code
o	AGRICULTURE, MINING AND OPEN LAND	
81,NEC	Farms, except livestock	5
815,817	Livestock farms	4
82	Agriculture related activities	5
83	Forestry activities	5
84	Fishery activities	5
85	Mining activities	5
91	Undeveloped land	5
93	Water areas	5

FOOTNOTES:

1/ Noise Code 1 contains the most noise sensitive land uses; Noise Code 5 the least sensitive. See text for approximate correlation with NEF values.

2/ Reference 10.

3/ "x" after SLUCM numbers means it represents a category broader or narrower than, but generally inclusive of, the category described.

4/ NEC - Not elsewhere classified.

5/ "o" denotes no closely comparable grouping or category in SLUCM code.

6/ Ordinarily medical services would be subsumed under this heading, but noise sensitivity considerations led to a separate listing.

* A noise sensitivity code rating of 2 is appropriate for many government services. However, this land use encompasses activities having varying noise sensitivities, hence noise ratings for some specific services may range from 1 to 4.

** The noise sensitivity code rating is 1 for outdoor theaters and outdoor music amphitheaters or pavilions.

As discussed in Part I of this report, there may be considerable variability in people's reaction to noise or assessment of a given noise environment. In addition, any given land use category may incorporate a range of activities having varying sensitivities to noise. Further, there may be a considerable range in noise insulation of buildings that might be found suitable for a given work activity. Taking into account such variables, the noise compatibility interpretations must be used as guides to land use planning and should not be blindly applied as inflexible criteria.

To privide for some degree of flexibility in setting limits, the NEF range of many of the compatibility interpretations in Fig. 1 overlap, providing a range of NEF values where boundaries may be modified by local considerations.

Major factors to consider in adjusting or selecting a specific NEF boundary between interpretations are the following:

a. Previous community experience. One may utilize past experience in selection of boundaries, taking into consideration known response or complaint history in previously developed areas which are exposed to similar NEF values. Such experience may aid in selection of NEF descriptor boundaries with limits indicated in Fig. 1.

b. Local building construction, particularly as influenced by climate considerations. In northern portions of the country, wall and roof constructions may be slightly heavier and houses are likely to be more tightly constructed, thus reducing the amount of noise leakage paths. In addition windows would typically be kept closed for a larger portion of the year. On this basis, one might select a higher NEF value as the boundary for a noise compatibility interpretation, rather than a lower NEF value range which might be suitable for a more moderate climate.

c. Existing noise environment due to other urban or transportation noise sources. For NEF values greater than about 30 to 35, the influence of other transportation or urban noise sources is likely to be quite small. However, for NEF values less than 30 to 35 the noise environment due to other noise sources may temper the response or consideration of restrictions on land use. For example, introduction of aircraft noise in a rural or semi-rural area where existing background noise levels are very low may produce a much more apparent change in the noise environment and more pronounced reactions from residents than would aircraft noise introduced in a dense urban area long exposed to traffic noise. Such considerations may make adjustments of the noise compatibility interpretation boundaries appropriate in specific local situations.

d. Time period of land use activities. The basic NEF values as developed by the equations of Appendix A, consider both daytime and nighttime operations, with a weighting factor for nighttime operations. This procedure is particularly appropriate for residential land use considerations, but may lead to over estimation of NEF values for work activities or land uses which are confined to daytime hours only. Thus, it may be desirable to adjust NEF boundary limits (or NEF values) to define the noise exposure for only daytime operations.

Of course, NEF values can be determined separately for daytime or nighttime operations. However, where NEF contours are calculated on the basis of both daytime and nighttime operations, Fig. 2 can be used to adjust NEF values, provided the approximate proportion of nighttime operations is known. For example, if the nighttime operations account for 10% of total 24-hour operations, reference to Fig. 2 shows that the NEF values for only daytime operations would be about 4 units less than the NEF value calculated considering both day and night operations.

The NEF values for noise compatibility interpretation boundaries are based upon consideration of the type of building construction contemplated which would normally be used where aircraft noise is of no concern. Thus the land use compatibility ratings for schools assumes building construction involving single glazing in classrooms. Special noise construction incorporating double glazing or elimination of windows entirely has not been considered.

It is beyond the scope of this report to provide procedures and data for determining the degree of noise insulation required for a specific Noise Exposure Forecast value and land use, or to specify the types of constructions or special noise control measures that might be required for a particular building. Basic information for such inquiries are given in a number of references including 5, 12, 13 and 14.

