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https://doi.org/10.4224/20393376

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A-1505.6

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(3) *Final Report*

Contract Report A-1505.6(Final)

This report was jointly funded by:

Institute for Research in Construction, National Research Council

and

Transport Canada

J.S. Bradley December, 1996

NEF VALIDATION STUDY:

(3) FINAL REPORT

The contents of this report are the results of analyses carried out by the Acoustics Laboratory of the Institute for Research in Construction at the National Research Council of Canada. While they are thought to be the best interpretation of the available data, other interpretations are possible, and these results may not reflect the interpretation and policies of Transport Canada.

SUMMARY

This is the summary of the final report of a project to evaluate the validity of the NEF measure of aircraft noise. This final report is intended to directly respond to the specific requirements of the original proposal. A database of references and two technical reports have already been sent to Transport Canada as part of this project. Summaries of the previous technical reports are included in the Introduction of this report. The highlights of this final report include:

General Recommendations

- Upgrade (and provide ongoing support for) the continuing development of the NEF_1.7 program.
- Establish and publish noise criteria for all major Canadian airports in terms of NEF values and supplementary single event noise criteria.
- Undertake a major Canadian survey of response to aircraft noise to include: isolated single event type problems, various smaller airport situations, tests of various time-of-day weightings, evaluation of the long term effectiveness of additional home insulation, and to provide a comprehensive calibration of the NEF measure.
- Support updating of the CMHC document on new housing and aircraft noise.
- Consider adopting an A-weighted NEF measure.
- Encourage all levels of government to follow a uniform national approach to the management of airport noise in Canada.

Acceptable Aircraft Noise Level Criteria

- It is proposed that the following noise level criteria thresholds, which are essentially the same as current recommendations, be adopted in terms of NEF_{CAN} values: NEF_{CAN} 25, the onset of negative effects of aircraft noise; NEF_{CAN} 30, homes should include additional sound insulation; NEF_{CAN} 35, no new homes should be built. (NEF_{CAN} refers to NEF values calculated by Transport Canada's NEF_1.7 program).
- Supplementary single event noise criteria should also be adopted to control noise problems involving small numbers of unusually loud events. Initial proposals were based on previous sleep interference studies and new considerations of speech interference by aircraft noise.

Historical Development of the NEF Measure

- The NEF measure evolved from the older CNR measure, initially intended for general community noise problems.
- The development was based on a pragmatic common sense approach using specific consulting community noise case studies.
- The basic concepts did not come from systematic studies and there was never any thorough attempt to calibrate the NEF measure in terms of negative human responses.

Details of the NEF Measure

- The equal energy principle for adding multiple events that is incorporated in the NEF measure is widely accepted and is used in almost all other aircraft noise measures.
- The EPNL metric, which determines the frequency response of the NEF measure, is probably a slightly more accurate predictor of adverse human responses, but it makes NEF values more difficult to measure and hence it is more difficult to validate NEF calculations.
- The NEF measure incorporates the largest night-time weighting in common use. There are arguments for a smaller night-time weighting and for the addition of an evening weighting.
- The prediction of the number of operations for future Peak Planning Days could be improved. Errors in forecasting future operations could lead to errors of up to 2 dB in NEF_{CAN} values and up to 30 % in contour areas. Smaller errors would more typically occur.

- The NEF_1.7 program has archaic input and output procedures, needs to be thoroughly validated, and needs ongoing support for both technical improvements and for improving the user friendliness of the software in coordination with the improvements of computer hardware.

Users' Evaluations

- Most users seem to be familiar and comfortable with the NEF measure.
- Many users say that the NEF_1.7 program is not user friendly and lacks sufficient detail in the description of flight paths.
- We do not know how to combine the impact of aircraft noise with other types of community noise such as road traffic noise.
- Too much attention to complaint data can distract us from a rational approach to aircraft noise management.
- Because Transport Canada does not have authority over all aspects of the problem, there is a need for a coordinated effort to manage airport noise and related land use planning that includes all levels of government and is carried out uniformly across the country.

Changes and Special Cases

- Excess ground attenuation algorithms in the NEF_1.7 program are in need of modification because they over-estimate the size of calculated NEF contours. New procedures must be based on, or validated in terms of, the measured attenuations of aircraft noise.
- There is a need to be able to include more complex approach and departure flight paths to correctly model current operations as well as to include the normal dispersion about the nominal flight path in the NEF_1.7 program.
- There is only limited information on changes of responses to aircraft noise over time from European studies. These show no change of dose-response curves over time.
- Although there are many smaller airports in Canada, the negative impact of these airports on residents is not well understood. The evidence suggests that disturbance may be less at smaller airports but larger where there are significant numbers of general aviation operations.
- Land use planning needs to be in terms of more stable maximum long term goals. It should be based on standard noise level criteria

and it should be applied in a coordinated manner by all levels of government.

CONTENTS

1.0 INTRODUCTION

1.1 The Final Report

This is the final report of a project to re-evaluate the use of the Noise Exposure Forecast measure (NEF) to manage aircraft noise in Canada. The initial proposal for this project indicated that all aspects of the use of the NEF measure should be examined. Specific topics to be considered were grouped into four major areas:

(a) the historical development of the NEF measure,

(b) various specific features of the NEF measure,

(c) user's experiences with the NEF measure, and

(d) the effects of various changes and special cases.

Because the work on this project has been extended considerably beyond the originally intended scope, the bulk of the technical results have been provided to Transport Canada in two previous technical reports[1,2]. Summaries of each of these previous reports are included later in this chapter. The present report is intended to respond directly to the issues in the original proposal under the four headings given above. Frequent references are made to the two earlier technical reports to avoid extensive repetition of material.

The activities of this project included a literature review, analyses of various human response studies, as well as extensive calculation studies with airport noise calculation programs. A large number of technical references related to aircraft noise and its effects on people were acquired and a computer database of these references was created. Copies of this database, sorted by author and by topic, were provided to Transport Canada. More up-to-date information was obtained by direct discussions with people working on various aspects of the overall airport noise problem in a number of countries. To evaluate Transport Canada's NEF_1.7 program, extensive calculation studies were performed that included comparisons with two American aircraft noise calculation programs. The results of these studies were provided in the first technical report[1]. Extensive analyses of a large number of studies were performed to evaluate current knowledge concerning the effects of aircraft noise on residents near airports. This produced new relationships between annoyance and aircraft noise, and between speech disturbance and aircraft noise. New proposals for acceptable noise level criteria were also produced and included in the second technical report[2]. These new proposals clarify but do not significantly change existing recommendations[3].

This final report is intended to respond to the issues in the original proposal on a point-by-point basis. Thus, the headings of each section are mostly those of the original proposal. In some cases, additional headings have been added to reflect the full scope of the work of the project. An additional chapter summarizes new proposals for acceptable noise level criteria developed as part of this work. The technical details of the two previous reports are usually not repeated in this report.

The initial proposal refers to "the calibration of the NEF model". The "model" refers to an assumed model relating community response to aircraft noise levels measured in terms of NEF values. The "calibration" of this model suggests that studies of community response to aircraft noise have been used to quantify human response to aircraft noise as measured in terms of NEF values. As discussed in Chapter 2, there has never been such a "calibration" and to refer to such a "model" is an exaggeration of the true nature of the history of the development of the NEF measure.

There is certainly a need for such a calibration relevant to Canadian situations. However, it is important to appreciate both the history of the development of the NEF measure, as well as its validity as used today. The three reports of this project are intended to examine in detail various aspects of the NEF measure as currently used. It is hoped that they will stimulate the development of an improved, more uniform, and more technically correct approach to managing airport noise in Canada.

1.2 Summary of Report A1505.3, "NEF Validation Study: (1) Issues Related to the Calculation of Airport Noise Contours"

The NEF_1.7 program is a critical part of the management of airport noise in Canada, and it is extremely important that its validity and accuracy are as good as is reasonably possible. The use of millions of dollars worth of land near each airport is often determined by the noise level contours from this program. Similarly, the acceptability of land near airports for residential use is determined from the calculated noise contours produced by the NEF_1.7 program. The analyses of this report suggest that improving the detail of the flight path description and developing a more correct excess ground attenuation calculation procedure would considerably improve the NEF_1.7 program. It is therefore essential that the required continuing development of the NEF_1.7 program receive the necessary financial and technical support.

The analyses of Contract Report A1505.3 were focused on the errors associated with calculating noise levels around airports. The related problems of determining acceptable noise level limits and the practical application of these limits were considered in Contract Report A1505.5. These two reports formed the technical background for this final report evaluating the use of the NEF measure to quantify airport noise levels near Canadian airports.

Some of the major technical findings of Contract Report A1505.3 are as follows:

- The NEF_1.7 program is similar to other models such as the Integrated Noise Model (INM) and NoiseMap used in U.S.A. Compared to these two models, NEF_1.7 uses simpler flight path descriptions and a different excess ground attenuation calculation. More sophisticated simulation type models are being developed that are potentially more accurate.
- Comparisons of the NEF_1.7, INM, and NoiseMap programs using the same input data from four Canadian airports showed that the NEF contours from the NEF_1.7 program were 60 to 80% larger and NEF values at particular locations were 3 to 4 dB higher. However, it is not known which calculation model agrees best with measured aircraft noise levels. When the complete Canadian approach of using a Peak Planning Day with the NEF_1.7 program was compared with the American approach of using a mean planning day and the INM model, even larger differences resulted.
- Errors in estimating the expected future total aircraft operations could typically lead to 1 dB errors in NEF values and 12% errors in contour areas. Errors in estimating the number of night time operations would usually be about half as large. Other errors in the estimated input data for future conditions would have smaller overall effects but often quite significant local effects.
- The detail in which the horizontal ground track and the vertical profile of the flight path are described influence the accuracy of the calculations. It is particularly important that the expected horizontal dispersion of aircraft about the nominal flight track be included in airport noise contour calculations.
- Differences in the calculation of the excess ground attenuation are the major cause of differences in the contours produced by the NEF_1.7 program and the two American programs. Evidence from European research and limited measurements of modern civil aircraft suggest that the most appropriate excess ground attenuation is intermediate to the NEF_1.7 procedure and the SAE procedure used in the INM and NoiseMap. Data from more

extensive experimental studies are required to determine a better excess ground attenuation calculation procedure.

- A-weighted SEL values and PNL weighted EPNL values can be related with standard errors of less than 2 dB. L_{dn} and NEF values were found to relate with errors of less than 1 dB.
- Approximate conversions between various airport noise measures were systematically derived. The largest scatter in these relationships is caused by different frequency weightings and time of day weightings.

1.3 Summary of Report A1505.5, "NEF Validation Study: (2) Review of Aircraft Noise and Its Effects"

Airports can be both an asset and a liability to nearby communities. Much of the negative impact of an airport is directly due to aircraft noise. Thus, the trade-offs between the costs and the benefits that an airport provides are very strongly related to the details of exposures to aircraft noise.

Contract Report A1505.5 reviewed:

- how people react to aircraft noise,
- how we evaluate aircraft noise exposures,
- various counter measures to reduce aircraft noise problems, and
- determined acceptable noise level limits.

This was the second of two reports intended to provide a comprehensive technical basis for evaluating the use of the NEF measure to quantify aircraft noise in Canada. The first report, A1505.3, considered issues related to the calculation of airport noise contours. Contract Reports A1505.3 and A1505.5 formed the technical background for this final report to Transport Canada reviewing all aspects related to the use of the NEF measure.

