NEF validation study: (1) issues related to the calculation of airport noise contours

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NEF Validation Study:

(1) Issues Related to the Calculation of Airport Noise Contours

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J.S. Bradley December, 1996

NEF VALIDATION STUDY: (1) ISSUES RELATED TO THE CALCULATION OF AIRPORT NOISE CONTOURS

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 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 first of three reports containing the results of an NEF validation study for Transport Canada. Summaries of the other two reports are included in Appendix 2 of this report.

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 be as good as is reasonably possible. The use of millions of dollars worth of land near airports is 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 this report were focused on the errors associated with predicting noise levels around airports. The related problems of determining acceptable noise level limits and the practical application of these limits will be considered in a second report. These two reports will form the technical background for a final report evaluating the use of the NEF measure to quantify airport noise levels near Canadian airports.

Some of the major technical findings of this report 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 now being developed that are potentially more accurate, such as the Swiss model.

- Comparisons of the NEF_1.7 program with the 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 prediction 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 from 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 predictions. It is particularly important that the expected horizontal dispersion of aircraft about the nominal flight track be included in airport noise contour predictions.

- The major cause of differences between the contours produced by the NEF_1.7 program and those from the two American programs is their calculation of excess ground attenuation. 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. Performing calculations in octave bands would permit more accurate estimates of the propagation of aircraft noise.

- A systematic procedure for relating single event noise measures to combined measures for many aircraft is presented.

- 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 differences in frequency weightings and time of day weightings.

CONTENTS

1.0 INTRODUCTION

1.1 The Importance of Airport Noise Level Predictions

Airports are both a major asset and a liability to nearby communities. They provide jobs to residents, stimulate the local economy, and provide essential transportation for both passengers and freight. At the same time, aircraft create noisy areas around airports that may not be suitable for residential use. The development of land for residential use is usually more profitable than for other purposes. Thus, there is a conflict between the growth and development of the airport and the development of land for residential use.

Transport Canada provides land-use planning guidelines for areas in the vicinity of airports to assist both aviation planners and those responsible for planning the use of land adjacent to airports. Only guidelines are provided because in Canada the provinces are empowered to regulate the use of land not under federal jurisdiction via local land-use zoning by-laws. Provinces are free to choose whether to implement these guidelines

Planning guidelines are usually based on predicted airport noise level contours. That is, equal noise level contours are calculated around the airport and a noise level is set above which residential development is considered unacceptable. The process of predicting these noise contours is thus critical to the development of millions of dollars worth of land at each major airport. It is, of course, also critical to protecting residents from excessive levels of airport noise. Therefore, one cannot over-stress the importance of the validity and accuracy of airport noise level predictions.

There are two parts to the process of resolving land use conflicts around airports. The first part is the purely physical problem of accurately predicting noise levels around airports. This part of the problem is examined in this report. The other part of the problem concerns the determination of acceptable noise limits and the practical application of these limits. These issues will be discussed in a second report. It is intended that these two reports will form the technical background for a final report evaluating all aspects of the use of the NEF measure to quantify noise levels near Canadian airports.

1.2 Content of this Report

Transport Canada uses the NEF_1.7 computer program to calculate NEF contours around airports. It is therefore of considerable importance to consider the magnitude of various possible errors included in the complete prediction process involving the NEF_1.7 program. This includes errors in the prediction of the details of future aircraft operations as well as errors in the estimation of noise levels from specific aircraft operations. The analyses of possible sources of error included in this report were performed largely by systematic manipulation of the input data and by comparisons of results from the Integrated Noise Model (INM) and the NoiseMap programs used in the United States with those from the NEF_1.7 program. Unfortunately, differences between NEF_1.7 and the INM program do not indicate which prediction program is more correct.

Each of the following chapters examines specific aspects of the problem of predicting noise levels around airports. Chapter 2 discusses the basic principles of different approaches to calculating airport noise levels. The errors associated with predicting future numbers of aircraft operations are examined in Chapter 3. In Chapter 4, the calculations of three computer programs (NEF_1.7 INM, and NoiseMap) are compared for four Canadian airports varying in size from small to large. The sensitivity of the NEF_1.7 program to systematic changes in the input data is examined in Chapter 5. Chapter 6 contains analyses of the effects of various details of the prediction programs such as the specification of the complete flight path and the propagation of sound from aircraft to specific receiver points. In Chapter 7, a procedure for relating single event measures to combined airport noise measures is developed. A-weighted and Perceived Noise Level based measures are compared in Chapter 8. Finally, Chapter 9 presents overall conclusions from the various analyses.

2.0 BASIC PRINCIPLES OF AIRPORT NOISE MEASURES AND AIRPORT NOISE PREDICTION

2.1 Airport Noise Measures

Although there are a variety of airport noise measures, they can be divided into two types: measures of the noise of individual aircraft and measures of the combined effect of many aircraft.

For both types of measures there are different frequency weightings that cause the noise in each frequency band to be combined with different weighting factors. These frequency weightings are intended to rank the importance of each frequency band in a similar manner to the human hearing system. For aircraft noise, sounds are usually either A-weighted or expressed in terms of Perceived Noise Levels, PNL. The A-weighting curve is an approximation to an equal loudness contour and is widely used in all areas of noise control. The Perceived Noise Level system is more complicated and was specifically developed to rate the noisiness of jet aircraft typical of the 1960's. These two frequency weighting approaches are compared in Chapter 8 of this report.

Individual aircraft noise measures are either maximum level type measures or integrated measures that represent the integration or sum of the noise energy over a complete pass-by of an aircraft. The most common maximum level measures are: the maximum A-weighted level (L_{max}) and the maximum Perceived Noise Level (PNL_{max}). They correspond to the maximum level of the aircraft and so represent noise levels from one particular point of an aircraft fly-over. Integrated measures sum the noise energy over a complete fly-over and can also be either A-weighted (e.g. the Sound Exposure Level, SEL) or Perceived Noise Level weighted (e.g. the Effective Perceived Noise Level, EPNL). Because they include the entire pass-by, the integrated measures are a better representation of the total noise radiated by an aircraft.

Both the maximum levels and the integrated measures are influenced by the directionality of the noise radiated by the aircraft and by the propagation of the noise from the aircraft to the receiver. The interaction of the direct sound and the ground reflected sound can cause considerable attenuation of the total sound from the aircraft at a receiver. This varies considerably with the distance and elevation of the aircraft. Thus, during a complete fly-over the directional radiation of sound from the aircraft and the propagation to a particular receiver is changing continuously in a very complex manner. This detail is lost in the integrated measures which only represent the sum of all these details.

The complete noise climate around an airport is usually described in terms of the combined effects of all aircraft operations over some typical day. Again, these can be based on A-weighted levels or Perceived Noise Levels. Most commonly, the effects of each aircraft are added on an energy basis. That is, the total is just the sum of the noise energy contributed by each aircraft usually presented as an average for a typical day's operations. In some cases, the number of events is given more importance and the result is no longer a simple energy sum. Most combined airport noise measures also include various time-of-day weightings. Frequently, time of day weightings are in the form of an additional night-time penalty whereby night-time noise levels are counted as more detrimental than day-time noise levels.

The Noise Exposure Forecast, NEF, used in Canada, and the day-night sound level, L_{dn}, used in the United States, are two examples of combined airport noise measures that add the contributions of each aircraft on a simple energy basis. The NEF measure is based on the integrated EPNL values of individual aircraft fly-overs and the L_{dn} is based on the A-weighted SEL values of integrated individual aircraft fly-overs. Both NEF and L_{dn} include night-time weightings. In calculating L_{dn} values, the contribution of night-time SEL's is increased by 10 dB to represent their expected increased disturbance. In the NEF measure, the night-time weighting is approximately 12 dB.

Two examples of combined airport measures that are not simple energy summations are the quantities used in Switzerland and Germany. The Noise and Number Index, NNI, formerly used in the United Kingdom and still in use in Switzerland, gives a higher importance to the number of events. Similarly, the German Störindex, or Airport Noise Equivalent Level, gives increased importance to the number of events. For a simple energy summation measure, doubling the number of aircraft operations and halving the energy from each aircraft would not change the total. For the Swiss and German measures, this example would result in an increase in the value of the combined measure.

The major combined airport noise measures are defined in Appendix 1 of this report, and approximate relationships between the measures used in various countries are calculated. The question of which is the most appropriate measure must include consideration of how people are affected by airport noise. This will be included in a subsequent report.

2.2 Fundamentals of Airport Noise Prediction

There are many different airport noise prediction programs that attempt to model a very complex problem with a variety of simplifying approximations. There are approximations to the actual aircraft flight paths, to the production of noise by the aircraft, and to the propagation of the noise to receiver points.

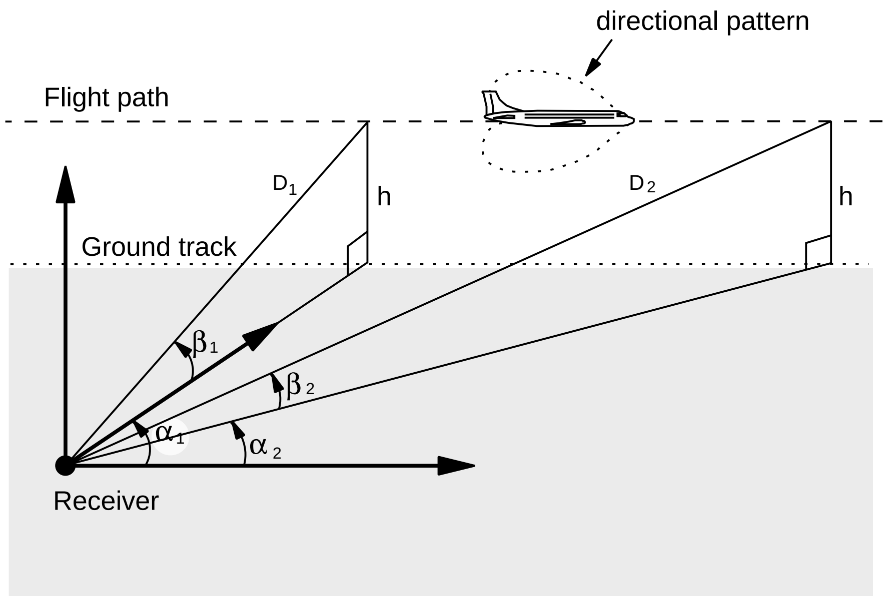

Figure 2.1: Illustration of the geometry of a simple straight path aircraft pass-by.