It is important to point out that when one wishes to determine the specific noise insulation required for a given work activity, definition of the noise environment in terms of the NEF value alone is insufficient. In general, one must supplement the NEF value by more detailed specification of the

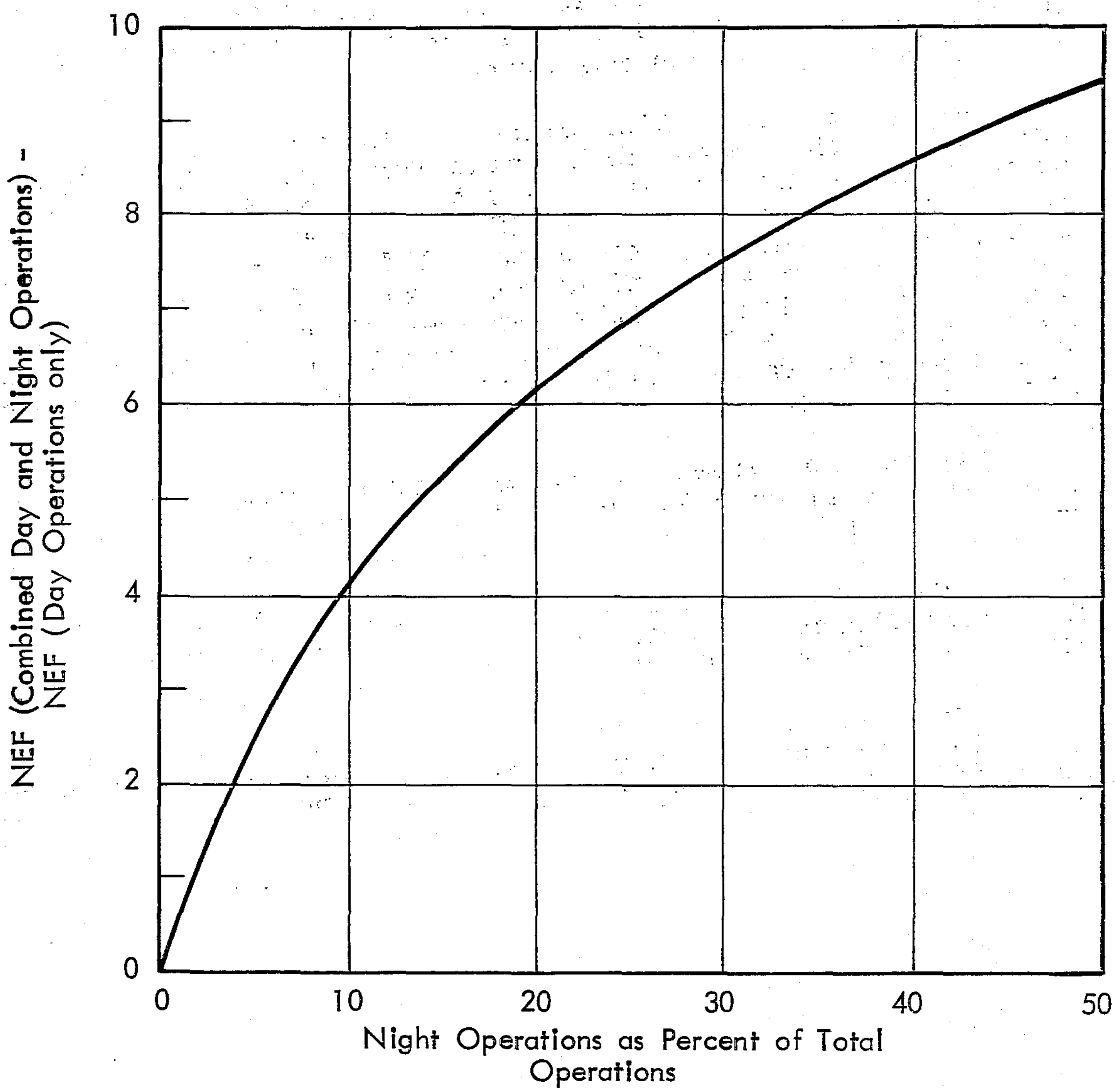


FIGURE 2. ADJUSTMENT FOR ESTIMATING NEF VALUES FOR DAY OPERATIONS ONLY

magnitude of aircraft noise intrusions. In general this would begin with determining the effective perceived noise levels (or perceived noise levels) for the different flyover intrusions. This must often be followed by more detailed description of the noise events in terms of octave band noise spectra and signal duration considerations, as well as knowledge of the background noise levels and interior noise criteria. These steps follow well defined noise control procedures.