Some of the major technical findings of Contract Report A1505.5 were as follows:

- The current form of the NEF measure and related accepted noise level limits have evolved based mostly on intuitive arguments from various practical consulting case studies.
- Aircraft noise is very unlikely to lead to permanent noise induced hearing impairment in populations living near airports.
- There is limited evidence of medical effects related to our cardiovascular systems in populations living near a major airport,

but this evidence comes from studies by one research team at a single airport.

- When peak outdoor levels exceed 80 dBA, sleep indoors can be disturbed.
- New calculations from the details of aircraft fly-overs more accurately relate outdoor single event levels, SEL, and building facade noise reductions to speech intelligibility. When aircraft noise SEL exceeds 90 dBA, indoor speech communication can be degraded.
- The Schultz dose-response curve considerably underestimates the percentage of highly annoyed residents near major airports.
- The Perceived Noise Level more accurately reflects human response to noise than the A-weighting, but the difference in prediction accuracy is only 0.5 dB.
- Summing the effect of combinations of levels and numbers of events on an energy basis is as good as any other approach.
- The 12 dB night-time weighting incorporated in the NEF measure is larger than in other aircraft noise measures. There is evidence to suggest that smaller night-time weightings are more correct and that evening weightings are also important.
- There is no evidence that attitudes to aircraft noise change over time independent of noise levels.
- There is little information concerning the negative effects of aircraft noise near smaller airports and the effects of general aviation activities. In previous studies, the effects of airport size and types of aviation activity have usually been confused.
- Reduction of aircraft noise at the source most effectively and universally controls airport noise problems. Although possible reductions over the next few years will be small, it is important to encourage the continuing development of quieter aircraft.
- Various counter measures can be used to provide immediate reductions in noise exposures near airports. Such countermeasures must be tailored to the operational and geographical details of each airport.
- Better techniques are needed to provide improved sound insulation of buildings against aircraft noise, and the perceived benefits of such insulation need to be thoroughly evaluated.

- Almost all major developed countries have their own aircraft noise measure, their own set of acceptable noise limits, and their own particular approach to controlling airport noise problems.
- A new set of acceptable aircraft noise level limits have been derived from the best available technical information. These thresholds correspond to: NEF_{CAN} 25 the onset of negative effects, NEF_{CAN} 30 extra sound insulation required, and NEF_{CAN} 35 the maximum acceptable level for constructing new homes. (Where NEF_{CAN} refers to the NEF values calculated by the Transport Canada NEF_1.7 program). These new proposals are essentially the same as existing recommendations[3].

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2.0 THE HISTORICAL DEVELOPMENT OF THE NEF MEASURE

The Noise Exposure Forecast (NEF) is a single number rating of overall aircraft noise. It combines the noise levels of individual aircraft and the numbers of aircraft to give a single number rating of the average negative impact of the aircraft noise. The current NEF metric evolved from the earlier Composite Noise Rating (CNR) which was initially developed for general community noise situations and later modified to evaluate aircraft noise. While these measures were being developed in the United States, other early airport noise measures were being developed in Europe. In the United Kingdom, the Noise and Number Index (NNI) was introduced in the early 1960's. Shortly after this, the Störindex (Q) was introduced in Germany, and the Psophique Index (I_p) in France. The development of these aircraft noise measures in the early 1960's was a direct result of the public reaction to the widespread introduction of jet engine powered civil aircraft.

2.1 History of the CNR and NEF Measures (see also Chapter 2 of [1])

(a) <u>CNR as a Community Noise Measure</u>

There were five major steps in the development of the NEF measure from the initial versions of the Composite Noise Rating (CNR)[2]. The CNR was first proposed by Rosenblith and Stevens in 1952. The initial concept was to rate general community noise. This was modified somewhat by the same team from Bolt Beranek and Newman in 1955. In 1957, a new scheme was proposed for considering aircraft noise in terms of a CNR rating. This aircraft noise CNR method was further modified in the early 1960's so that it was based on the perceived noise levels. The full NEF concept was proposed in 1967.

These early developments were engineering proposals that were not systematically tested. They were based on concepts intuitively suggested by experiences with various consulting case studies. Responses were described in terms of "community response" that generally included references to complaints, and threats of legal actions. Such concepts pre-date scientific annoyance surveys and an understanding that complaint data is not a reliable measure of community response.

The initial version of CNR for general community noise was proposed by Rosenblith and Stevens in 1952[3]. It was based on octave band noise measurements that were given an equivalent sound pressure level (SPL) in the 300-600 Hz octave frequency band (an older system of octave bands that is no longer used). This equivalent SPL was obtained by plotting the measured octave band spectrum on a system of level ranking contours that were similar to equal loudness contours. The level rank contours were in 5 dB intervals and hence the resulting CNR values were also in 5 dB intervals. A number of corrections were then made to better approximate the expected negative community response. These related to: the presence or absence of pure tone components, impulsive or non-impulsive sounds, repetition of the sound, background noise levels, time of day, and expected community adaptation to the noise. CNR values were determined from noise levels and associated corrections for the data from 11 case studies of community noise problems. The CNR values were then compared with a six item scale describing the estimated community response. This scale varied from "no annoyance" to "vigorous legal action". The scheme was a sensible first attempt, but apparently did not relate well to the 11 case study results[2].

The original community noise CNR scheme was modified by Stevens, Rosenblith, and Bolt in 1955[4]. Changes to the consideration of the repetitive sounds brought the procedure closer to an equal energy approach, and corrections for seasonal variations were introduced. The descriptive scale of community response was reduced from six to five items, and the labels attached to each step were changed. The new scale referred only to "complaints" and "community reaction". The revised procedure was said to be successful for predicting changes in community response but less successful on an absolute basis.

(b) <u>CNR as a Measure of Aircraft Noise</u>

In the late 1950's, the U.S. Air Force began developing procedures for evaluating noise levels and for land use planning around air bases. This led to a new version of the CNR concept specifically for aircraft noise and an associated scheme to predict aircraft noise levels. The scheme proposed by Stevens and Pietrasanta in 1957[5] evaluated aircraft noise in terms of its equivalent level in the 300-600 Hz octave band. It no longer included tone and impulsiveness corrections, but corrected for repetitions in a true energy equivalent manner. Seasonal corrections and background noise level corrections were retained. The day/night correction was expanded to be a day/evening/night correction with 5 and 10 dB relative adjustments for the evening and night periods, respectively. The scale describing community response was reduced to three steps where the extremes were labeled "no concern" and "unquestionably unacceptable".

A procedure for calculating noise levels from aircraft on the ground (ground run-up noise) and aircraft in flight was also developed[6]. The procedure used the combination of the maximum pass-by level and the effective duration of the pass-by to estimate the total energy received from a single aircraft pass-by. That is, the contribution of each aircraft was essentially described in terms equivalent to a sound exposure level (SEL). The calculations included estimates of the directivity of aircraft as well as profiles of aircraft height versus distance from the start of the take-off. The contributions of multiple aircraft were added on an energy basis. No consideration was given to excess ground attenuation.

The use of the CNR measure to evaluate aircraft noise was further modified in 1962 to include the use of Perceived Noise Levels developed by Kryter[7]. Kryter developed a set of equal noisiness functions for sounds in various frequency bands that was quite similar to the Stevens loudness calculation procedure. From the complete spectrum of a noise, a single value termed the Perceived Noise Level, in PNdB, was intended to rank the noise in terms of how noisy it would be perceived. However, the resulting rankings were quite similar to the earlier level ranking contour scheme.

At about the same time, a new airport noise planning document was produced for the U.S. Air Force[8]. It included aircraft noise contours in terms of PNdB as well as other improvements. Several simplifications were also made. Time-of-day weightings were reduced to a single 10 dB night-time weighting. Corrections for background noise levels and community attitudes were dropped. Again, by using data from case studies, the resulting CNR values were related to the previous three-category scale describing expected community response. These three categories were essentially: no complaints, some complaints, and vigorous complaints. The separations between the three regions were set in terms of the sum of the average maximum perceived noise level, $\langle PNL_{max} \rangle$, and 10 times the logarithm of the number of aircraft, N, i.e.

$$\langle PNL_{max} \rangle + 10 \bullet \log(N)$$

Initially, the separation between the lower and middle categories was set for this sum equal to 112 and the division between the middle and upper region at 122. In order to “give airports the benefit of the doubt”[2], this last value was increased to 127. To obtain values that were multiples of 5 (because of the desire for 5 dB steps), these values were normalized to a base case of 10 to 30 operations per day by subtracting 12 dB from each. The resulting CNR values of 100 and 115 divided the three regions of the estimated community response scale. A similar table with 20 dB lower CNR values was devised for ground run-up noises.

(c) The Noise Exposure Forecast, NEF

Reports published in 1967[9,10] introduced the Noise Exposure Forecast (NEF) as a development from the earlier CNR scheme for aircraft noise. The new NEF procedure included new developments associated with perceived noise levels, removed the limitation of doing all calculations in 5 dB steps, but included no new information on community response to aircraft noise. At the same time, procedures for calculating expected aircraft noise in terms of the new NEF measure were also improved.

The perceived noise level concept had been extended to include corrections for the presence of pure tones and for the influence of the duration of each aircraft pass-by. The combination of these two additional factors resulted in a new measure referred to as the Effective Perceived Noise Level (EPNL). Performing all calculations in 5 dB steps was intended as a simplification to make calculations easier, but led to unnecessary errors. The NEF calculation also included an arbitrary constant so that the resulting NEF values were quite different than the corresponding CNR values. NEF values were related to the three levels of community response by assuming an approximate equivalence of NEF 40 to CNR 115 and NEF 30 to CNR 100. These approximations were obtained from comparisons of calculated CNR and NEF values[2]. Thus, the conversions would be influenced by possible errors in these early calculation algorithms.

Bishop and Horonjeff's[9] proposal included a night-time weighting that resulted in night-time operations being counted as 12.2 dB more significant than day-time operations. The weighting was chosen so that with the same number of operations per hour during the night-time hours as during day-time hours, the night-time NEF would be 10 dB greater than the day-time NEF. Because there were 9 night-time hours and 15 day-time hours, the number of night-time operations was multiplied by 10(15/9) = 16.67, which is equivalent to 12.2 dB. No evidence was presented to support the choice of this particular night-time weighting and no other aircraft noise measure has ever used this night-time weighting.

NEF is defined as follows and is summed over all aircraft types and all flight paths:

$$NEF = \langle EPNL \rangle + 10 \bullet \log(N_d + 16.7 \bullet N_n) - 88$$

where <EPNL> is the mean EPNL of aircraft fly-overs; N_d and N_n are the numbers of day-time and night-time operations, respectively.

By the late 1960's, the complete NEF measure had been developed to the form that is used today. At no point was the formulation influenced by any scientific survey of residents' responses to aircraft noise. (Of course, subjective laboratory studies were involved in the development of the EPNL measure that is a part of the NEF measure.) The implied principle of energy summation and the night-time weighting were not based on any systematic studies. Expected community response was described in very general terms of complaints. These descriptions were based on consulting experiences from a limited number of specific cases of community noise problems. Although Borsky's[11] early survey results had already indicated that complaint data were not a reliable measure of community response, there was no attempt to develop a noise measure or acceptable noise level criteria from such systematic surveys of responses to aircraft noise.