Figure 2.1 illustrates the simplest of cases: a single aircraft traveling on a straight horizontal flight path, past a single receiver position. The total noise exposure at the receiver can be obtained by integrating the noise from the aircraft over the complete pass-by. As the aircraft proceeds from left to right in this figure, it gets further and further away from the receiver and hence noise levels tend to decrease. This decrease with increasing distance is first modified by the directional characteristics of sound radiated from the aircraft. That is, aircraft do not radiate noise equally in all directions. The decreased noise levels with increasing distance are also modified by excess ground attenuation which is approximately related to the vertical angle of elevation, β. The further away the aircraft is from the receiver, the smaller the vertical angle of elevation. For example, in Figure 2.1, angle β_2 is smaller than angle β_1. As this elevation angle β decreases, excess ground attenuation increases. Unfortunately, our knowledge of the directionality of sound radiation from various aircraft and of the excess ground attenuation is not complete. Atmospheric absorption and weather conditions such as wind or thermal inversion also affect sound propagation. Thus, modeling the integration of aircraft noise over a single straight line pass-by, to provide either EPNL or SEL values, is at best a rough approximation to a quite complex phenomenon.

Airport noise prediction programs must sum the effects of many aircraft pass-bys for aircraft on more complex flight paths. There are two basic approaches to the problem. Programs such as the NEF_1.7 program, the Integrated Noise Model, and NoiseMap, start from a database of integrated aircraft noise levels as a function of distance and power setting. They then calculate the contribution of each aircraft only at the point of closest approach to each receiver position. Because the databases include SEL or EPNL values for infinitely long flight path segments, corrections must be made for finite path segments and curved path segments of the aircraft path. Several more recent European models [1,2,3] simulate the complete aircraft pass-by and therefore this is usually described as a simulation approach. In a simulation model, aircraft are moved incrementally along flight paths and the effects of source directivity and sound propagation are calculated for each position of the aircraft. Simulation models are potentially more accurate but involve much longer calculation times. For example, if each flight path was divided into 100 steps, the resulting calculation time would increase by approximately the same factor of 100. No extensive comparisons have been published to demonstrate the benefits of using the simulation approach for real airport situations.

A Danish model [1] uses a slightly simplified simulation approach. Calculations are first performed to obtain integrated noise levels over one pass-by for each aircraft type following a straight flight track with an appropriate vertical profile. This provides SEL values at a grid of points. Only a few generalized directional characteristics are included and ground attenuation calculations follow the SAE procedure [4]. The calculated SEL values are then modified to represent the contributions of finite segments of both straight and curved flight tracks.

A Swiss model[2] uses a complete simulation process. Each aircraft is moved incrementally along its flight track and the noise energy contributions at each receiver grid point are calculated for each position of each aircraft. This approach makes it possible to accurately model more irregular flight paths such as those of military and small general aviation aircraft. The program uses the measured directional characteristics of each aircraft type and a Swiss algorithm to account for excess ground attenuation [5]. The calculation time for a large airport using a DEC 8820 computer was said to be 55 hours. There are plans to further improve the program to perform calculations in octave bands.

Most computer prediction programs such as NEF_1.7, INM ,and Noise Map, perform calculations starting from a database of integrated aircraft noise levels as a function of both distance and power setting. At each point of the grid of receiving points, the contribution of each aircraft is determined only for its point of closest approach. The contribution of each aircraft is obtained by interpolating between the SEL or EPNL values in the database to represent the correct levels for the actual slant perpendicular distance from the receiver point to the aircraft at its point of closest approach.

Because aircraft do not usually follow simple straight line paths, flight paths must be divided into segments of finite length and that are sometimes curved. Thus, the total noise exposure from one aircraft at a particular receiver grid point is the sum of the contributions from each flight path segment. The contribution of each flight path segment is obtained from the input database of integrated aircraft noise measures with corrections for finite length segments, curved paths, and aircraft speed.

2.3 The Components of Airport Noise Predictions

While the various computer models can be quite different in detail, the general procedures for describing, flight paths, aircraft noise generation, and sound propagation, involve the same details.

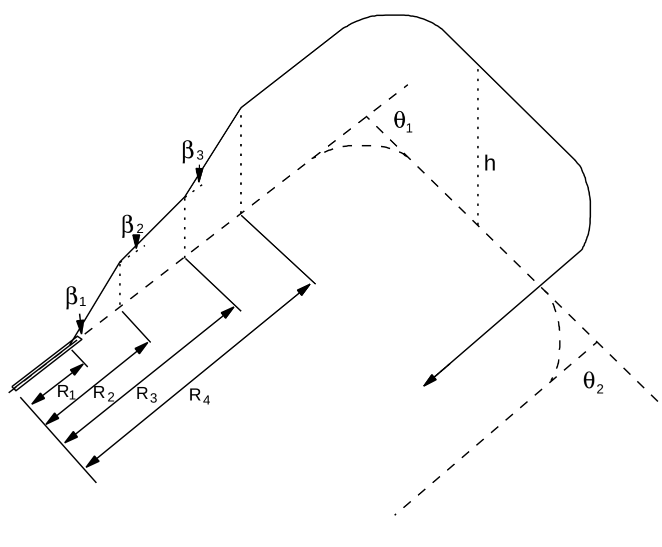

Figure 2.2: Flight path description for the NEF_1.7 program.

Figure 2.2 illustrates the details of describing an aircraft flight path for the NEF_1.7 model. The path of the aircraft is first described by its ground track, the projection onto the ground of the actual flight path.

This is shown by the dashed line in Figure 2.2. It can include both straight and curved segments and hence is described in terms of the lengths of straight sections and the radius and turn angle of curved sections. The flight track in Figure 2.2 contains two approximately 90° turns, Θ_1, and Θ_2. One must also describe the vertical profile of the flight path. In Figure 2.2 this is described in terms of the distances, R_1, R_2, R_3, R_4, and the angles β_1, β_2, and β_3. The vertical profile will vary with the aircraft type and the stage length of the aircraft flight. That is, the length of a flight is described in terms of stage lengths from 1 to 7, and aircraft on longer flights are assumed to climb more slowly because of their increased fuel load and hence have different vertical profiles.

While similar procedures are used to describe aircraft paths in other computer programs, the detail in which the path is described can vary. That is, other programs may allow more segments in both the ground track and the vertical profile. The horizontal and vertical dispersion of actual flight paths about the nominal path is rarely included in prediction programs. The importance of dispersion about the nominal flight track is examined in Chapter 6.

The level of noise generated by an aircraft is influenced by the aircraft type, its power setting, its speed, and the directionality of the radiated noise. Airport noise prediction programs usually include a database of integrated aircraft noise levels (SEL or EPNL values) as a function of both distance and aircraft power setting. Some programs correct for the effects of aircraft speed but usually directional effects are ignored. Aircraft noise directionality may not be important for integrations over long straight flight paths, but for short segments these effects could become more important.

Some propagation effects are included in the input database of SEL or EPNL values versus distance. Further corrections are added to reflect the added effects of sound attenuation due to propagation close to the ground. This excess ground attenuation is caused by the interference at a receiver point of the direct sound and the ground reflected sound. It is usually estimated in terms of separate ground-to-ground and air-to-ground propagation effects. Meteorological effects and non-level terrain can further complicate the propagation of aircraft noise, but these effects are usually not included in airport noise prediction programs.

2.4 Comparison of the NEF_1.7 INM, and NoiseMap Programs

Specific comparisons of the NEF_1.7, INM, and NoiseMap programs are of particular interest. It is difficult to compare the details of the complete calculation process used by each model because such details are usually not published. Some of the known differences can be summarised here.

Both the flight ground track and the vertical profile are described in less detail when using the NEF_1.7 than for the INM and NoiseMap programs. As illustrated in the example of Figure 2.2, the NEF_1.7 program allows up to two turns in the ground track and up to three segments in the vertical profile. The INM program allows up to a 16-segment ground track and up to a 10-segment vertical profile. NoiseMap allows up to 25 segments in the ground track and up to 14 segments in the vertical profile. While the two American models seem to provide more flexibility than would normally be necessary, the NEF_1.7 program provides only a very approximate description of the flight path. The effects of these details are included in the analyses of Chapter 6.

All three programs have some correction for the effect of curved flight path segments. These corrections tend to increase integrated levels on the inside of the curve and to decrease them on the outside.

The excess ground attenuation algorithms used in the NEF_1.7 program are different than in the other programs. The INM and NoiseMap programs use the SAE [4] procedure for civil aircraft. NoiseMap has a different procedure for military aircraft. The excess ground attenuation included in the NEF_1.7 program results in less attenuation than the SAE model. The effects of various ground attenuation calculations are examined in Chapter 6.

Most other details of the calculation process used in these three programs are not clearly defined in available published documents.

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3.0 PREDICTING THE NUMBER OF AIRCRAFT OPERATIONS

3.1 Forecasting Future Aircraft Movements

Transport Canada's Air Statistics and Forecasts group makes forecasts of the expected future activity at major Canadian airports. This includes forecasts of the expected passenger traffic, cargo tonnage, and total number of aircraft movements [1]. The forecasts are based on a number of factors and are, of course, strongly influenced by the expected general state of the nation's economy.

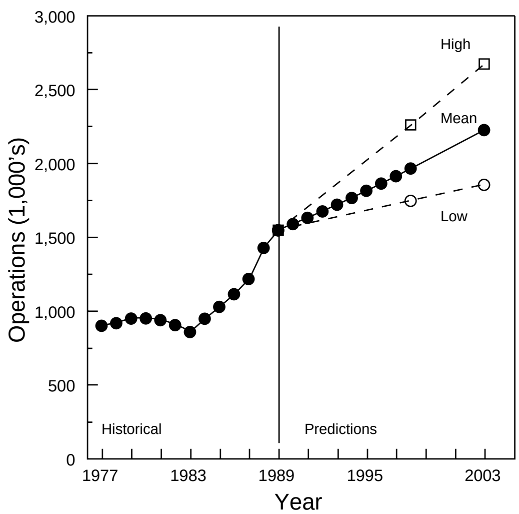


Figure 3.1: Forecast itinerant aircraft movements at top 77 airports (from Fig. 6.6 Ref. [1]).