As an aid in initial planning purposes, Fig. 3 provides an estimate of the "mean" EPNL value for a given NEF value. In using this figure one must know the approximate number of operations per day upon which the NEF value was calculated. Fig. 3 is based upon the assumption that 15% of the total daily operations occur during the nighttime period (2200 to 0700), a typical proportion of nighttime operations for all but general aviation airports.* For other proportions of nighttime operations the EPNL value can be adjusted using the inset graph given in Fig. 3.

Figure 3 provides an energy weighted estimate of the noise level that will usually underestimate the noise level of the "noisiest" class of aircraft by several EPNdB.

Hence, Fig. 3 should be used for initial planning purposes only when direct measurements or flyover noise levels or more detailed estimates of noise levels are not available.

More accurate estimates of EPNL values can be made by utilizing the basic EPNL vs. slant distance data and takeoff and profile information, or the several EPNL contours given in Ref. 2.

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* For the airports described in Ref. 2 and 3 the percentage of nighttime operations for 1975 ranged from 0 to 24% for all but the general aviation airports. The median value for the larger airports was 14%. For general aviation airports, the percentage was considerably lower, ranging from 0 to 8.5%.

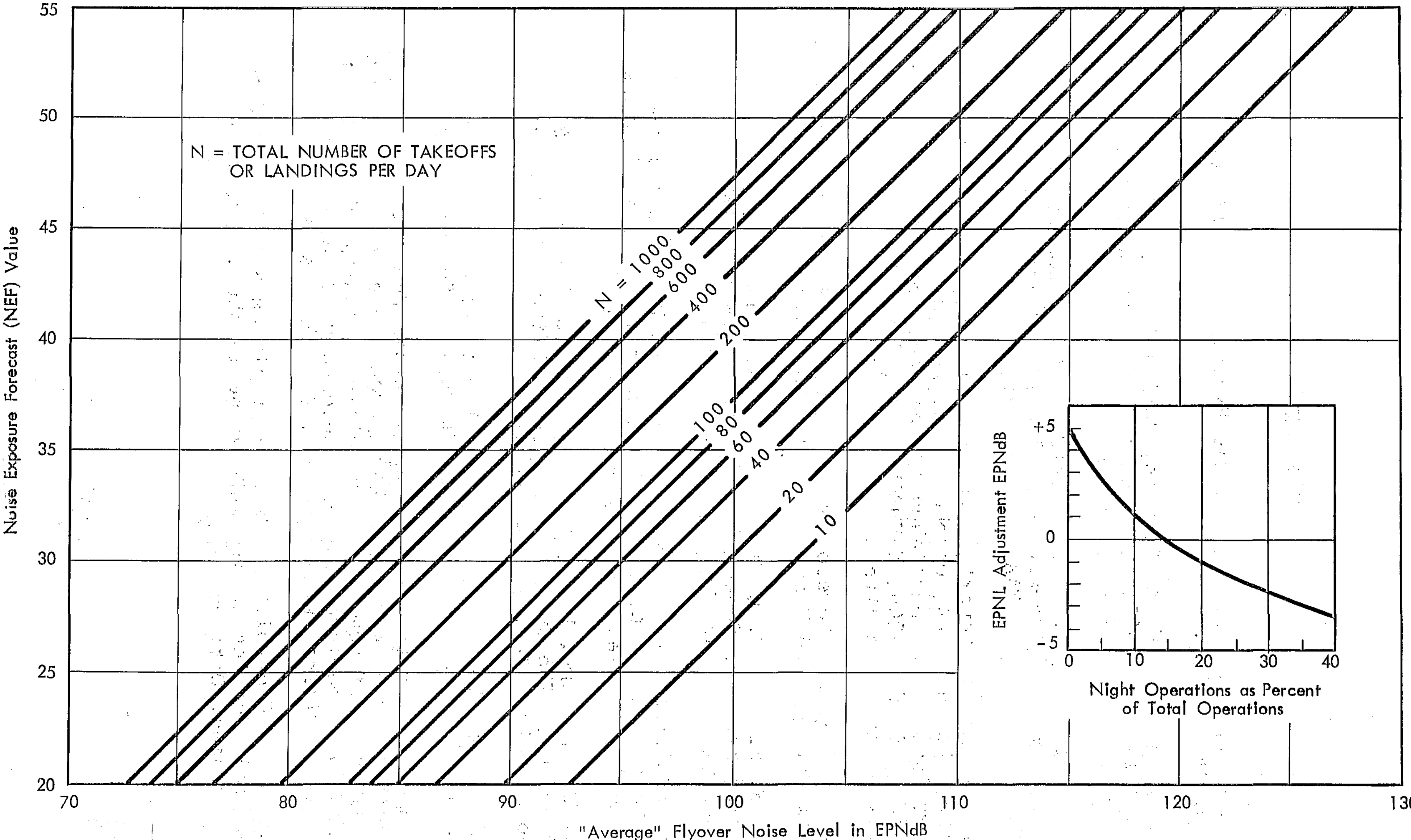

FIGURE 3. CORRELATION BETWEEN NEF VALUES AND "AVERAGE" FLYOVER NOISE LEVELS IN EPNdB (FOR AIRPORT WHERE NIGHT OPERATIONS ACCOUNT FOR 15 PERCENT OF TOTAL OPERATIONS)

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APPENDIX A
SUMMARY OF BASIC NOISE EXPOSURE FORECAST EQUATIONS

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SUMMARY OF BASIC NOISE EXPOSURE FORECAST EQUATIONS

In calculation of NEF values, aircraft noise levels are expressed in terms of the effective perceived noise level (EPNL) as defined in Ref. 1. In estimating the noise exposure near an airport or flight path resulting from the operation of a number of different aircraft, it is convenient to group the aircraft in classes based upon consideration of the aircraft noise characteristics and takeoff and landing performance. Each class is assigned a description of the noise in terms of a set of EPNL vs. distance curves and a set of takeoff and landing profiles. Thus, for a given class of aircraft at a particular power setting (i.e. takeoff power) it is assumed that the aircraft noise characteristics may be described by a single EPNL vs. distance curve.