The NEF measure has been used in Canada, Australia, Yugoslavia, and Hong Kong. However, in Australia the time-of-day weightings were changed as a result of a major subjective survey of residents near Australian airports. The NEF measure was not widely used in the United States. In the early 1970's, the political requirement for a single environmental noise measure led to the adoption of the day-night sound level (L_{dn}) in the United States.

2.2 The Introduction of the NEF Measure in Canada

The CNR system was initially used by Transport Canada as a tool for land use planning around airports[13]. Tabular calculations of CNR values were described with a 10 dB night-time weighting. A table of expected community response was also given that was similar to that described above. Thus, initially the American CNR system for aircraft noise was adopted without obvious changes.

The same Transport Canada report[13] also describes the NEF system and compares it with the older CNR method. The critical CNR values of 100 and 115 were again approximated as NEF 30 and NEF 40, respectively. The table of expected community response from this report[13] is in terms of NEF values and is duplicated here in Table 2.1. This table is very similar to the earlier American tables from which it was derived. Table 2.1 was included in early versions of the CMHC document "New Housing and Aircraft Noise"[14]. This same table is also used in more recent CMHC and Transport Canada documents[15,16].

NEF Range	Expected Response
> 40	Repeated and vigorous individual complaints are likely. Concerted group and legal action might be expected.
35-40	Individual complaints may be vigorous. Possible group

	action and appeals to authorities.
30-35	Sporadic and repeated individual complaints. Group action is possible.
<30	Sporadic complaints may occur. Noise may interfere occasionally with certain activities of the resident.

Table 2.1. Relation of expected community response to NEF values from reference [13].

The CMHC documents on airport noise were one result of a three-party collaboration on airport noise problems during the early 1970's in Canada. The National Research Council, Canada Mortgage and Housing, and Transport Canada pooled their efforts to develop a rational approach to airport noise problems. The National Research Council carried out measurements of the sound attenuation of a test house constructed with the support of CMHC. Transport Canada provided the aircraft noise sources. All three parties worked together to produce the above table of acceptable values. The details of this table were a compromise to address several different concerns. There was the desire to ensure that people would be protected from high levels of aircraft noise. There were also concerns about the accuracy of NEF calculations at lower NEF values. Finally, there was also the concern that excessively restrictive limits would eliminate large areas of land from possible residential development with CMHC backed mortgages.

The currently used descriptions of expected community response were derived from the original CNR descriptions based on general impressions of community response for a small number of specific consulting case studies. These descriptions have not been influenced by more modern systematic community surveys of residents near airports. They have not been influenced by studies of any Canadian subjects. Thus, there has never been any serious attempt to calibrate values of the NEF measure with the negative effects on residents near Canadian airports.

2.3 The Development of Other Early Airport Noise Measures

The Noise and Number Index (NNI) was derived from the results of the first major survey of residents around London's Heathrow airport. While the CNR and NEF were developed on the basis of a simple energy summation, the NNI introduced the concept of different trade-offs between the noise levels of individual aircraft and the numbers of aircraft. The NNI is defined as follows:

$$NNI = \langle PNL_{max} \rangle + 15 \bullet \log(N) - 80$$

where <PNL_{max}> is the mean of the maximum perceived noise levels of the aircraft pass-bys, in PNdB, and N is the total number of aircraft pass-bys.

With this noise measure, doubling the number of operations results in a 4.5 dB increase in NNI values, which is greater than the 3 dB increase that would result from a simple energy summation approach. It has been suggested[2] that a simple energy summation measure would have been practically as successful in relating to the response data in the original London survey as was the NNI measure. The suitability of the simple energy summation approach will be considered in more detail in section 3.1.

The German Störindex (Q)[12], developed after the NNI, also weighted the influence of the number of operations more than for a simple energy summation. The Q measure was based on a doubling of operations causing a 4 dB increase in the noise measure. Q is defined as follows:

$$Q = 13.3 \bullet \log(\Sigma\, \tau \bullet 10^{(Lmax/13.3)}/T)$$

where τ is the duration of the pass-by, L_{max} is the maximum A-weighted sound level during the pass-by, and T is the time period over which the Q value is calculated. The summation is made over the τ and L_{max} values of all aircraft operations in the time period T. The measure was originally based on maximum PNdB levels.

The French Psophique Index (I_p) was developed in the late 1960's. It is a simple energy summation type measure based on aircraft levels in PNdB. Although it originally included a complicated two-part night-time correction, it now has a simple 10 dB night-time weighting. It is currently defined as follows:

$$I_p = \langle PNL_{max} \rangle + 10 \bullet \log(N_d + 10 \bullet N_n) - 32$$

where N_d and N_n are the number of operations during the day and night periods, respectively. Values of this measure were initially related to residents' responses from the results of a large survey near four French airports.

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3.0 EVALUATION OF DETAILS OF THE NEF CALCULATION PROCEDURE

This chapter reviews several specific issues associated with the NEF measure. These include: the equal energy approach, the EPNL metric, and time-of-day weightings which are at the heart of the NEF measure. Also included are: evaluation of the forecasting of aircraft operations, a critique of the NEF_1.7 program, and comparisons with other types of aircraft noise measures.

3.1 Equal Energy Principle (See also Section 4.2 [1])

Residents near airports are exposed to varying numbers of aircraft, each producing different levels of noise at a particular resident's home. Many noise measures have been devised to predict the combined disturbance of these multiple aircraft noise events. The most common basic hypothesis concerning the combination of noise levels and numbers of noise events is that annoyance is proportional to the total energy of the aircraft noise events. Thus, many noise measures are of a form that is similar to the following,

$$\%\ \text{Highly Annoyed}\ \alpha\ \langle SEL \rangle + K \bullet \log(N) \qquad (3.1)$$

where <SEL> is the integrated sound exposure level for an average aircraft and N is the total number of such events.

If K is exactly 10, then the summation, <SEL>+10•log(N), corresponds to the total energy of the aircraft noise events.

Other values of K have been incorporated into aircraft noise measures. The Noise and Number Index, NNI, has a K value of 15. The German Störindex, Q (now referred to as an aircraft noise equivalent level, L_{eq}(FLG)) includes a K of 13.3. Both were derived from early aircraft noise surveys and have been widely used. These K values greater than 10 suggest that the number of operations is relatively more important than the noise levels of each aircraft.

Deciding whether the above relationship, expression (3.1), is appropriate, and the correct value of K, has been considered using both field and laboratory subjective studies. Laboratory experiments can provide more precise subjective evaluations than field studies, but cannot duplicate all of the influences of the real situation in the subject's home. Thus, the level of annoyance cannot be absolutely correct. While field studies can include realistic settings, they are notorious for producing subjective response data that are only weakly correlated with noise measures. Using this type of data, it is very difficult to reliably differentiate between two noise measures, having different K values, as predictors of annoyance.

Rice[2] reviewed laboratory studies on this subject that had been carried out in the United States and the United Kingdom. He concluded that an equal energy approach could satisfactorily explain many of the results, although it may not always be the correct explanation.

Rylander et al.[3] produced the most controversial field study results concerning the trade-off between levels and numbers of events. Their results suggested that the percentages very annoyed were related to the numbers of operations. However, a re-analysis of this data[1] suggested that an equal energy measure such as L_{dn} was an equally satisfactory predictor of responses.

Fields[4] reviewed the results from 14 surveys of various types of noise. He calculated optimum K values from the results of each of these surveys. His calculations resulted in a wide range of K values usually with large standard errors. Fields found a mean K value of 5 from these studies. However, the data were not precise enough to conclude that a K value of 10 was not optimum.

The NNI measure, that incorporates a K of 15, has been used in Switzerland for a number of years, even though the Swiss aircraft noise survey in 1971[5] found a K value of 8 to be best. The Swiss use of NNI seems to be based on the use of NNI in the United Kingdom. However, a more recent survey in the United Kingdom[6] designed specifically to evaluate the relative merits of NNI and L_{eq} measures concluded that a K value of 9 or 10 would be best.

The original studies that led to measures such as NNI are no longer considered to be representative. Laboratory studies cannot predict absolute annoyance because they do not reproduce the complete realistic long term experience of living in a home exposed to aircraft noise. It is unlikely that field studies can be accurate enough to precisely define an optimum value of K. Thus, the practical solution is to use a K value of 10 because it is within the range of possible optimum values and because the simplicity of the equal energy approach is so appealing.

This lack of precise knowledge as to the correct value of K is important because of the expected changes in operations at Canadian airports over the next few years. Both the average noise levels of aircraft and the numbers of operations are expected to change. With the introduction of quieter Chapter 3 aircraft, average aircraft noise levels will be reduced. However, the expected increase in the numbers of operations will eventually lead to increased overall noise levels. Whether or not the resulting combination of reduced aircraft noise levels and increased numbers of operations is acceptable will depend on the true nature of the trade-off between the number of events and aircraft noise levels. With currently available knowledge, we can only use the equal energy approach (K = 10) with the expectation that it is sufficiently close to the way people react to aircraft noise.

3.2 EPNL Metric (See also Section 4.1[1])

The human hearing system is not equally sensitive to all frequencies of sound. When rating sounds that are a mix of various frequencies, it is therefore necessary to weight the relative importance of the different frequency components of the sounds. This has been done by calculation schemes as well as by electronic frequency weighting networks. The various schemes have been designed to approximate one of the sets of equal perception contours which can be thought of as the frequency response of our hearing system.

The system of equal loudness contours can be used to rate the loudness of single frequency sounds[7]. More complex systems have been developed by Stevens[8,9] and Zwicker[10] to determine the loudness of sounds that include a mixture of different frequencies. These loudness schemes require relatively complicated calculations from the individual 1/3 octave sound levels to determine the overall loudness of the sound.

Kryter[11] devised a similar system for rating the ‘noisiness’ of complex sounds. This is based on a set of equal noisiness contours that are quite similar to equal loudness contours. From the 1/3 octave levels and the equal noisiness contours, the noisiness of each band is determined, and from these the overall Perceived Noise Level, PNL, is calculated. Critics have suggested that for every adjective describing sound there could be further sets of equal perception contours. For example would equal annoyance contours be similar to equal noisiness contours?

Tone corrections are usually added to Perceived Noise Levels to account for the expected additional annoyance of sounds with strong pure tone components. The addition of the pure tone corrections adds further complexity to the calculated noise measures.

A simpler approach to the frequency weighting of sounds is to use a simple frequency weighting network to electronically filter sounds. The oldest of these weighting networks is the A-weighting which dates from the 1930’s and is intended to be an approximation to an equal loudness contour. The D- and E-weightings were intended to approximate equal noisiness contours. In current practice, the A-weighting is almost universally used as a simple single number rating of all types of sounds and the other weighting networks are rarely used.

The major difference between the calculation schemes and weighting networks is that the shapes of weighting networks do not vary with sound level. The equal loudness and equal noisiness contours are not parallel, but get closer together at lower frequencies. This more correctly approximates the response of the hearing system and represents the changing frequency response of the hearing system with changing sound level. Ignoring this changing response with sound level is one reason why weighting networks are less accurate predictors of negative responses to sounds.

The relative merits of the various frequency weighting networks and calculation schemes have been considered in a number of studies. The Perceived Noise Level, calculated from equal noisiness contours, is a more complex procedure specifically developed to evaluate the noisiness of aircraft sounds. It is usually found to more accurately predict negative responses to aircraft noise. On the other hand, frequency weighting networks are much simpler to use, but provide less accurate ratings of expected negative responses. For the relative rating of groups of sounds with similar spectra and similar sound levels, the simpler frequency weighting networks should be most successful.