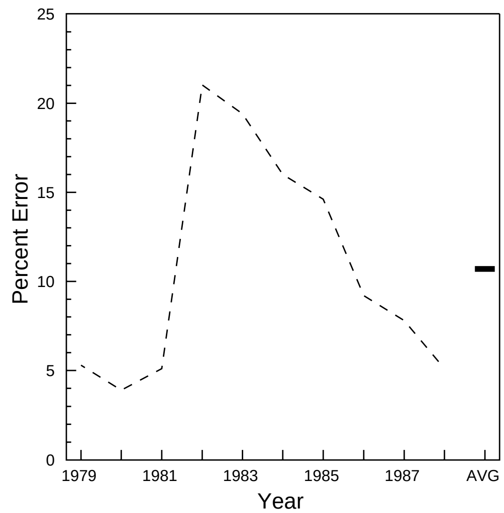


Figure 3.2: Mean absolute percent error of forecast number of aircraft movements.

Figure 3.1 is an example of the forecasts of the total number of aircraft movements at major airports reproduced from reference [1]. This shows the combined number of aircraft movements at the top 77 airports. Historical data of actual aircraft movements are shown up to the year 1989. In this example, short term forecasts are made up to the year 1998 and longer term forecasts to the year 2003. A mean forecast is made based on expected economic growth rates. Because there is some uncertainty associated with such forecasts, a low and a high estimate are also included to bracket the likely range of future aircraft movements.

The Air Statistics and Forecasts group have looked at the accuracy of their past predictions. The mean absolute percentage error in their forecasts of the total number of aircraft movements for a ten-year period are reproduced in Figure 3.2. The largest annual error was 21% and the average over this ten-year period was 11%. This data is averaged over all major Canadian airports. Larger errors would be expected on an individual airport basis.

Aircraft noise contours around airports are predicted from the forecast number of aircraft operations. Thus errors, in the forecast number of operations lead to errors in the expected noise levels. Errors of about 21% in the number of operations would lead to errors in NEF values of close to 1.0 dB if the percentage error is approximately the same for the numbers of day-time and night-time operations. If the unexpected increase or decrease in operations occurred mostly during the night-time period, errors in predicted NEF values could be as much as 3 to 4 dB. However, this is extremely unlikely. The influence of differences in the number of operations on NEF contours is explored in more detail in sections 5.2 and 5.3. Differences in NEF values are approximately related to contour area differences in section 5.1.

3.2 Predicting the Number of Operations for the Peak Planning Day

3.2.1 The Transport Canada Approach

Airport noise predictions are usually made for the number of daily operations associated with a planning day. Transport Canada uses a Peak Planning Day, PPD, that is approximately a 95th percentile day and that represents close to a worst case without the statistical uncertainties of using the actual worst case. In the United States, predictions are made for a mean planning day. One can predict the number of operations for the mean planning day more accurately than for the 95th percentile day or the PPD. However, the mean day would have considerably fewer operations than the PPD, and thus using the mean planning day would result in lower noise levels at a given location and in smaller noise contours.

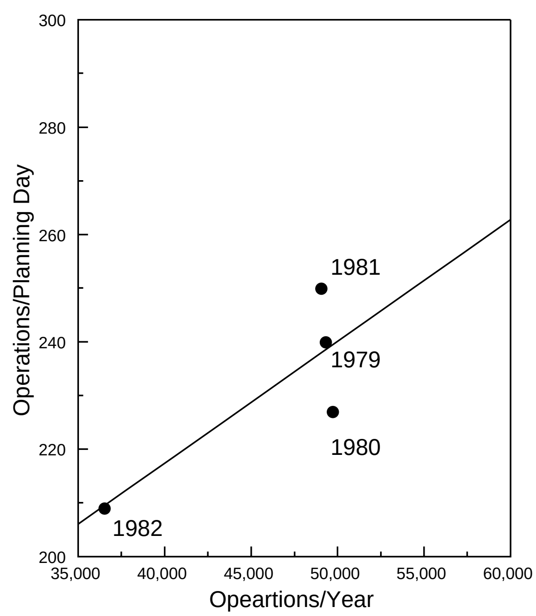


Figure 3.3: Number of operations per Peak Planning Day versus total annual operations at Prince George airport (from Figure B-3, Reference [2]).

The planning day is determined for future years by extrapolating the relationship between the number of operations for a planning day and the total number of operations/year (see Figure 3.3). (Usually calculations are performed separately for itinerant movements and do not include local movements.) This relationship is not exact and hence there are statistical errors associated with fitting a regression line to this data and extrapolating to future years. The magnitudes of these statistical errors are expected to vary according to whether a mean or a peak planning day is used. Transport Canada uses an approximation to the 95th percentile day which would be expected to introduce further errors. They take the average of the busiest seven days from each of the three busiest months to calculate the number of operations for the PPD. The average of these 21 days gives values close to the number of operations for the 95th percentile day. Finally, the extrapolation process is tedious, time consuming, and may tend to introduce calculation errors.

Figure 3.3 (taken from Figure B-3, reference [2]) is an example of Transport Canada's method for calculation of expected future numbers of operations for a PPD. Each point on this graph was derived from consideration of the numbers of daily operations for a complete year. The regression line is then used to predict the number of operations for some future PPD. Basing a future prediction on four data points as in this figure is not very reliable and depends on the particular four years that are used in the calculation. One can easily appreciate that removing the 1982 data point would considerably change the resulting regression line. (The regression line that is shown in Figure 3.3 is not quite the same as in the original figure which contained a calculation error.)

The analyses in this section were intended to produce a more reliable procedure for predicting the number of operations for future PPD's. Since the Transport Canada PPD is an approximation to the 95th percentile day, it is first of interest to determine how closely it agrees with the true 95th percentile day and to test which of the two can be predicted more accurately for future years. Similarly, comparisons should be made between the number of operations for the PPD and the mean planning day to determine the relative accuracy of predicting each of these for future years. For a normal distribution, the 95th percentile value can be estimated as the mean plus two times the standard deviation. This was considered as a possible alternative technique for estimating future planning days and was compared with the other approaches. All of these planning day estimation procedures were compared to determine which is the most statistically reliable and convenient method for predicting the number of operations for future planning days at typical Canadian airports.

3.2.2 Analysis Procedures

Data, giving the number of operations per day at five Canadian airports, was provided by Transport Canada. The airports were chosen to represent a wide range of airport sizes and included: Montreal (Dorval), Ottawa, St. John's, Thunder Bay, and Windsor. For each of the five airports, micro-fiche data for the number of operations per day for five different years of data were entered into a computer spreadsheet program. For each year at each airport, the following planning day statistics were calculated: (1) the number of operations for the mean planning day, (2) the standard deviation of the daily operations, (3) the number of operations for the 95th percentile day, (4) the number of operations for the PPD (21 day average), and (5) the number of operations for combinations of the mean and standard deviation.

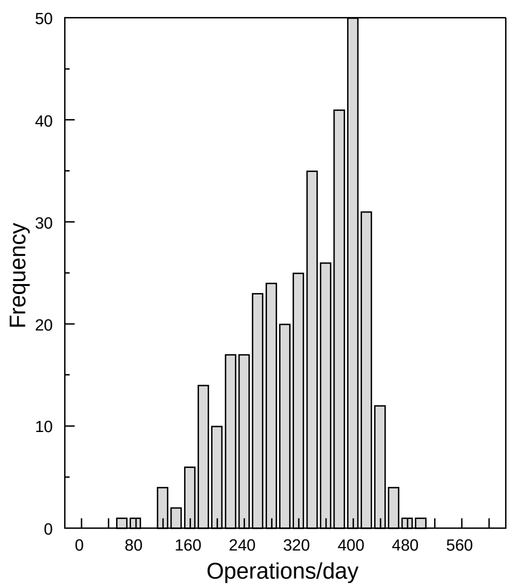


Figure 3.4: Distribution of the number of aircraft operations/day, Ottawa, 1985.

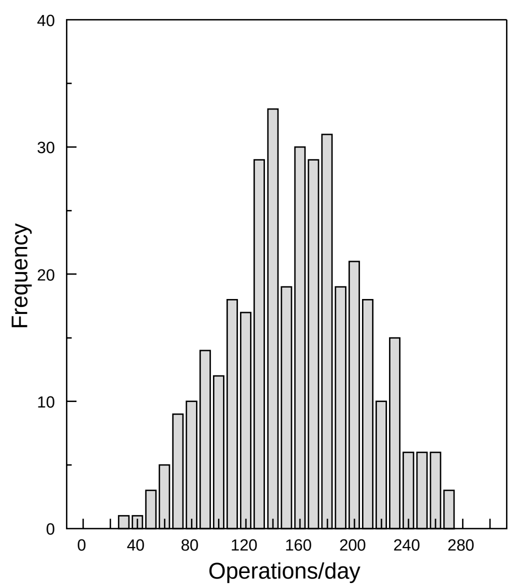


Figure 3.5: Distribution of the number of aircraft operations/day, Thunder Bay, 1988.

For each of the 25 sets of daily data (five years by five airports), the distribution of the frequency of occurrence of the numbers of operations per day were plotted. The form of these distributions was rarely normal and the shape of the distributions varied among airports and from year to year. Some distributions were very skewed. For example, Figure 3.4 illustrates the skewed distribution of daily operations at Ottawa airport in 1985. Other plots seemed reasonable approximations to normal distributions (see Figure 3.5 for 1988 Thunder Bay airport data). In some cases, such as the 1985 Montreal data in

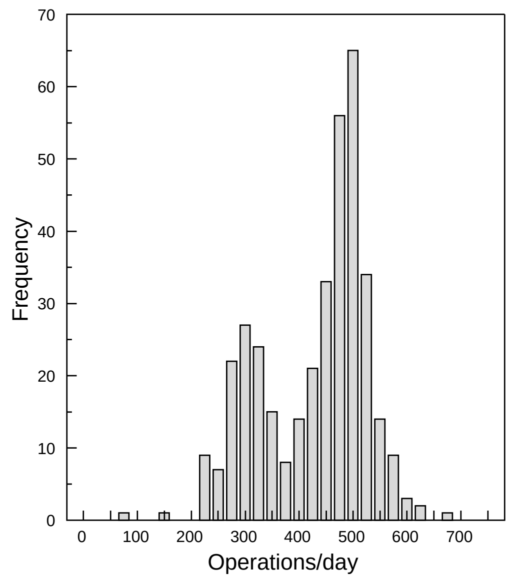


Figure 3.6: Distribution of the number of aircraft operations/day, Montreal, 1985.