The total noise exposure produced by aircraft operations at a given point is viewed as being composed of the effective perceived noise levels produced by different aircraft classes flying along different flight paths. For aircraft class i on flight path j, the NEF (ij) can be expressed as

$$\text{NEF (ij)} = \text{EPNL (ij)} + 10 \log \left[\frac{\text{N (day) (ij)}}{\text{K (day)}} + \frac{\text{N (night) (ij)}}{\text{K (night)}}\right] - \text{C} \qquad \text{(Eq. 1)}$$

where

NEF (ij) = Noise Exposure Forecast value produced by aircraft class (i) along flight path segment (j).

EPNL (ij) = Effective perceived noise level produced at the given point by aircraft class (i) flying along flight path segment (j).

K - Constant normalizing the adjustment in NEF values due to volume of operations. Different values of K are used for daytime and nighttime movements.

C = Arbitrary normalization constant.

K (day) is chosen so that for 20 movements of a given aircraft per daytime period, the adjustment for number of operations is zero. Hence,

$$10 \log \frac{20}{K\ (day)} = 0;\ K(day) = 20$$

K (night) is chosen such that for the same average number of operations per hour during daytime or nighttime periods the NEF value for nighttime operations would be 10 units higher than for daytime operation. Hence,

$$10 = 10 \log \left(\frac{K\ (day)}{K\ (night)} \cdot \frac{9}{15} \right)$$

where 9 and 15 are the number of hours in the nighttime and daytime periods respectively.

And, K (night) = 1.2

The value assigned to C is 75. Choice of this value is based upon two considerations. First, it is desirable that the number assigned to the NEF values be distinctly different in magnitude from the effective perceived noise level so that there is little likelihood of confusing effective perceived noise levels with NEF values. A second aspect is the desirability of selecting a normalization factor that will roughly indicate the size of the NEF value above some threshold value, indicating the emergence of the noise exposure from levels which would have little or no influence on most types of land usage.

With the above choices for values of K and C, Eq. (1) becomes:

$$NEF\ (ij) = EPNL\ (ij) + 10 \log [N\ (day)\ (ij) + 16.67\ N\ (night)\ (ij)] - 88$$

(Eq. 2)

The total NEF at the given ground position may be determined by summation of all the individual NEF (ij) values on an "energy" basis:

$$NEF = 10 \log \sum_i \sum_j \text{antilog} \frac{NEF\ (ij)}{10}$$

(Eq. 3)