There is still some uncertainty as to which measure is the most accurate predictor of responses in general, and in particular of responses to aircraft noises. The results of various studies suggest that Perceived Noise Levels are a little more accurate than A-weighted levels, but that tone corrections do not improve the prediction of subjective responses. It is not clear that this small improvement in prediction accuracy, relative to A-weighted levels, is of practical importance, or whether it is worth the added complexity of calculating Perceived Noise Levels.

It is interesting to note that A-weighted and Perceived Noise Levels of Chapter 3 aircraft were found to be related to each other with a standard deviation of only 1.6 dB[12]. Thus, if one limited the question to the consideration of modern civil jet aircraft, the similarity of the noise spectra would probably lead to smaller differences in prediction accuracy between the various frequency weighting schemes.

For the precise certification of aircraft, it is arguable that the extra accuracy of the Perceived Noise Level frequency weighting system is justified, although tone corrections should probably not be included. For the rating of noise levels in areas near airports, integrated A-weighted noise levels are thought to be sufficiently accurate. The difference in prediction accuracy between A-weighted levels and Perceived Noise Levels is less than 0.5 dB and only about 0.3 dB for tone corrected PNL values. This error is much smaller than the accuracy of predicting noise levels around airports and quite tiny compared to the errors in predicting the expected annoyance of residents near airports. The magnitude of the error may be an over-estimate in that if only modern jet aircraft noises were considered, the differences in prediction accuracy would be expected to be smaller.

3.3 Night-Time Weightings (See also Section 4.3[1])

It has generally been assumed that noises during the evening and night-time hours are more disturbing and annoying than those during the day time. There is a long history of the addition of arbitrary time-of-day weightings to aircraft noise measures (see also Chapter 2). Although some early measures used a 5 dB night-time weighting, a 10 dB weighting has most commonly been used. Some measures have also incorporated a separate evening weighting that has most commonly been 5 dB. By arbitrarily assuming that the integrated exposure over the nine night-time hours should be 10 dB greater than the integrated exposure over the 15 day-time hours, the NEF measure obtained a 12.2 dB night-time weighting. None of these time-of-day weightings was derived from a rigorous scientific study of subjective responses to noise.

The existing time-of-day weightings are simply a consensus of various "common sense" type arguments from groups responsible for the development of the various noise measures. For example, lower noise levels are assumed to be required at night because sleep is more sensitive to disturbance by noise than most day-time activities. While some have challenged these "common sense" type arguments, the evidence in the literature is not conclusive.

The results of surveys are limited by the input data. In particular, at almost all locations night-time noise levels are highly correlated with day-time noise levels. That is, sites that are more noisy during the day time are usually more noisy at night too. At the same time responses are usually only weakly correlated with noise measures. Thus, it has not been possible to accurately determine the combination of day and night-time noise levels that best predicts subjective responses.

Various practical and "common sense" arguments suggest that some time-of-day weightings are necessary. Existing survey results tend to confirm that some form of time-of-day weighting is required. As a result of a major Australian study, the NEF measure was modified there to include an evening weighting and a reduced night-time weighting[13].

Several other studies have suggested that an evening weighting is more important than a night-time weighting. The tentative support for an additional evening weighting and lower night-time weightings are counter to the NEF measure which incorporates the largest night-time weighting in common use.

3.4 Forecasting the Number, Type, and Mix of Aircraft (See also Chapter 3[12]).

In order to predict future aircraft noise levels, it is first necessary to predict the details of future aircraft operations. It is necessary to know: the total number of aircraft operations, the number of operations for each aircraft type, the portion of the operations that are during the night-time hours, the stage length of each departing flight, the runway use, and the flight paths to be followed. Errors in each of these input variables will influence the resulting NEF values and the contour areas. In some cases, the average NEF values will change, while in others there may be larger local effects where there are increases in some locations and decreases at others. The magnitude of the various possible errors were examined in detail in Chapters 3 and 5 of reference [12].

Transport Canada's Air Statistics and Forecast group forecast expected future total operations at major airports. In analyzing the accuracy of their predictions they found an average error of 11% over a ten-year period and up to a 21% error in a single year. These estimates were averages for Canada's top 77 airports[14]. At individual airports, larger errors in the predicted total number of operations could occur.

Transport Canada calculates NEF values for the number of operations occurring on a Peak Planning Day (PPD) that is approximately a 95th percentile day. Further errors are incurred estimating the number of operations for future PPD's from expected future total operations. Values for the number of operations for a PPD are approximated by determining the number of operations for the seven busiest days of the three busiest months. These estimates of the number of operations per PPD from several years of data at a particular airport are extrapolated to predict future values of the number of operations per PPD. This was found to be an inaccurate cumbersome procedure prone to errors[12]. Standard errors of up to 40 operations per day were found. By combining a number of years of data from several airports, a single equation was derived that more simply and more reliably predicts the number of operations for a future PPD.

The effect of various errors in the input data were determined using the NEF_1.7 program[12] and are summarized in Table 3.1. The average changes in NEF values within each NEF contour for three quite different airports were assessed and Table 3.1 gives the range of changes that were found. Errors in the total number of operations have the largest effect. One dB changes in NEF values and 10 to 15% changes in contour areas are quite likely to occur as a results of errors in the estimated total number of operations. The current procedures for predicting the number of operations for future PPD's could lead to further errors corresponding to as much as 0.4 dB in average NEF values and 4 to 7% in contour areas. Because these two sources of error could be multiplicative, the total error in the estimated number of operations for a future PPD could be larger. It seems unlikely that the combination of these two errors would exceed a 40% error in the predicted total number of operations corresponding to an average error of 1.5 dB in NEF values and 13 to 26% in contour areas.

Input Data Change	Change in Mean NEF, dB	Change in Contour Area, %
±20% total operations	±1 dB	±10 to 15%
±40% total operations	±1.5 dB	±13 to 26%
±10% in PPD estimate	0.4 dB	±4 to 7%
+20% night operations	0.3 to 0.5 dB	+4 to +7%
+1 stage length	-0.3 to 0 dB	±4%
+20% Chapter 3 aircraft	-0.3 to 0 dB	-4 to +2%
+20% use of one runway	-0.1 to +0.5 dB	-3 to +9%

Table 3.1. Summary of expected errors in NEF values and contour areas for various changes in the input data.

Changes in the other input data included in Table 3.1 tend to produce smaller average changes in NEF values but sometimes larger local effects. Typically, average NEF values changed by up to 0.5 dB and contour areas by 4 to 7%. Errors in each of these other input variables would usually be independent of each other. Thus, several errors are not likely to all add in the same direction. However, at particular locations errors in expected runway use and aircraft stage length moved the contours by up to 1500 feet (460 m) and changed particular NEF values by up to 1.5 dB.

As a typical worst case, errors of up to 2 dB in average NEF values and up to 30% in contour areas seem quite possible.

3.5 The NEF_1.7 Program (see also [12], particularly Chapters 3 and 5)

The NEF_1.7 program is the primary tool for managing aircraft noise near Canadian airports. It is used to manage the use of land that is worth many millions of dollars. Therefore, it is essential that this program be as technically accurate and efficient to use as possible. However, its archaic user-interface makes it cumbersome to use, and its accuracy has not been adequately verified. Neither its algorithms nor its accuracy are well documented, and more support is required to continue the development of this essential tool.

(a) <u>Technical Accuracy</u>

The excess ground attenuation routines included in the NEF_1.7 program are thought to lead to overestimation of NEF contour areas. Extensive experimental studies of the propagation of aircraft noise are required to develop and validate improved algorithms for excess ground attenuation.

Flight paths are not modeled in enough detail to accurately represent actual conditions. The numbers of segments of the horizontal flight track and the vertical take-off profile are too limited. The normal dispersion of aircraft about the nominal flight track is not included in the NEF_1.7 program.

The algorithms on which the program is based are not documented. They should be fully documented so that the validity of the current program can be better assessed and so that improvements can be more easily made.

Some European groups are developing much more sophisticated simulation type aircraft noise models that more precisely model the movement of aircraft and the propagation of sound from them. Work is proceeding to include the effects of the directionality of each aircraft type, irregular terrain, and meteorological effects.

There is a real danger that the NEF_1.7 program may soon become technically obsolete.

(b) <u>Efficiency of Use</u>

The NEF_1.7 program has an archaic user interface that seems to be the result of a quick conversion from the original main frame version that included card input. Use of the program is unnecessarily cumbersome and time consuming. The program would benefit from a smart front end that would help the user with data entry.

The input aircraft noise data are not included in external files, but are combined with the compiled program. Thus, the user has no access to this data and cannot easily add revised aircraft noise data.

The program does not include sufficiently refined contour plotting routines. Such routines should be included and should plot to modern printers such as postscript laser printers.

In the United States, new versions of the INM program have been announced that will include a more sophisticated user interface and the ability to combine contours with other graphical information.

(c) Support

Although Transport Canada have done their best to maintain the NEF_1.7 program, more support is required for the maintenance and development of this software. The technical basis of the calculations, the user interface, and the range of features that the program includes need ongoing maintenance and development. This is not a question of a one-off fix up, but a need for a major change in philosophy and a recognition of the importance of this computer program.

As one small example of the current problems, an experimental version of the program was found to run many times faster than the standard version. This same considerable speed increase could be available to all users if enhanced support for this software were available.

Areas requiring full-time support and some example activities are:

(1) technical development of the program: Excess ground attenuation routines being developed in various countries need to be evaluated and an improved algorithm needs to be incorporated in the NEF_1.7 program.

(2) software development: The user interface, the speed and efficiency of the program need to be upgraded to meet the standards of modern commercial software and to match the capabilities of current computer hardware.

(3) technical support for users: Those developing the software should be available to provide assistance for users of the software to ensure that results are correct and are efficiently obtained.

(4) new developments: The process of estimating the number of operations for future PPD's could be completely automated. This would require procedures to acquire the operational statistics

electronically and software to estimate operations for future PPD's.

(5) verification: The accuracy of the current program and all future modifications must be experimentally validated.

3.6 Comparisons with Other Approaches (See also Chapter 6[1])

Almost every country with major airports uses a different aircraft noise measure to manage noise problems in areas around their airports. Although these different noise measures look very different, they all combine the noise levels of individual aircraft and the number of noise events to get an overall integrated measure of aircraft noise. Many of these measures were compared in detail in a previous report[12] and procedures were developed to convert from NEF and L_{dn} values to each of the other measures.

There are only three basic elements that differ between the various aircraft noise measures. These are:

- the frequency weighting of sounds,
- the levels versus number of events trade-off, and
- time-of-day weightings.

Measure	Country	Frequency Weighting	K, for Energy/Levels trade-off	Evening Weighting	Night Weighting
NEF_{CAN}	Canada	PNL	10	1	16.7
ANEF	Australia	PNL	10	4	4
L_{dn}	USA	A	10	1	10
L_{den}	Denmark	A	10	3.2	10
L_{eq}(FLG)	Germany	A	13.3	1	5
I_p	France	PNL	10	1	10
NNI_{UK}	UK	PNL	15	1	none
NNI_S	Switzerland	A	15	1	none
$WECPNL_j$	Japan	A	10	3	10

Table 3.2. Summary of principal components of aircraft noise measures used in various countries.