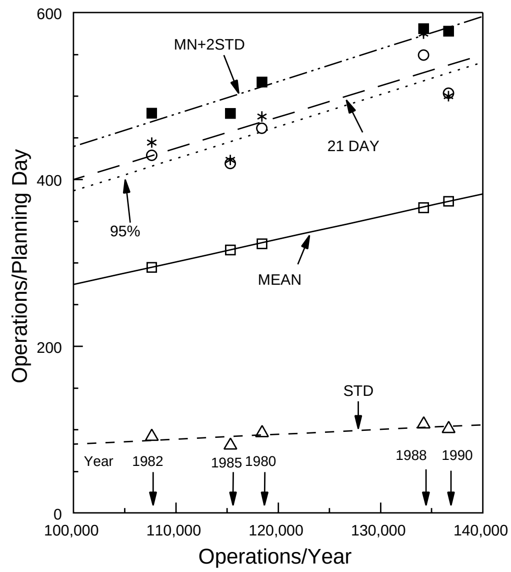


Figure 3.7: Yearly variation of operations per planning day at Ottawa airport.

Figure 3.6, the distributions were distinctly bi-modal. Therefore, one cannot assume that the distributions of daily operations are in general normal, and the observed great variety of distributions would be expected to lead to increased statistical errors associated with predicting future planning days.

For each airport, values of the numbers of operations for the various planning days were calculated and plotted versus the total number of operations per year. Figure 3.7 illustrates such a plot for Ottawa airport data showing: the mean number of daily operations, the standard deviation of the daily numbers of operations, the number of operations for the 95th percentile day, the number of operations for the PPD (average of busiest 21 days), and the combination of the mean plus two standard deviations. For each of these quantities, regression lines were calculated and the standard errors about these regression lines were determined. These standard errors allow one to compare the statistical uncertainty associated with predicting future values of each quantity.

If one considers the data from each airport separately and calculates regression lines for the number of operations per PPD versus the total annual number of operations (i.e. similar to Figures 3.3 and 3.7), different results are obtained for each airport. Figure 3.8 compares calculated regression lines from the five Canadian airports for operations per PPD versus total annual operations. A different regression line was

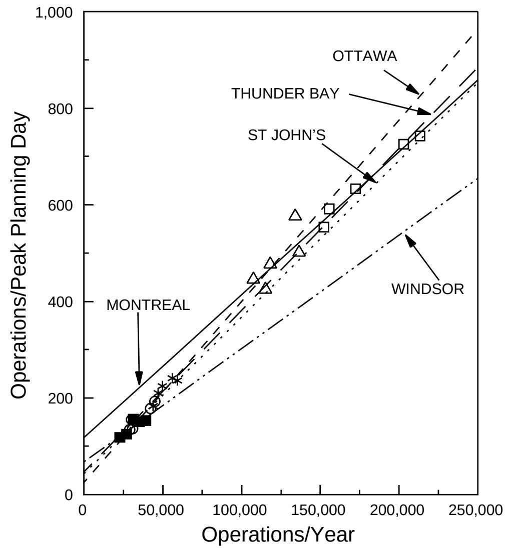


Figure 3.8: Number of operations per peak planning day versus total annual operations with separate regression lines for each of five airports.

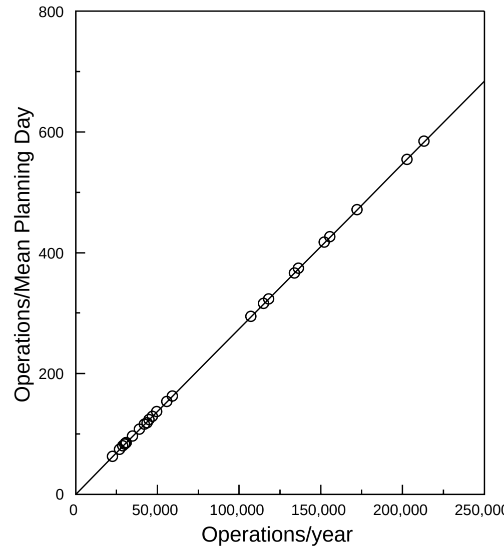


Figure 3.9: Variation of the number of operations per mean planning day versus the total number of annual operations.

calculated for each airport. The differences between these regression lines are partly due to the limited number of data points for each airport. It can be seen from Figure 3.8 that the data from all five airports follow a single common trend. Thus, regression analyses were performed on the combined data from all five airports to give more reliable results. In all cases, the combined data provides a more reliable estimate of the numbers of operations for future planning days.

3.2.3 Average Analyses at All Airports

Combined data for the number of operations for each of the planning days were plotted versus the total number of operations per year for all five airports. Regression equations were calculated for each plot and the standard error about the regression line was determined to estimate the prediction accuracy of these regression equations.

Figure 3.9 plots the number of operations per mean planning day versus the total annual number of operations. The data is a very close fit to a straight line with a negligible standard error in the estimated number of operations per mean day Thus, from the expected number of total annual operations one can predict the expected number of operations for a mean planning day very accurately.

The relationship between the number of operations per PPD and the total annual number of operations is shown in Figure 3.10. Here there is more scatter than in the previous plot and a standard error of 21.6 operations. Thus, one cannot expect to predict future numbers of operations for a PPD as accurately as for the mean planning day.

Similar plots and regression analyses were performed for the other planning day measures. The resulting regression equations and the associated standard errors are given in Table 3.1. The standard errors vary considerably between the different measures and hence some can be predicted more accurately than others. The mean daily number of operations can be most accurately predicted. Airport noise predictions that use the mean daily number of operations will have minimal statistical error associated with the estimation of the expected mean daily number of operations from the total annual number of operations. (However, the predicted noise levels will be markedly lower than those predicted from a 95th percentile planning day.) Use of other planning day values will introduce larger errors. The Transport Canada 21-day average PPD introduces the largest errors with a standard error of 21.6 operations.

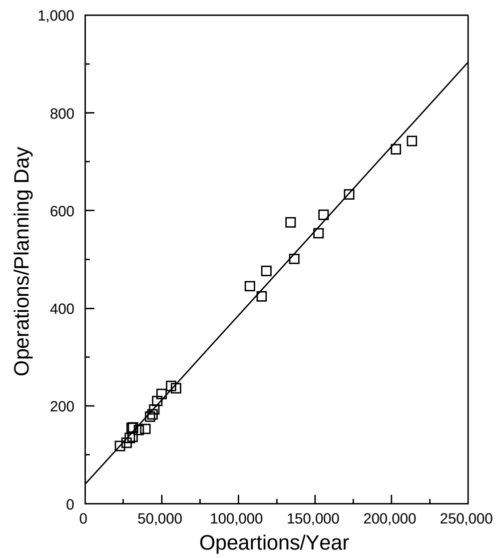


Figure 3.10: Variation of number of operations per Peak Planning Day versus total annual number of operations at five airports.

Table 3.1 Regression Equations for Number of Operations, NOPS, per Planning Day

MN	= 0.002737•NOPS	- 0.1399,	S.E.	= 0.6 operations
STD	= 0.0005713•NOPS	+ 17.505,	S.E.	= 6.4 operations
95PD	= 0.003431•NOPS	+ 35.622,	S.E.	= 16.8 operations
21PPD	= 0.003454•NOPS	+ 39.922,	S.E.	= 21.6 operations
MN2STD	= 0.003880•NOPS	+ 34.871,	S.E.	= 12.7 operations
MN14STD	= 0.003537•NOPS	+ 24.370,	S.E.	= 8.9 operations

Planning Day Measure	Symbol
Mean	MN
Standard Deviation	STD
95 Percentile day	95PD
21 day PPD	21PPD
Mean + 2 •STD	MN2STD
Mean +1.4•STD	MN14STD

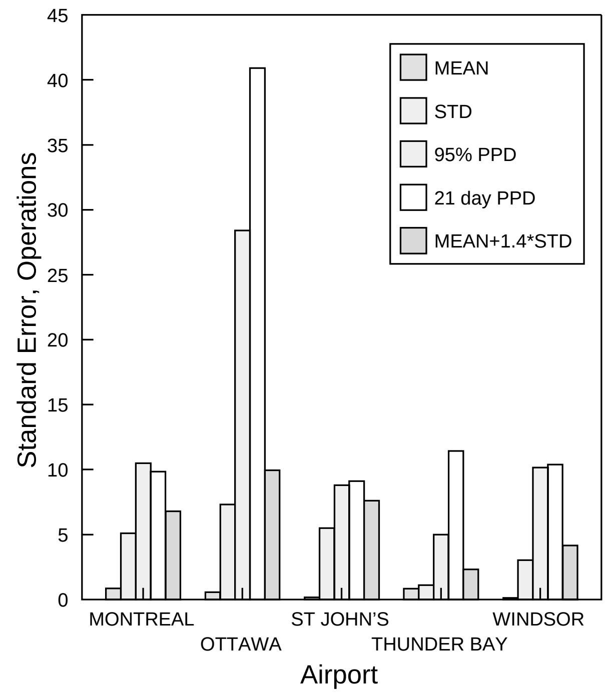


Figure 3.11: Summary of standard errors for prediction of the numbers of operations for each planning day by airport.

Although using the mean plus two times the standard deviation, MN2STD, leads to a smaller standard error, this gives numbers of operations for a planning day that would be significantly larger than either the 95 percentile day or the 21-day average PPD. However, using the mean plus 1.4 times the standard deviation leads to very close agreement among the three planning day values: 95PD, 21PPD, and MN14STD, as shown in Table 3.1. This measure also leads to one of the lowest standard error values and hence predicted future values would be more accurate. The 1.4 factor being optimum is a result of the distributions of daily operations not being normal. For distributions typical of these Canadian airports, it gives good agreement with the PPD values and minimizes the associated standard error.