Table 3.2 summarizes how each of these basic components vary among nine different aircraft noise measures.

(a) Frequency Weighting

The frequency weighting of the aircraft noises are either A-weighted or PNL-weighted. No other frequency weightings are in common use. The United Kingdom has recently stopped using the NNI_{UK} measure that included a PNL weighting. This leaves only Canada, Australia, and France that use aircraft noise measures that include PNL weighted levels. Japan and Switzerland use approximate A-weighted equivalents to PNL levels in their aircraft noise measures. For modern Chapter 3 aircraft, A-weighted and PNL weighted noise levels are very closely related, with a standard error of only 1.6 dB[12]. A major drawback of using PNL-weighted aircraft noise measures is that it is very difficult to measure PNL-weighted levels and hence it is very expensive to validate NEF calculations with measurements.

(b) Levels Versus Number of Events Trade-off

Table 3.2 lists values of the K parameter from expression 3.1. A value of 10 corresponds to an equal energy trade-off. That is, when K = 10, the influence of levels and number of events are summed according to the total noise energy. Most of the noise measures listed in Table 3.2 use an energy summation approach with a K value of 10. As mentioned above, the NNI_{UK} measure is no longer used. Although the Swiss still use an NNI_S measure with K = 15, their own data suggests that an energy summation approach would be better. The value of K = 13.3 continues to be used in the German noise measure because it is fixed in legislation rather than because of a strong technical argument.

(c) Time-of-day Weightings

The time-of-day weightings shown in Table 3.2 are the equivalent linear weightings and not weightings in decibels. The 16.7 used in the NEF measure is the largest night-time weighting in common use. There were no sound technical arguments for this weighting when it was introduced and it has never been supported by studies of subjective responses to aircraft noise. A night-time weighting of 10 is commonly used and some jurisdictions also include an evening weighting of about 3. These are based more on pragmatic arguments than on the results of scientific evaluations of responses to aircraft noise. Only the Australian time-of-day weightings were the result of an extensive community noise study. The Australian survey and other published studies suggest the need for a substantial evening weighting and reduced night-time weightings.

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4. EVALUATION OF USERS' EXPERIENCES WITH THE NEF PROCEDURE

To evaluate users' experiences with the NEF and other procedures, many people were approached personally in both Canada and in other countries. The names of the major technical contacts are listed in Contract Report A1505.5. A wide range of people are "users" of NEF values. These include: Transport Canada employees in both Ottawa and the regions, airport officials, local and provincial environmental and planning officials, and consultants. Although most users have some comments concerning the NEF procedure, few have significant experience with the NEF measure and very few have experience with other aircraft noise measures. However, the various comments do add further practical details that may help to fill in gaps in the extensive technical studies to evaluate the NEF procedure[1,2].

Comments are grouped according to topic in each of the following sub-sections.

4.1 The NEF_1.7 Computer Program

The NEF_1.7 program is frequently criticized by users. Criticisms concern: the need for an intelligent front end, insufficient detail for flight path descriptions, difficulties getting some of the required input data, the need for additional features, and the need to experimentally validate the existing program and future changes to it.

The limited descriptions of flight paths in the NEF_1.7 program make it impossible to accurately model many existing airport situations. For example, departure paths from the Pearson Airport's north-south runway contain more segments than the NEF_1.7 program can model. Similarly, the program only allows straight-in arrival paths with a 3 degree descent. It is not possible to model the procedure of an aircraft approaching on a down-wind leg, turning, and landing up-wind.

The user interface is criticized as archaic and unfriendly. It is said to be a rough conversion from a main frame program that still includes extra variables that apparently were only used by the former main frame version. With the proposal to add more complex flight path descriptions, there was also the suggestion that this should be accompanied by a more intelligent front end that would help the user to enter the more complicated flight path information. The program should incorporate the more sophisticated types of user interface that are common with modern commercial software.

There were also criticisms concerning the problems of acquiring some of the necessary input data. Predicting the details of future mixes of aircraft types to the point of specifying aircraft and engine types becomes a matter of guess work, because this information is not available for future situations. However, it is difficult to imagine how one could more accurately predict future mixes of aircraft types. Estimates of the effects of errors in the input aircraft types[1] suggested that this would normally lead to quite small errors in the calculated NEF values.

Users' comparisons with the INM program produced suggestions that the excess ground attenuation algorithm should be reviewed, and that new features such as the ability to include meteorological effects and the influence of non-level terrain should be considered.

Several people pointed out the need to experimentally verify the NEF_1.7 program and the resulting calculated aircraft noise contours.

Most of these points are closely related to the results of our own review of the NEF program in section 3.5.

4.2 The NEF Noise Measure and its Use

Most people using the NEF measure feel "comfortable" with it and have a feel for the meaning of various NEF levels. This is a very strong argument against changing the NEF measure. Although there was one comment that the NEF was an archaic measure, few users have the technical knowledge to evaluate whether the NEF measure is superior or inferior to other aircraft noise measures.

There were some criticisms that NEF contours, as currently calculated, do not represent the worst cases. One suggestion was that instead of using the Peak Planning Day, input data should be representative of a worst hour. A related suggestion was a composite contour system. Contours would be calculated for each of the commonly used operational configurations of the airport. The final result would be a composite of the maxima of all of these sets of contours. It is not known whether such overall maximum values would be better related to mean community annoyance.

Some suggested there were problems because residents didn't believe that flight tracks used in calculating NEF contours were the same as those used by current aircraft operations. This may be partially due to the inability of the NEF_1.7 program to model more complicated flight paths and to the normal dispersion of aircraft about the nominal flight path. Such concerns can only be properly answered by extensive analyses of combined flight track radar and noise monitor data.

One consultant pointed out the problems of estimating the combined impact of aircraft noise and other sources of environmental noise. This is complicated by the fact that one cannot readily add NEF values to A-weighted measures of other noises such a road traffic noise. However, the more important problem is that we do not really understand the combined effects of different sources of noise on people and it is most likely that equal levels of different sources of noise are not equally disturbing. A detailed review of the subject[2] suggested that there is a trend for aircraft noise to be more annoying than equal levels of road traffic noise which is usually more annoying than equal levels of train noise. Thus, it is not correct to simply add the energies of different types of noise sources. Using a quite different measure for aircraft noise, such as NEF, helps to emphasize these differences. However, we do not understand how to correctly combine the effects of different sources to estimate the total impact on people. Further work is required to resolve this problem.

Many pointed out the severe problems that would be faced if Canada were to change from using NEF to some other measure. This would include the need to re-educate large numbers of people who have developed an understanding of the NEF measure and the significance of various NEF values. A change to another aircraft noise measure would require a massive coordination of those concerned with aircraft noise problems at the federal, provincial, and local levels of government as well as with others such as consulting companies working in this area.

It was suggested that an A-weighted measure such as L_{dn} would be easier to explain. Perhaps, the most significant reason for changing to an A-weighted measure is that the computer calculations of aircraft noise levels could be more easily experimentally verified.

4.3 The Planning Process

A major problem with the current approach to using NEF contours in the land use planning process is that they are always changing. Sensible planning cannot permit the building of new houses in an area one year and prohibit them the next year. Planners must somehow estimate what the worst case scenario will be sometime in the future. The most successful procedure for managing aircraft noise problems has been the Alberta approach of setting up Airport Vicinity Protection Areas. This process creates practical blocks of land around airports that give the airport room to develop to meet the community's needs, but prevent the construction of new homes within areas where noise levels are greater than NEF_{CAN} 35.

At Calgary airport, noise management is carried out on a consultative basis and there is a serious attempt to educate residents, particularly in areas of NEF_{CAN} 25 to 30, concerning aircraft noise issues. In Calgary, people moving into homes in areas of NEF_{CAN} 25 to 30 are given a brochure by the city planning department explaining aircraft noise issues.

In Ontario, different branches of the provincial government recommend different limits for the construction of new houses near airports. The Ontario Ministry of Housing still recommends that new housing be permitted up to NEF_{CAN} 35 while the Ministry of the Environment recommends a limit of NEF_{CAN} 30. Several communities near Pearson airport have planning limits for new housing of NEF_{CAN} 30 while others are at NEF_{CAN} 35. Thus, there is not even a consistent approach in all communities surrounding this one airport let alone among various airports.

Other provinces do not seem to have regulations that would generally limit the building of new homes in noisy areas near airports.

Various users recommended that planners and others using NEF_{CAN} contours need guidelines concerning how to interpret NEF_{CAN} contours. It is particularly important that users appreciate the degree of imprecision in the published contours so that they can be more intelligently used in the planning process. One suggestion was that Transport Canada should produce a document to explain these issues and to help users of the published NEF_{CAN} contours.

One particular problem in the planning process is the question of infill. Where there is available land between existing houses, the construction of new homes is usually permitted even in areas of high noise levels. A longer term focus on the problem would suggest that this is not desirable, but alternatives such as industrial use of this land would usually be quite unacceptable too. Each potential infill area will be different to others and it is desirable to develop guidelines for the process of deciding where new homes should be permitted.

It was mentioned by one consultant that the CMHC document on aircraft noise[3] was seriously out of date and very much in need of an update. It is based on aircraft noise spectra that are no longer representative of today's aircraft and does not include many modern types of building facade constructions.

4.4 Use of Complaint Data

Airports in Canada and throughout the world are particularly sensitive to complaint data. Employees are dedicated to investigating and responding to complaints concerning aircraft noise. Automatic noise monitoring systems with public display boards are often largely for good public relations purposes and to help to minimize complaints.

Unfortunately, complaint data often do not correlate well with noise levels. Thus, the causes of complaints include many factors that are more significant than the actual noise levels. Complaints have been shown to be influenced by the socio-economic status of complainers and their general ability to be an effective complainer. Putting a strong emphasis on responding to complaints makes it difficult to have a rational noise management program and leads to a lack of credibility for the airport noise contours. That is, one might conclude that if people living well outside the noise contours complain as frequently as people in high noise areas, the noise contours must be wrong or even useless.

Of course, this is not true. Carefully planned community surveys of annoyance produce results showing significant correlations between responses and airport noise levels. Such surveys can give representative results for the entire community. Complaint data are usually not representative of the entire community. While it may be advisable to investigate complaints, concern for complaints should not be allowed to interfere with a rational approach to managing airport noise problems.

4.5 Coordination Among Various Levels of Government

The effective management of airport noise and associated land use planning must involve all three levels of government: federal, provincial, and local. Transport Canada's powers are limited. Without a coordinated effort of all three levels of government, there cannot be a coherent approach at all major airports. The fact that the approach to aircraft noise problems in Canada varies greatly from airport to airport shows clearly this lack of a coordinated effort.

While establishing such cooperation across the country may be an enormous task, Transport Canada should at least take the initiative in getting it started. Transport Canada should first produce clear revised guidelines for the acceptable use of land near airports as a function of noise level. These should include an explanation of NEF contours and their use for non-acoustical experts. It is recommended that new guidelines should incorporate the revised estimates of acceptability criteria in Chapter 6 of this report, which are essentially the same as current recommendations[4].

It would be very desirable if all communities near major airports were to use the same system of noise level contours to determine the use of land in noisy areas near airports. Transport Canada should do everything possible to promote and encourage such a unified national approach. There are many ways in which such a more uniform and coordinated management of airport noise could be developed. One approach would be to follow a scheme similar to that in the United States. There, the federal government takes money gained from airport operations and gives it back to fund approved airport noise mitigation schemes. By insisting that such plans include an acceptable land use planning scheme in terms of approved noise level contours, a coherent national approach is ensured.

4.6 Experience in Other Countries

The approaches to managing airport noise in a number of developed countries were reviewed in Chapter 6 of [2]. Most developed countries seem to take airport noise problems more seriously than Canada in that they have devoted more money and effort to the management of airport noise. A number of countries have: (1) a unified national approach to airport noise management, (2) developed their own airport noise computer calculation programs, (3) extensive noise monitoring systems, and (4) programmes to finance extra sound insulation and other mitigation procedures.

Many developed countries have a more complete national approach to the management of airport noise. In Germany, all details of airport noise criteria and even calculation procedures are specified in a national law. Australia has a national standard that specifies the details of the noise measure and land use planning limits to be used at all Australian airports. While almost all developed countries have a more unified national approach, in some countries such as Denmark, France, and the United Kingdom, there is an emphasis on problems at the major airports near the national capitals. Of course, in these countries these airports represent a large percentage of the total air traffic.

Most developed countries have their own airport noise calculation programs. While some countries have one official program, others have a number of different programs. In Germany, the full calculation procedure is specified in a national law. Australia uses a slightly modified version of the American INM program, as do some other smaller countries. Groups in Denmark and Switzerland are developing a more sophisticated generation of computer models based on simulation techniques.

Many countries have automatic noise monitoring systems at major airports. However, in many cases these are not integrated with flight track radar information. Where noise level data and flight track data are combined, such as in Australia and Switzerland, the noise monitoring systems become a much more useful noise management tool. Specific complaints can be resolved; modified operational procedures can be devised and tested to minimize the adverse impact of the aircraft noise. Without the flight track information, noise monitoring systems can become a public relations gesture and a tool for acquiring mountains of statistics.

In most developed countries, there have been schemes to fund the addition of sound insulation to homes and other buildings such as schools. Very large sums of money have been spent for this purpose in Japan. In Denmark, France, and the United Kingdom, these schemes have been concentrated on areas near a few major airports. Often these schemes are funded by noise weighted landing fees. In the United States, the FAR 150 (Federal Aviation Regulation) program provides funding for added sound insulation as a part of overall airport noise mitigation plans (over $200 million US for 1994).

While many countries fund added sound insulation, evaluation of its effectiveness is less often performed. Objective measurements of the building facade sound insulation are sometimes made and there is a standard method for this in the Scandinavian countries. There is very little social survey data to verify residents' evaluations of the long term effectiveness of such added sound insulation. That is, we do not know how much overall annoyance is reduced by added sound insulation.

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5.0 EVALUATION OF EFFECTS OF CHANGES AND SPECIAL CASES

This chapter reviews the effects of various changes to airport operations, and particular special cases and aspects of the overall airport noise problem. In the calculation of NEF contours, various changes can affect the results. These would included changes to: excess ground attenuation calculations, flight path details, aircraft type descriptions, as well as changes in operations over time. Smaller airports, quieter sites, and land use planning procedures represent special issues that are also discussed in this chapter.

5.1 Excess Ground Attenuation (See also section 6.6[1])

The calculation of excess ground attenuation has a major impact on the size of the resulting noise contours. There is evidence[1] that the calculation procedure in the NEF_1.7 program significantly underestimates the actual excess ground attenuation and that the SAE procedure used in the American INM program overestimates excess ground attenuation. Several newer estimates of excess ground attenuation and limited measurement data confirm that a procedure providing results intermediate to the NEF_1.7 program and the INM program would be closer to the actual excess ground attenuation.

Changes to improve the excess ground attenuation calculations would significantly change the resulting NEF contours. For some typical aircraft types, the NEF_1.7 program produced contours that were approximately double the area of those produced by the INM program, apparently largely because of differences in excess ground attenuation. Complete airport contours calculated for Windsor, St. John's, Ottawa, and Montreal airports showed that with the same input data, the NEF_1.7 program produces contours that are 60 to 80% larger in area than the INM program contours. Again, these differences are believed to be almost entirely due to differences in excess ground attenuation.

It is extremely important that excess ground attenuation algorithms be changed to accurately model real conditions. Because of the complexity of the aircraft noise source, improved excess ground attenuation algorithms can best be derived from extensive measurements of aircraft noise levels at various distances and elevations. Such measurements should be a priority and would be the first step to deriving improved calculation procedures.

5.2 Flight Path Details (See also parts of Chapter 6[1])

The detail with which flight paths are described tends to influence particular parts of noise contours rather than general characteristics such as their area[1]. Thus, the contour area may be almost unchanged, but at some points the contour may move by several thousand feet, and noise levels may change by several dB. The NEF_1.7 program has quite limited capabilities to accurately describe flight paths in both the horizontal and vertical planes. The NEF_1.7 program allows only: up to two turns in the departure track, up to three segments in its vertical profile, and only straight-in approach paths. The limited ground track descriptions are inadequate to describe many operational procedures at Canadian airports. The three-segment vertical profiles cannot satisfactorily approximate the more detailed profiles used in the INM program which are assumed to more accurately represent actual aircraft take-off profiles.

The NEF_1.7 program ignores the normal dispersion of aircraft paths about the nominal path. Again, this was shown[1] to produce local changes in noise contours moving the contour by several thousand feet and changing noise levels by several dB. Accurately modeling the real horizontal and vertical dispersion of aircraft paths would require an analysis of the flight track radar information at several airports.

Turns can be specified either in terms of a turn radius or a rate of turn. The two approaches change the details of flight paths and the resulting NEF contours.

Changing the details of flight path specifications usually has only small overall effects on average NEF values and contour areas. At particular locations, the changes can cause contours to move by several thousand feet, and NEF values to change by 1 or 2 dB.

5.3 Changes in Aircraft Type

Earlier versions of the NEF_1.7 program included input noise data for about 20 categories of aircraft. The current version uses data specific to 81 combinations of aircraft and engine type. The new approach more accurately represents the source noise levels of each aircraft type, and must lead to improved accuracy of the resulting contours.

It is difficult to accurately estimate the possible errors introduced by the older system of using data for only 20 categories of aircraft. Examining the input data for the INM program suggested that groups of similar aircraft would have output noise levels that agreed within 1 to 2 dBA. Thus, the noise levels of one particular aircraft type might differ by 1 or

2 dBA from the mean of the group, but averaged over several aircraft types the errors would be much smaller.

Calculations were performed for a 20% increase of the portion of Chapter 3 aircraft operating at three different sizes of airport[1]. Average NEF values changed by up to 0.3 dB and contour areas by no more than 4%. For most cases, the changes were less. These effects are probably indicative of the magnitude of the effects of changes in specifying aircraft types. Thus, the improvement in specifying input data, from 20 categories to 81 specific aircraft types, probably led to relatively small improvements in the accuracy of calculated NEF values of no more than a small fraction of a decibel.

5.4 Changes Over Time

Annoyance to aircraft noise may change over time due to changes in the noise environment, changes in attitudes, or a combination of both factors. There is limited experimental data describing these effects.

Evidence[reference 2, Section 4.4] from London's Heathrow airport, over a 17-year period, and from major Swiss airports, over a 20 year interval, showed no effect of changing attitudes to aircraft noise. That is, at similar levels of airport noise the amount of annoyance was essentially the same both before and after the 17 and 20 year intervals. It is possible that different populations might react differently, but there is no similar Canadian data.

Large changes in aircraft noise levels have been shown to cause corresponding changes in annoyance responses[reference 2, Section 4.4]. There is also evidence that abrupt noise level changes cause transient larger changes in annoyance than would be expected from the difference in the noise levels. Thus, noise level increases tend to produce some extra annoyance and noise level reductions seem to lead to a temporary extra reduction in annoyance. Although these are assumed to be short term effects, it is not clear how long they may last.

Environmental noise levels in areas near airports have also changed over time. Changes in aircraft noise are well known from the statistics of operations at each airport and previous calculations of NEF contours. Transport Canada's air statistics forecasts[3] suggest an approximate 10% per year increase in future operations at Canada's top 77 airports. This would correspond to an average of about a 0.4 dB increase in NEF values per year if the noise output of individual aircraft were constant. The gradual introduction of quieter Chapter 3 aircraft will lead to the opposite trend until all aircraft are Chapter 3 types.

The evidence from the British and Swiss studies would suggest that annoyance will change gradually as the noise levels change. It is unlikely that these gradual changes will cause the transient effects in annoyance responses found for abrupt large noise level changes.

The other most common source of environmental noise is road traffic noise. In general, road traffic noise levels have increased over time due to increased road traffic. However, the effects of road traffic noise are limited to areas quite close to the road and residents are usually only disturbed by the noise from the road passing in front of their home. While no data was found to document the gradual changes in road traffic noise near Canadian airports, it seems unlikely that such gradual changes will lead to large modifications of subjective responses. The introduction of abrupt changes in noise levels by significant changes to the pattern of operations at an airport are much more likely to be a cause of extra concern for nearby residents.

5.5 Smaller Airports

Smaller airports are different from large airports because they tend to have much less air traffic and because there is usually a different mix of aircraft types. Several studies have shown general aviation traffic to be more annoying than commercial air traffic[2]. Results from the United Kingdom and the United States suggest that the increased annoyance caused by general aviation activities relative to large airport situations is approximately equivalent to a 5 dB increase in noise levels. At the same time, there is also evidence that aircraft noise near smaller airports tends to be less annoying than the same levels of noise near large airports. Although the evidence supporting this effect is weak, it would help to explain comparisons of annoyance near Oshawa and Pearson airports[4]. Thus, the actual degree of annoyance near a smaller airport may be a combination of increased annoyance due to the amount of general aviation activity, and decreased annoyance due to other factors related to neighbourhoods near smaller airports.

5.6 Quieter Sites

Several studies have looked at the question of how background noise levels and noise from other sources influence annoyance to aircraft noise. Studies of more constant noises such as residential air conditioner noise[5] have shown clearly that annoyance to the particular noise is related to how much it exceeds the level of the general ambient noise. Some similar results have been found for aircraft noise[2], but not all studies show a clear effect of general ambient noise. This is probably largely due to the unique character of aircraft noise with its very large sound level fluctuations over time. Thus, for a wide range of ambient noise levels, aircraft noise would still be quite obvious and potentially annoying.

It is possible that aircraft noise may be more disturbing at sites with very low ambient noise levels. Because such effects have not been unambiguously quantified, there is no solid evidence to suggest that the NEF measure would not be equally satisfactory at such very quiet sites. The evidence that does exist suggests that if there are problems, adding a measure of the ambient noise level would be a satisfactory solution.

5.7 Combined Effects

The maximum likely effects due to various possible changes and errors are summarized in Table 5.1. Each entry gives the estimated maximum likely effect on mean NEF values and NEF contour areas. Such worst case situations are not expected to occur frequently.

The effects of changes to excess ground attenuation calculations would produce the largest changes in NEF contours. The maximum effects in Table 5.1 are estimated from the differences between the NEF_1.7 program and an experimental version of the program with reduced excess ground attenuation. The excess ground attenuation in the experimental program was intermediate to that of the NEF_1.7 program and the SAE procedure used in the INM program, and seemed to better approximate expected actual excess ground attenuation. Differences between that of the NEF_1.7 program and the INM program or between that of the NEF_1.7 program and programs with no excess ground attenuation, would be much larger.