The prediction errors for the various planning day measures could be greater than those in Table 3.1 if predicted using the data from only one airport. The standard errors about the regression equations for each airport are given in Figure 3.11. The standard error associated with the PPD is either similar in magnitude to the largest errors (Montreal, St. John's, and Windsor) or is considerably larger than errors for the other planning days (Ottawa, Windsor). The standard error associated with predicting the value of MN14STD (the mean plus 1.4 times the standard deviation) is always less than the 95th percentile day and the PPD.

3.2.4 Recommendations

It is recommended that the number of operations for a future planning day be estimated from the total annual operations using the following regression equation,

$$\text{Planning Day Operations} = 0.003537 \bullet \text{NOPS} + 24.37$$

where NOPS is the related total annual number of operations.

This is based on the result that from the present data the mean number of daily operations plus 1.4 times the standard deviation is a close approximation to the 95 percentile peak planning day and the Transport Canada PPD. This measure is more reliably related to the total annual number of operations and is less influenced by infrequently occurring unusually busy days. The statistical uncertainty associated with the present PPD measure can be estimated by the standard error associated with its estimation. This was 21.6 operations per day from the analysis of the combined data from five airports. This could become much larger if one follows the normal procedure of using data from only one airport. For example, an analysis of the data from Ottawa airport indicated a standard error of 40.9 operations per day for the PPD measure. The standard error associated with the proposed new procedure is 8.9 operations per day. This is much less than the error associated with the current procedure of estimating the number of operations for the PPD. The results of sections 5.1, 5.2 and 5.3 relate errors in the number of operations per PPD to effects on calculated NEF contours.

The above equation, or a similar one derived from an even larger set of airport data, is a more reliable method of predicting expected future events because it represents the average trend of a wide range of airport conditions. Predictions from extrapolations of a small number of data points at a single airport can lead to considerably larger errors.

This method completely avoids the need for tedious calculations from daily data at each airport and individual extrapolations from this data. Thus, it is not only a statistically more reliable method but it is also a much simpler technique.

REFERENCES

1. Anon., “Transport Canada Aviation Forecasts, 1990-2003”, Transport Canada Report TP 7960 (1990).
2. Anon., “NEF Micro Computer System Users Manual”, TP6907, June (1990).

4.0 COMPARISONS AT FOUR CANADIAN AIRPORTS

4.1 Comparisons of NEF_1.7, INM, and NoiseMap Results for Similar Input

Comparisons were made of the NEF contours calculated by three different prediction programs at four different airports. The NEF_1.7 program is the current official Transport Canada NEF contour prediction program. NoiseMap is the program developed by the United States Air Force and the Integrated Noise Model, INM, was developed by the United States Federal Aviation Administration. The NoiseMap and the INM programs are used widely in the United States and can be used to predict either L_{dn} or NEF contours. The INM program is widely distributed and the program or its input aircraft noise level data base are found in use in a number of countries for comparisons with local programs.

The airports were chosen to cover a wide range of conditions representative of Canadian airports. Transport Canada officials suggested airports that would meet our requirements and they provided the input data files for the NEF_1.7 program. The data used were: Windsor 1996 (total 193 operations/PPD), St. John’s 1996 (total 192 operations/PPD), Ottawa 1994 (total 387 operations/PPD), and Montreal 1989 (667 operations/PPD). The input data were then converted to the required input formats for the INM and NoiseMap programs. In these first comparisons, exactly the same input data including the number of operations per day were used for all three programs.

The output from each program was translated to a common format for plotting and contour area calculation. Contours were plotted using the Axum commercial plotting package on an IBM PC compatible computer. After some experimentation, it was decided to use no smoothing in plotting these contours. Various amounts of smoothing can be applied to eliminate minor irregularities, but the smoothing can change the shapes of the contours. To enable the most accurate comparisons, no smoothing was used and thus some contours exhibit minor irregularities.

For each airport, the calculated contours and the areas within each contour were first compared. The NEF contours were calculated in 5 dB intervals from NEF 20 to NEF 40. In each calculation, integrated NEF values were calculated for a matrix of 100 by 100 points to give a total of 10,000 NEF values. The noise levels at all of the points in a particular NEF interval, such as from NEF 25 to NEF 30, as determined by the NEF_1.7 output, were then compared with the noise levels at the same points from the other programs.

As a guide to interpreting the importance of differences, a difference of 3 dB in sound levels is usually considered to be a readily noticeable difference while a difference of 1 dB is only reliably detectable under carefully controlled conditions. Although these rule of thumb relationships are strictly only valid for constant amplitude sounds, they are usually assumed to be valid for aircraft noise.

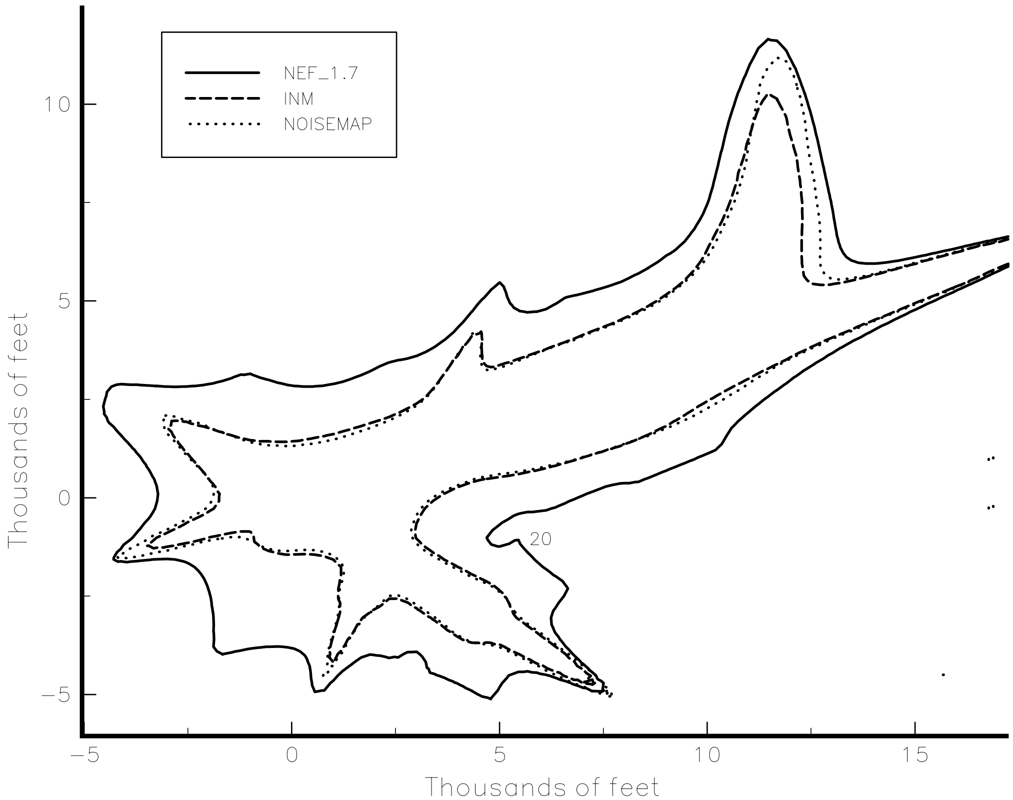


Figure 4.1: Comparison of NEF 20 contours produced by three programs: NEF_1.7, INM, and NoiseMap for Windsor airport.

Figure 4.1 compares the calculated NEF 20 contours from the three computer programs for the Windsor airport data. Although Transport Canada policies relate to NEF 30 contours, in this section NEF 20 contours are compared to better illustrate differences. (Subsequent analyses indicated that there are essentially no negative effects of airport noise at these low noise levels.) The two American computer programs produced similar contours but these contours were considerably smaller in area than the those produced by the NEF_1.7 program. These and subsequent results indicate differences between the predictions, but do not indicate which is more accurate.

The calculated contour areas are compared for the same Windsor airport case in Figure 4.2. As was seen from the contours, Figure 4.2 shows that the two American programs produced contours with very similar areas, and that the areas of the contours from the NEF_1.7 program are approximately 1.8 times larger than the other two sets of contours. Thus, with exactly the same input data, the Canadian program gives quite different results to the two American programs.

The NEF levels within each contour interval are compared in Figure 4.3. For each contour interval, this plot shows the mean difference and the standard error of this mean difference. These results show that for a given point on the ground, the NEF_1.7 results give values that are 4 to 5 units higher than the two American programs. In Figure 4.3, it is seen that the two American programs agree quite well at lower NEF values, but at the highest NEF locations, the mean difference is in excess of 2 dB.

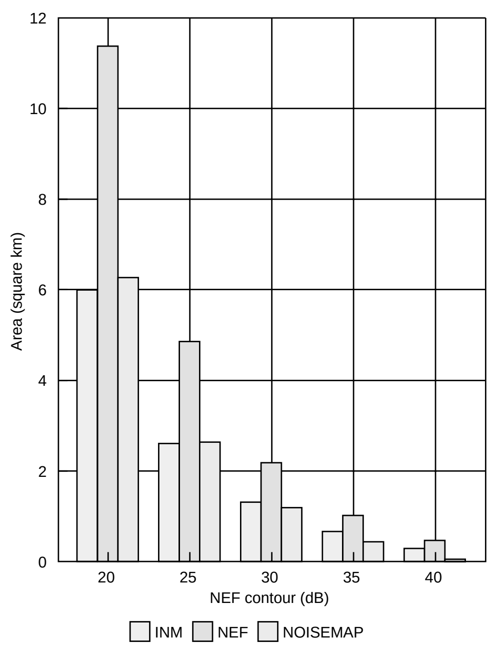


Figure 4.2: Comparison of contour areas produced by three programs: NEF_1.7, INM, and NoiseMap for Windsor airport.