The accuracy of specifying the details of the flight paths would lead to local changes in the NEF contours and would not usually lead to significant changes of the total contour areas or the average NEF values.

Errors or changes to the total number of operations, and the number of night operations, would have smaller overall effects. Changes to the method of specifying aircraft type and aircraft stage length would lead to quite small average effects, but could lead to significant local changes to the NEF contours.

The worst possible combination of effects would be the sum of the various maxima in Table 5.1. However, the factors in Table 5.1 would tend to vary independently and it would be very unlikely for the maximum effect of several of these to occur at the same time. Thus, the effects of various possible changes may frequently average together to give no greater maximum errors than those given for excess ground attenuation. Of course, on some occasions larger average changes in NEF contours will occur.

Factor	Average NEF Change	Average Area Change	Local Effects
Ground attenuation	3 dB	35 %	
Flight path details	-	-	Yes
Number of operations	1.5 dB	14 %	
N. Night operations	0.4 dB	7 %	
Aircraft type, and stage length, etc.	0.3 dB	4 %	Yes

Table 5.1. Summary of maximum likely changes to NEF contours. Local effects are typically contour shifts of 1000 to 3000 feet and NEF changes of 1 to 2 dB.

5.8 Legal and Land-Use Planning Issues

Land use planning according to expected noise levels in areas near airports is essential for a rational approach to the management of aircraft noise problems. The changes of aircraft noise levels over time are one factor that complicates the land use planning process. Unfortunately, zoning land according to expected aircraft noise levels is not done in a uniform manner near all major Canadian airports.

There are a number of problems with the current situation:

- Calculated future NEF contours can be a moving target that makes them less than ideal for long term planning.
- The NEF measure and published acceptability criteria[6,7] are not uniformly accepted for planning near all major Canadian airports.
- The accuracy and significance of the calculated NEF contours are not well understood by planners and other non-acoustical experts.
- The management of aircraft noise is not well coordinated between the three levels of government.
- There is a need for revised acceptability criteria and supplementary single event criteria.

Some new initiatives and modifications to the current situation are needed to produce a workable approach that can be applied to planning near all major airports.

At each airport, planning should be based on a worst case or worst year set of contours. These could be calculated for the maximum capacity of the airport or some other definition of a worst case. From the calculated worst case contours, practical land use planning areas should be determined similar to the Airport Vicinity Protection Areas used in Alberta. In this way airports and nearby communities could grow in a harmonious planned manner.

Such areas would be developed from the worst case NEF contours but would have practical boundaries such as roads. It is important that the local communities be involved in developing these planning zones, because they reap the benefits and suffer the impact of the airport. Such land use planning zones could remain unchanged for many years. Major expansions to the airport would require the airport to re-negotiate the planning zones with local communities.

Clear acceptability criteria are required to encourage uniform standards for new housing near all Canadian airports. Chapter 6 shows that NEF criteria can be essentially the same as current recommendations[7]. There are a number of situations where a small number of unusually noisy events can cause the most disturbance. Thus, a system of supplementary single event noise level criteria is also needed. The implementation of a more uniform approach would require a large educational effort to explain and to encourage the use of the new procedures and recommended limits.

Some technical problems also require further work. One problem concerns infill construction of homes in noisy areas between existing homes. This is an area where there is a need to develop detailed guidelines concerning the acceptability of various infill situations. There is also a major problem in determining the total noise impact in areas subjected to significant levels of several types of environmental noise. Developing guidelines for such areas would require new survey research.

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6.0 AIRCRAFT NOISE LEVEL CRITERIA

6.1 Limits in Terms of NEF Values

Early estimates of acceptable levels of aircraft noise were determined from consulting experiences with limited case studies of various types of community noise. These early limits have been discussed in Chapter 2. Both Transport Canada[1] and Canada Mortgage and Housing Corporation[2] have used these early limits as recommended land use planning guidelines.

Acceptable limits can be set in terms of the onset of various unwanted negative effects of aircraft noise. Information on each of these unwanted effects was extensively reviewed in a previous report[3]. Such unwanted effects would include hearing impairment, sleep disturbance, medical effects, speech interference, and annoyance responses. In addition, acceptable land use planning limits from other countries can be considered for comparison purposes.

All criteria are expressed in terms of NEF_{CAN} values. These are the NEF values calculated by the Transport Canada NEF_1.7 program. Comparisons in an earlier report [4] showed that NEF values calculated by the Transport Canada NEF_1.7 program could be different than calculations by other programs. It was estimated that the NEF_{CAN} values were approximately 4 dB higher than corresponding average measured values.

Figure 6.1 summarizes the approximate aircraft noise level thresholds at which the various undesirable effects commence. The methods of obtaining each of these results and the techniques for converting critical levels to NEF_{CAN} values will be explained for each bar in the figure.

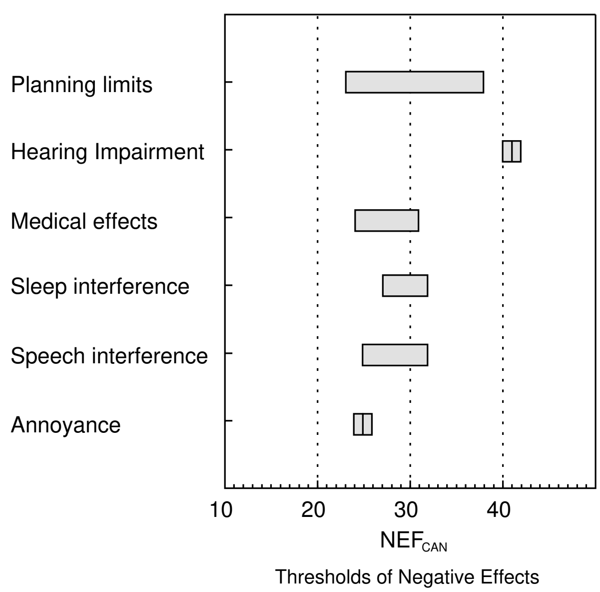

Figure 6.1. Summary of the thresholds of the onset of various negative effects of aircraft noise in terms of NEF_{CAN} values.

The first horizontal bar of Figure 6.1 summarizes the range of planning limits from various countries. These were taken from Table 6.1 of reference[3] and represent the level below which aircraft noise is not considered to be a serious problem. The lowest limits of NEF_{CAN} 23 and 24 are from Denmark and Australia, respectively. The highest limit, equivalent to NEF_{CAN} 38, is from Germany and is high because above this level German law requires action to be taken.

Hearing impairment is said to be possible above a 24 hour L_{eq} of 70 dBA. This is approximately equivalent NEF_{CAN} 41. Above this level of 24 hour outdoor exposure, permanent damage to the hearing system is possible. Although few (if any) people would be exposed to such aircraft noise levels 24 hours per day, people might spend a large part of the day in outdoor patio or balcony spaces.

Various non-auditory or medical effects have been related to aircraft noise. Knipschild's studies of populations near Amsterdam's Schipol airport suggest that above about L_{dn} 55 to 62 dBA, various unwanted medical effects are possible. This range would correspond to NEF_{CAN} 24 to 31.

The onset of sleep interference is better documented but more difficult to convert to equivalent NEF values. Griefahn's review (see Figure 3.5 of reference[3]) suggested that below indoor maximum levels of approximately 54 dBA, subjects were unlikely to be awakened. For typical well insulated wood frame construction with closed windows, this would correspond to an outdoor L_{max} of about 80 dBA. Thus, outdoor noise peaks above 80 dBA would cause awakenings. This was estimated to relate to an NEF_{CAN} of about 32 for a situation with 100 operations per day. For milder climates where windows are typically open, a lower limit would be required.

Of course, there is not one unique conversion between L_{max} values and NEF_{CAN} values. For example, assuming fewer operations per day would result in a lower NEF_{CAN} value. Other conversions from L_{max} to NEF_{CAN} values could be made depending on the number of operations. However, the approximate equivalence to NEF_{CAN} 32 is satisfactory for the purposes of the current overview.

Ollerhead's field study of sleep disturbance indicated arousals due to aircraft noise if L_{max} values exceeded 75-80 dBA. Translating to approximately equivalent NEF_{CAN} values, and including typical facade attenuation for Canadian homes, led to the conclusion that the range from NEF_{CAN} 27 to 32 best indicates the area of the onset of sleep disturbance.

A new procedure for estimating the effect of aircraft noise on speech intelligibility was based on the time history of a typical aircraft flyover[3]. It was calculated that the indoor aircraft noise SEL should not exceed 64 dBA to avoid significant speech interference. Again, assuming a typical well insulated home with closed windows, would lead to a maximum outdoor aircraft noise SEL of 90 dBA. Thus, outdoor aircraft noise that produces an SEL of greater than 90 dBA will cause significant speech interference inside the home. For situations with open windows, a lower limit would be required. Although it is not possible to convert this to a unique NEF_{CAN} value, an SEL of 90 dBA and 100 operations per day would correspond to an NEF_{CAN} of approximately 32. These calculations were based on a 'normal' voice level. If they were repeated for a 'casual' voice level, typical of conversations in homes, the resulting equivalent NEF_{CAN} would be reduced from 32 to 25.

In setting the US FAR Part 150 limits of an L_{dn} of 65 dBA, the Schultz curve is often referenced. Using the Schultz curve, an L_{dn} of 65 corresponds to a threshold of approximately 15% of the population being highly annoyed. An analysis of more recent airport noise surveys[3] produced a new Mean trend curve that indicated greater annoyance than the Schultz curve. Using the new Mean trend curve leads to a threshold of 15% highly annoyed at an L_{dn} of 56 dBA. This would correspond to an NEF_{CAN} of 25 and is also shown on Figure 6.1.

Almost all of the thresholds of negative effects included in Figure 6.1 start in the NEF_{CAN} 25 to NEF_{CAN} 30 range. Most of the planning limits also start in this same range. Thus, it is only below this range that one can avoid the negative effects of aircraft noise. NEF_{CAN} 25 should be regarded as the threshold of negative effects of aircraft noise.

At NEF_{CAN} 30, the various negative effects are established and growing. By NEF_{CAN} 35, the negative effects of aircraft noise are very significant. These comparisons suggest that areas with noise levels greater than NEF_{CAN} 35 are definitely not suitable for residential development, and that in areas above NEF_{CAN} 30 all new homes must have extra sound insulation. Without substantial sound insulation, the negative effects would commence at significantly lower aircraft noise levels. The calculated onset of sleep and speech interference included a 26 dBA building facade noise reduction. If well sealed homes with extra insulation are not acceptable, then lower limits would be required.

At approximately NEF_{CAN} 41 and greater outdoors, in addition to the other unwanted effects of aircraft noise, permanent hearing impairment starts to become possible. At NEF_{CAN} 40, both speech and sleep impairment will be very significant and almost half of the population will be highly annoyed. Such high noise areas are clearly not suitable for use as residential areas.

These various thresholds of acceptability are all presented in Figure 6.2. They are similar to those accepted in many communities today. They are slightly more restrictive than some existing acceptable limits, but the limits in Figure 6.2 are based on the very extensive analyses of current knowledge on the effects of aircraft noise on people.