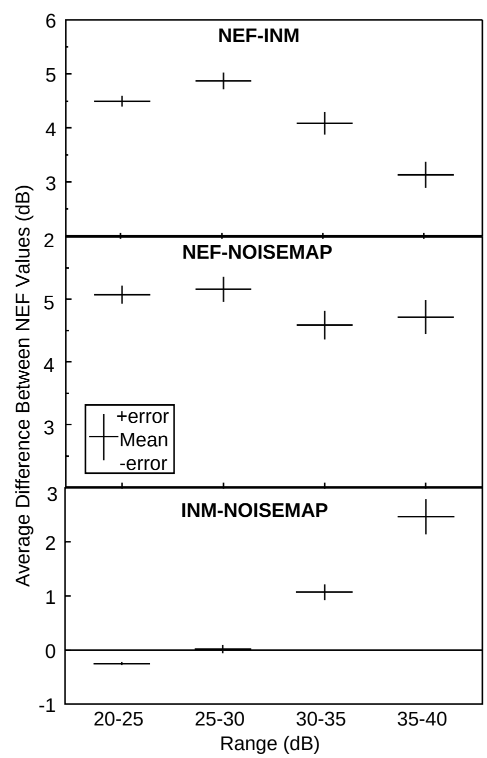


Figure 4.3: Average level differences between output of the three programs: NEF_1.7, INM and NoiseMap by contour interval for Windsor airport.

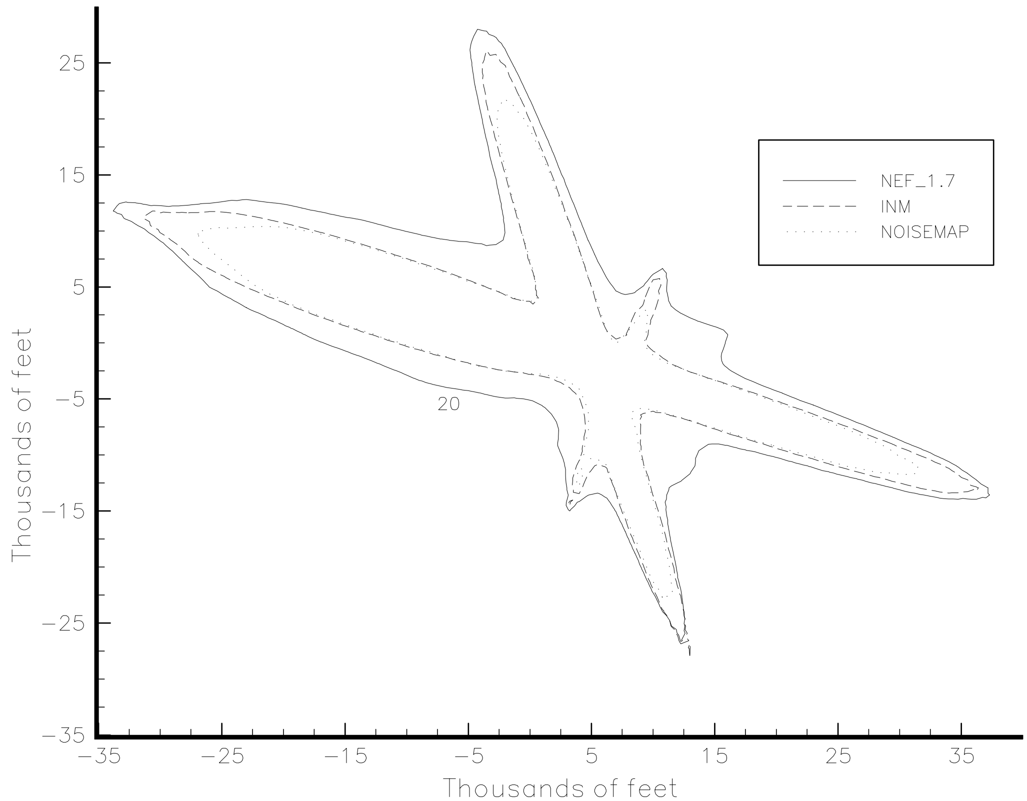


Figure 4.4: Comparison of NEF 20 contours produced by three programs: NEF_1.7, INM, and NoiseMap for St. John's airport.

The calculated NEF 20 contours for St. John's airport data are compared in Figure 4.4. Again, the area of the contour from the NEF_1.7 program is much larger than the other two contours. Differences between the output of the two American programs are also seen in this Figure.

The areas of the contours are compared in Figure 4.5. The INM program produced contours of larger areas than NoiseMap, but the NEF_1.7 contours were again approximately 1.8 times larger in area than the contours from the two American programs.

The NEF values within each contour interval are compared in Figure 4.6. The NEF_1.7 output was approximately 4 dB higher than the INM output and 4 to 5 dB higher than the NoiseMap output. Figure 4.6 shows that differences between the two American programs for the St. John's airport data were a little larger than data than for the previous case.

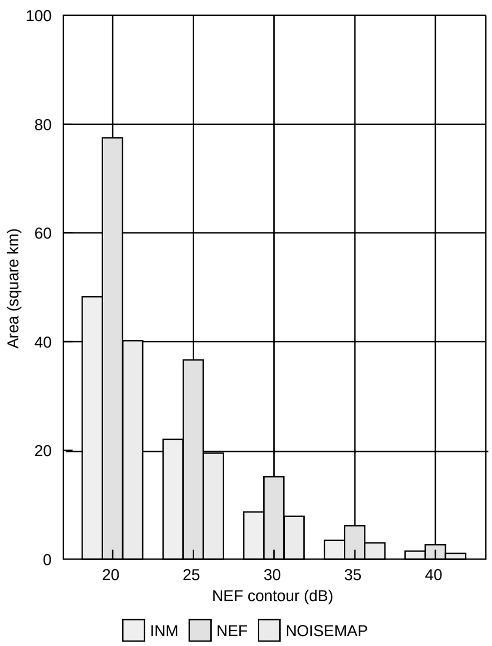


Figure 4.5: Comparison of contour areas produced by three programs: NEF_1.7, INM and NoiseMap for St. John's airport.

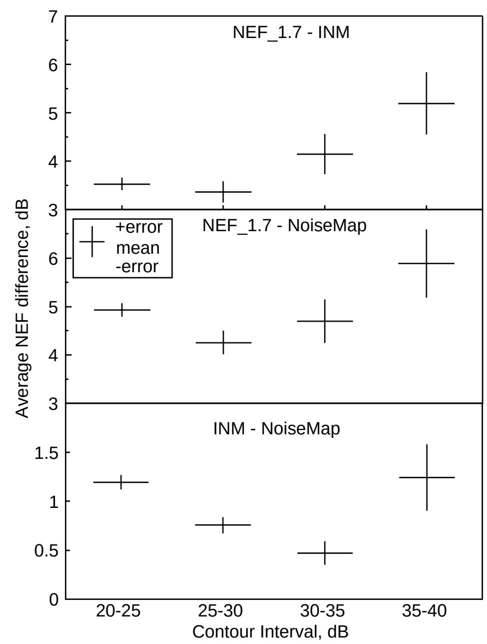


Figure 4.6: Average level differences between the output of the three programs: NEF_1.7, INM and NoiseMap by contour interval for St. John's airport.

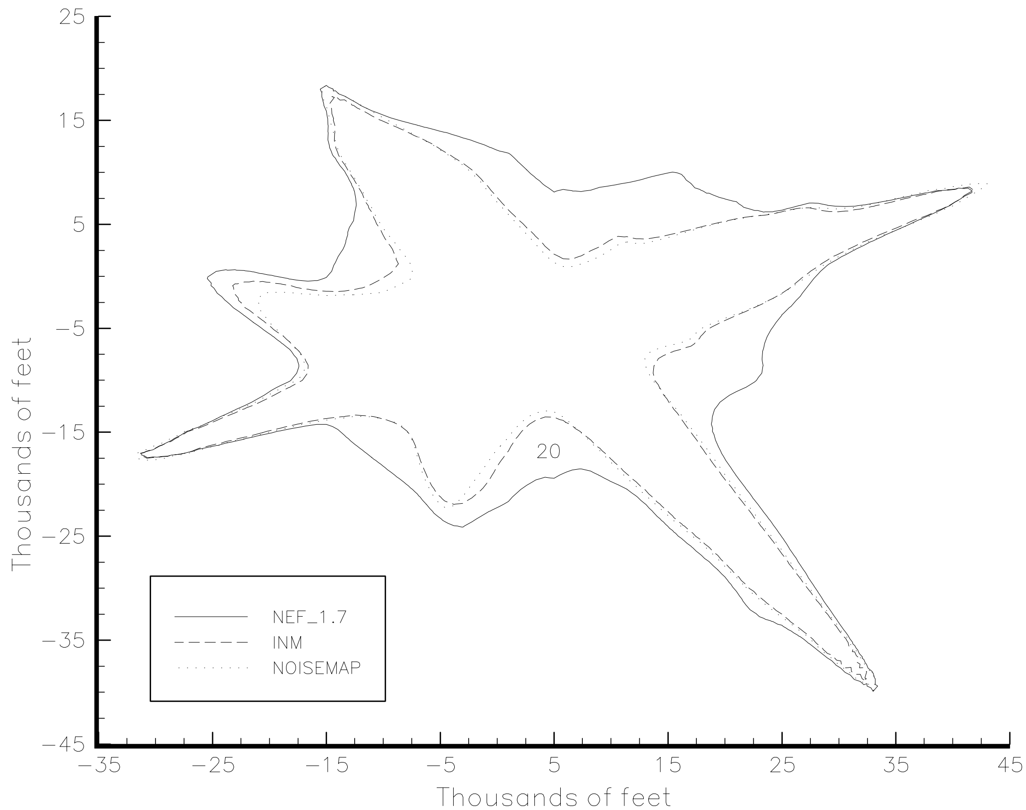


Figure 4.7: Comparison of NEF 20 contours produced by three programs: NEF_1.7, INM, and NoiseMap for Ottawa airport.

The Ottawa airport NEF 20 contours are compared in Figure 4.7. Again there are small differences between the NoiseMap and INM output and larger differences between the output of these two programs and the NEF_1.7 output.

Figure 4.8 compares the areas of the calculated contours for Ottawa airport. The areas of the contours calculated by the two American programs are very similar. The areas of the contours for the NEF_1.7 output are approximately 1.6 times larger than the other two sets of contours for this airport.

The point by point comparisons of the NEF values in Figure 4.9 show that for this case the results from the two American programs were very similar, with mean differences of no more than about 0.5 dB. However, both American programs gave NEF values 3 to 4 dB lower than the NEF_1.7 program output.

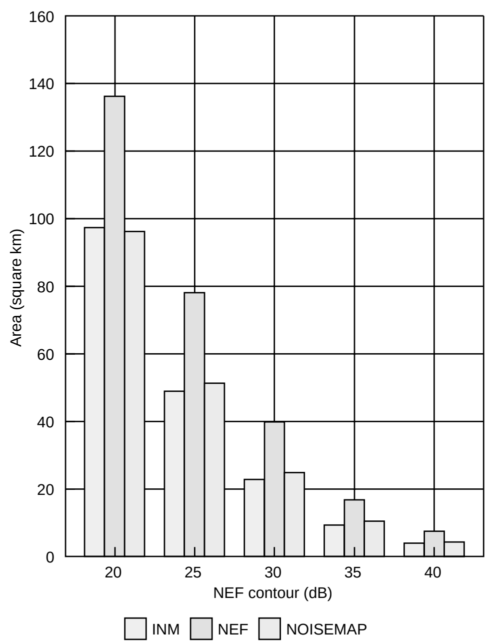


Figure 4.8: Comparison of contour areas produced by three programs: NEF_1.7, INM and NoiseMap for Ottawa airport.

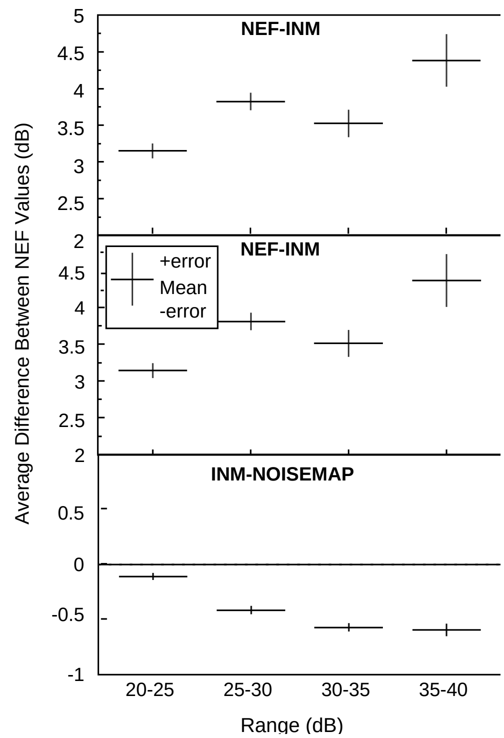


Figure 4.9: Average level differences between the output of the three programs: NEF_1.7, INM and NoiseMap by contour interval for Ottawa airport.

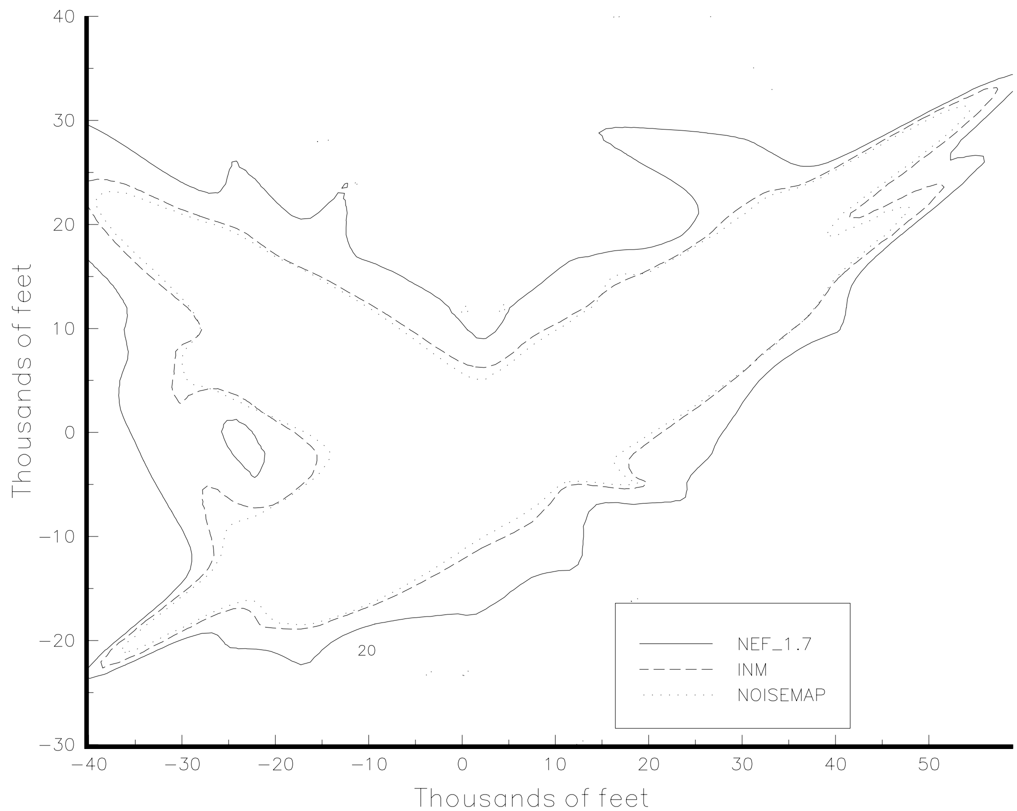


Figure 4.10: Comparison of NEF 20 contours produced by three programs: NEF_1.7, INM, and NoiseMap for Montreal airport.

The calculated NEF 20 contours for the Montreal airport data are compared in Figure 4.10. These contours show a similar pattern to the previous examples. There are small differences between the output of the two American programs and larger differences between their output and that of the NEF_1.7 program.

The comparison of the contour areas in Figure 4.11 is also similar to the previous examples. The two American programs produced very similar contour areas and the NEF_1.7 program produced areas that were approximately 1.6 times larger than the two American programs.

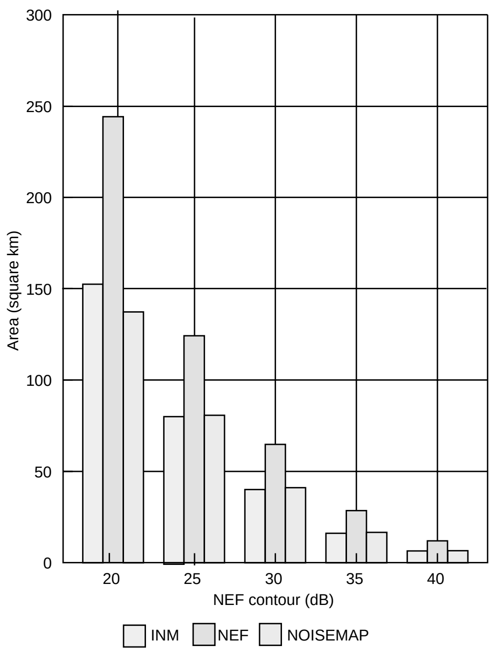


Figure 4.11: Comparison of contour areas produced by three programs: NEF_1.7, INM and NoiseMap for Montreal airport.

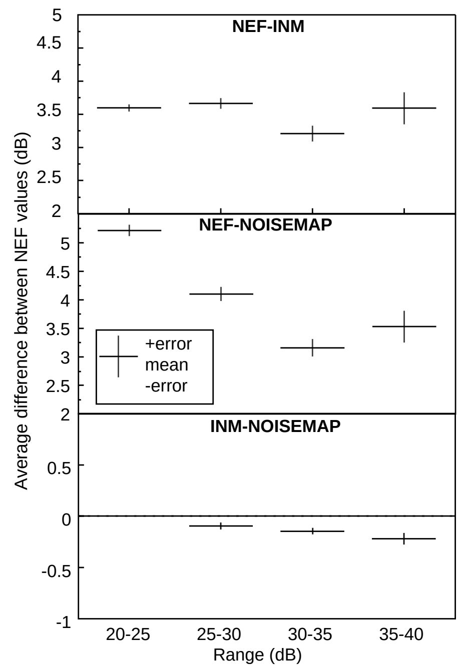


Figure 4.12: Average level differences between the output of the three programs: NEF_1.7, INM and NoiseMap by contour interval for Montreal airport.

For all four airports, the areas of the contours from the NEF_1.7 program were always greater than the areas of the contours from the other two programs. However, this difference was noticeably less for the two larger airports (Ottawa and Montreal). The point by point level differences for the Montreal airport data are summarised in Figure 4.12 and are also very similar to the corresponding Ottawa airport results. The two American programs produced very similar levels but were typically 3 to 4 dB lower than the NEF_1.7 output.

With identical input data, the three programs produce different output. The contours produced by the INM and NoiseMap programs are quite similar in overall area and differ in smaller details. The contours produced by the NEF_1.7 program were 60 to 80% larger than those from the other two programs. Thus, the NEF_1.7 program output is substantially different and the differences are especially noticeable along the sidelines of flight tracks rather than under the main flight tracks at the ends of the runways. These differences are explored further in Chapter 6 of this report.

4.2 Comparison of Results for the PPD and the Mean Day

The comparisons in section 4.1 above were based on exactly the same number of operations for all three programs. This does not correspond to the different procedures followed in the United States and Canada. In Canada, airport noise calculations are performed for a peak planning day, PPD, whereas in the United States a mean planning day is normally used. The number of operations for a PPD is typically 1.4 times larger than for a mean day. Thus, further contour calculations were performed to compare the actual contours that would be calculated in each country for the same airport situation. The NEF_1.7 program was used to calculate contours for a PPD and the INM program was used to calculate contours for a mean planning day. Thus, there are differences due to the different numbers of operations and also due to the different computer programs.