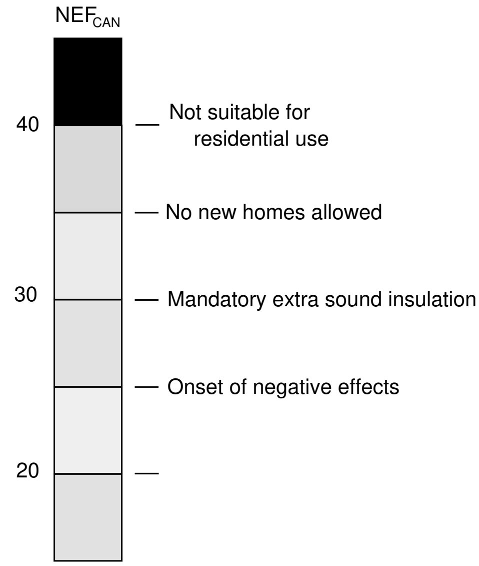

Figure 6.2. Summary of the thresholds of acceptability of aircraft noise.

While the limits recommended in Table 6.2 are thought to represent a balanced interpretation of the available data other conclusions are possible. Two particular weaknesses in the above arguments might lead to more restrictive land use planning limits. First, as mentioned above the calculations that led to Figure 6.2 were based on the assumption of a well insulated northern home with sealed windows. In areas where windows are typically open, one could readily argue for more restrictive limits for acceptable aviation noise levels. The second point is that the assumed long term benefits of added insulation have not been proven. Clearly added sound insulation does not improve outdoor living spaces. However, there is no reliable evidence that added sound insulation improves the more general acceptability of aviation noise. Thus, a cautious approach might be to accept more restrictive limits until it can be demonstrated that added sound insulation does improve the acceptability of aviation noise.

6.2 Limits in Terms of Single Event Noise Measures

In some cases, disturbance is related to the intensity of each noise event and not directly to long term average measures such as NEF. This is true for sleep and speech disturbance by aircraft noise. Thus, it is not completely satisfactory to consider only integrated measures such as NEF values. This becomes particularly true in some more extreme cases such as for relatively small numbers of quite noisy events. For these cases, speech or sleep could be quite severely disturbed even though NEF values are quite low.

It is therefore necessary to consider acceptable single event limits in addition to those given in Figure 6.2 in terms of NEF values. It is suggested that single event limits should restrict maximum levels at smaller airports and other special situations so that they do not exceed single event levels experienced near larger airports. From the analysis of indoor sleep disturbance studies, maximum outdoor night-time levels should not exceed 80 dBA to avoid disturbance of sleep. Analyses of indoor speech interference suggest a limit of 90 dBA for the outdoor SEL of individual aircraft fly-overs to avoid significant disruption of speech communication.

The use of these single event limits in addition to the NEF limits should ensure that the general noise environment, including particular worst case situations, is acceptable and that the negative effects of aircraft noise on people are minimal.

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7.0 CONCLUSIONS

7.1 Components of the Overall Problem

(a) Philosophy

The management of aviation noise in Canada needs a clear philosophy for the intended goals and the approach to achieving these goals. One of the most effective approaches to managing airport noise is by land-use planning and construction standards for areas near airports. Such land-use planning must be in terms of the long term goals of both the airport and nearby communities. The acceptability of land use, and the required construction standards should be determined in terms of clearly established noise exposure criteria, that are uniformly applied near all major Canadian airports. It is important to work towards putting such a uniform approach into place.

(b) Criteria

Universally applicable noise exposure criteria are necessary that can be applied in terms of standard noise measures at all major Canadian airports. The basic criteria should be in terms of an integrated noise measure such as the NEF measure, and should be essentially the same as current recommendations[3]. Supplementary single event limits are also desirable to ensure acceptable conditions in areas near all airports. These single event criteria should be applied universally and uniformly at all major Canadian airports. Although they are only required for various special cases, they can most easily be applied universally because they will naturally not come into effect at larger airports where criteria in terms of NEF values would be more restrictive.

(c) Tools

The basic tool for managing airport noise is the NEF_1.7 calculation program. Planning in terms of rational noise exposure criteria can only be achieved with a credible airport noise calculation program. The necessary improvements to the existing program and the continuing development of this essential tool require a new and ongoing commitment of resources to maintain the credibility of this program.

7.2 Acceptability of the NEF Measure

It has been suggested that the NEF measure should be replaced by an A-weighted measure such as L_{dn}. There are merits to both types of measures. They can be compared in terms of the three basic components of these measures: frequency weightings, time-of-day weightings, and level versus number of operations trade-offs.

The NEF measure is calculated from EPNL values that include a PNL frequency weighting and tone corrections. Although the tone correction procedures do not improve prediction accuracy, PNL weighted noise measures tend to be more accurately related to subjective judgments of aircraft noises. A major disadvantage of the PNL weighting is that it complicates the measurement of NEF values. Such measurements are essential to validate the accuracy of airport noise calculation programs, and to assist in their continuing development. Conversely, the advantage of A-weighted measures such as L_{dn} is that they are quite easily measured. That is, one can readily compare measured and calculated noise levels for a particular day's operations.

The NEF measure includes a much higher night-time weighting than other integrated airport noise measures in common use. There is evidence that a smaller night-time weighting would be more appropriate and that an evening weighting should be added. The evidence for changed time-of-day weightings is not unequivocal and such changes could only be justified if they were supported by new Canadian survey results.

Both the NEF and L_{dn} measures, as well as most other integrated airport noise measures, include an equal energy trade-off between aircraft noise levels and numbers of aircraft operations. There is no substantial argument to change to some other relationship.

The desire for an easily measurable quantity could be achieved by creating an A-weighted NEF measure similar to the approaches taken in Switzerland and Japan. In both of these countries aircraft noise measures, originally based on PNL weighted measures, were converted to A-weighted equivalents. Such an A-weighted NEF measure was considered[1] and was shown to be very closely related to the present NEF measure. The differences would be due to the very small differences between EPNL and SEL values for each aircraft type. With an A-weighted NEF measure, there would only be very minor changes in the resulting noise contours, but they would be in terms of a quantity that could be more easily measured. There would be no need to educate users to appreciate a new noise measure because values of the A-weighted NEF would be almost identical to values of the original NEF measure.

Changing time-of-day weightings would create more problems. There would be substantial changes to noise level contours and the changes would vary between flight paths as well as between airports. Substantial new Canadian aircraft noise survey research would be required to justify such changes.

There are four possible approaches to the question of converting to an A-weighted measure varying from keeping the NEF measure unchanged, to totally accepting some other existing measure. The four possibilities and their advantages and disadvantages are as follows:

1. ***No change.*** The major disadvantage is that one is left with the problem of not being able to validate computer calculations with convenient measurements.
2. ***Change to L_{dn}.*** Although this would provide a noise measure that can be readily measured, there is no evidence that L_{dn} values are more accurate predictors of human response to aircraft noise than NEF values. Changing to L_{dn} would significantly change noise contours and would require considerable effort to re-educate users and to develop new prediction procedures.
3. ***Major changes to NEF.*** Major changes would require significant new Canadian research but would be expected to result in more accurate predictions of responses of Canadians to aircraft noise. There would probably be a substantial additional effort required to modify prediction procedures and to re-educate users.
4. ***A-weighted NEF.*** This would solve the major weakness of NEF by creating a measure that would be easily measured for the validation of calculations. This should lead to more accurate calculations, but would not initially create significant changes to noise level contours. Such a change could be introduced in combination with improvements to the NEF_1.7 program.

7.3 Gaps in Our Knowledge

There are a number of specific areas that are particularly relevant to Canadian situations, but for which our knowledge is incomplete. These include community response to aircraft noise around small airports, general aviation activity, isolated especially noisy events, changes in airport noise levels, and the long term benefits of extra sound insulation.

There is evidence that annoyance to aircraft noise varies with airport size and the type of aviation activity. For a given noise level, annoyance seems to be less at smaller airports but higher among residents exposed to general aviation noise. At many smaller airports these two effects may influence annoyance responses in opposite directions. There has been no thorough investigation of the combined effect of these two factors.

A related problem concerns the disturbance caused by isolated noisy events. Such events could be caused by small numbers of jet aircraft operations at very small airports. There is a need to introduce supplementary single event type noise limits to ensure that these problems are controlled.

The combination of the various factors influencing community response near smaller airports has not been thoroughly investigated. These problems are related to aircraft operations at smaller airports that are very common in Canada. The results of previous studies near various major international airports may relate to only a few special large airport situations in Canada.

As quieter Chapter 3 aircraft are introduced, integrated noise levels such as NEF values will initially drop. However, over the longer term, increasing numbers of aircraft are expected to eventually increase noise levels. The effect of these changes where individual aircraft noise levels will decrease but overall integrated levels may stay the same or eventually increase is not unequivocally established. We are forced to rely on the assumption that an equal energy trade-off between individual aircraft levels and numbers of operations. There is less information concerning the expected effects of larger changes caused by major airport developments.

Increased home insulation is very widely recommended for homes situated in higher levels of aircraft noise. In many countries, special programmes funded from government or airport revenues have been carried out to add such additional sound insulation. There is little information to objectively verify the success of various constructions, and there is practically no evidence of the long term effects on the subjective disturbance of aircraft noise.

7.4 Recommendations

(a) Fill the Gaps in our Knowledge

Further research is required to help to fill in the gaps in our knowledge concerning the negative effects of aviation noise listed in section 7.3 above. A large survey of residents living near Canadian airports is required. It should include a range of airport sizes, aviation types, and include sites with a range of night-time operations. The study could thus help to fine tune the form of the NEF measure, and calibrate the NEF measure against subjective responses, as well as to ensure that it is relevant to the many smaller airport situations in Canada. This should include the validation of new single event limits, and the long term benefits of added sound insulation.

(b) Upgrade the NEF_1.7 Program

The NEF_1.7 program was found to require improved excess ground attenuation algorithms, more complex flight path descriptions, and ongoing support and development. The improvements to excess ground attenuation routines would require extensive measurements of aircraft noise as a function of position over various types of ground, or cooperation with groups having this type of data.

(c) Consider Adopting an A-weighted NEF Measure

This would solve one of the major weaknesses of the NEF measure by creating a quantity that could easily be measured for the validation of calculations. An A-weighted NEF measure would make possible the continuing improvement of the NEF_1.7 calculation program without large changes to the shape of the calculated contours.

(d) Establish Clear Criteria

It is essential to have clear criteria for the acceptable use of land at various levels of aircraft noise. An analysis of currently available information as part of this work suggested that new housing should not be permitted in areas of greater than NEF_{CAN} 35 and that additional home insulation should be required in areas above NEF_{CAN} 30.

Noise criteria should also include additional single event limits to ensure that special situations with occasional noisy events are acceptable. A new approach to deriving single event limits in terms of speech interference has been proposed[2], but requires further development.

(e) Publish Criteria and Recommended Solutions

Efforts should be made to publish a revised version of the CMHC document on new housing and aircraft noise.

(e) Encourage Uniform National Approach

The management of airport noise would be a much simpler problem if there was an accepted national approach applied in areas near all major airports. Because Transport Canada can only recommend land use guidelines, different communities may or may not adopt these guidelines. A uniform approach would require all three levels of government to accept a common system of noise measurement and noise criteria. While developing the necessary cooperation would be a significant task, in the long term the uniformity would lead to greater acceptability and a more stable approach to managing airport noise.

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