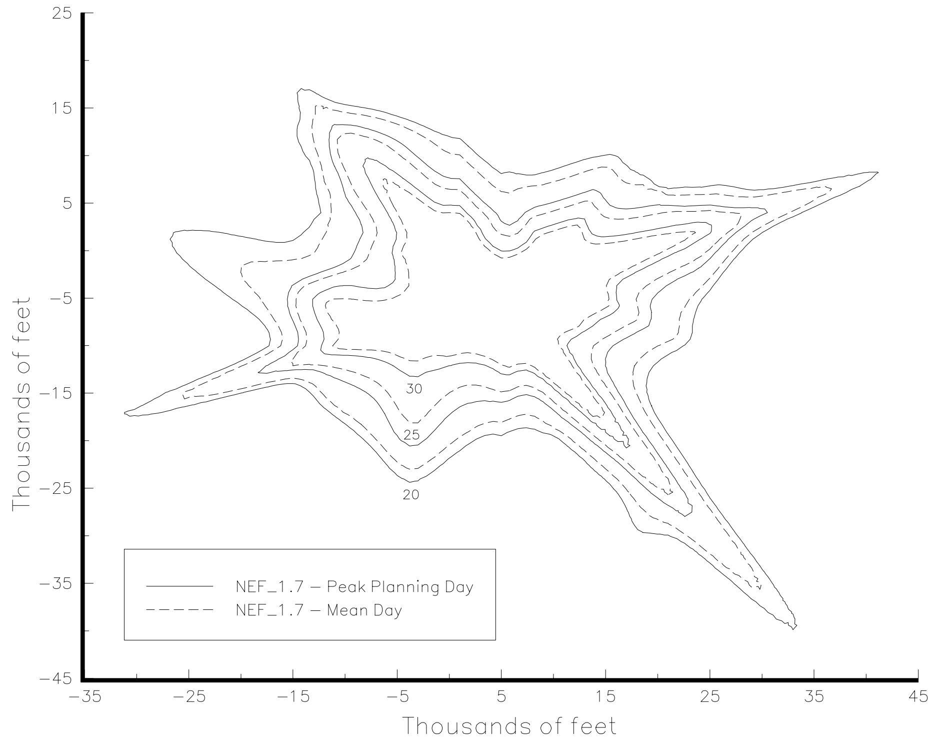


Figure 4.13: Comparison of NEF contours for Ottawa airport for the mean planning day and the PPD using the NEF_1.7 program.

As an intermediate first step, calculations were performed with the NEF_1.7 program for both a PPD and a mean day. Thus, in these cases only the number of operations was changed. Figure 4.13 shows the resulting NEF 20, 25 and 30 contours for the Ottawa airport data. (Because the number of operations was increased by a factor of 1.4, the NEF values would increase by 1.5 dB - i.e. 10 log (1.4) = 1.5.) The areas of the contours are compared in Figure 4.14. The areas for the contours for the PPD operations were approximately 1.3 times larger than the contours for the mean day operations. Similar comparisons were performed for the other airports, and in all cases the areas for the PPD input data were 1.3 times larger than for the mean day data.

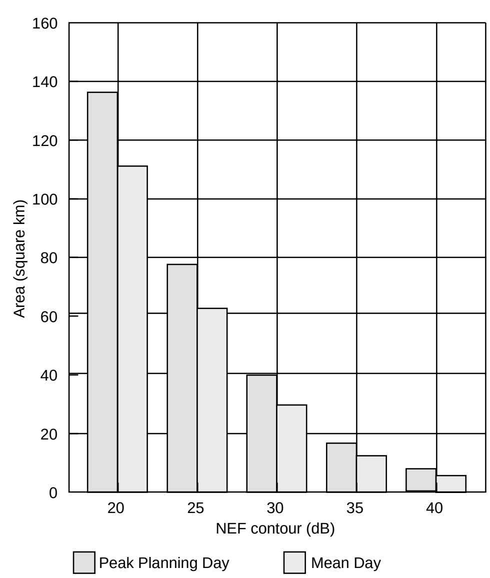


Figure 4.14: Comparison of contour areas for Ottawa airport for the mean planning day and the PPD using the NEF_1.7 program.

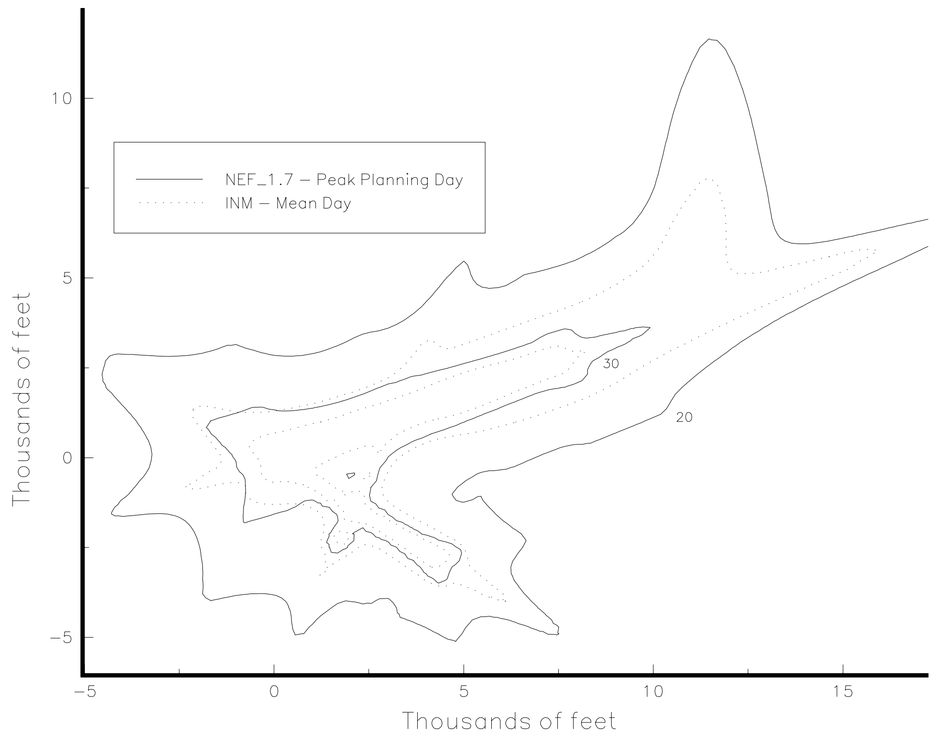


Figure 4.15: Comparison of NEF contours for Windsor airport using the INM program for a mean planning day and the NEF_1.7 program for a PPD.

Figure 4.15, for Windsor airport, compares the NEF_1.7 PPD contours with the INM mean day contours. The areas of the two sets of contours are compared in Figure 4.16. As was expected, the areas of the contours from the NEF_1.7 program with PPD input data were much larger than the areas of the contours produced using the INM program with mean day data. In fact, the NEF_1.7 PPD contours are approximately 2.2 times larger than the INM mean day contours for this airport.

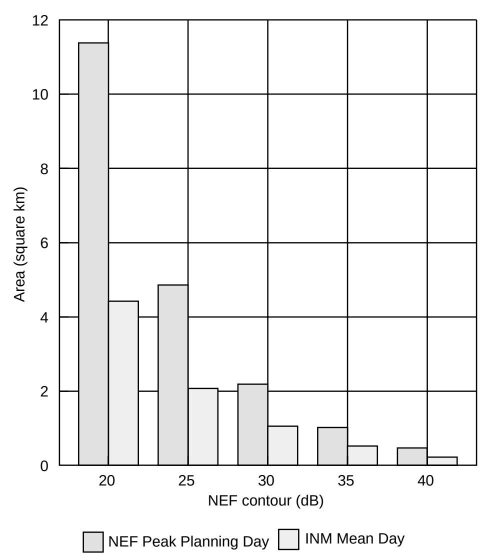


Figure 4.16: Comparison of contour areas produced for Windsor airport using the INM program for a mean planning day and the NEF_1.7 program for a PPD.

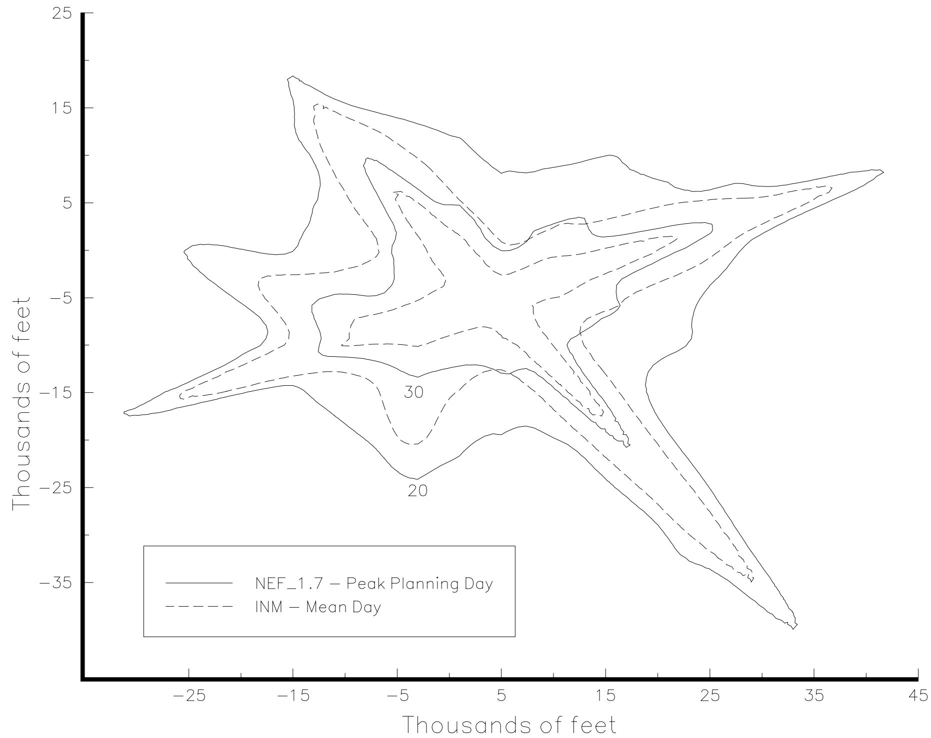


Figure 4.17: Comparison of NEF contours for Ottawa airport using the INM program for a mean planning day and the NEF_1.7 program for a PPD.

The NEF 20 and 30 contours for the NEF_1.7 program with PPD input and the INM program with mean day input are compared in Figure 4.17 for Ottawa airport data. The areas of the two sets of contours are compared in the bar chart of Figure 4.18. Again the areas from the NEF_1.7 program with PPD input were approximately 2.2 times larger than the areas of the contours from the INM program with mean day input.

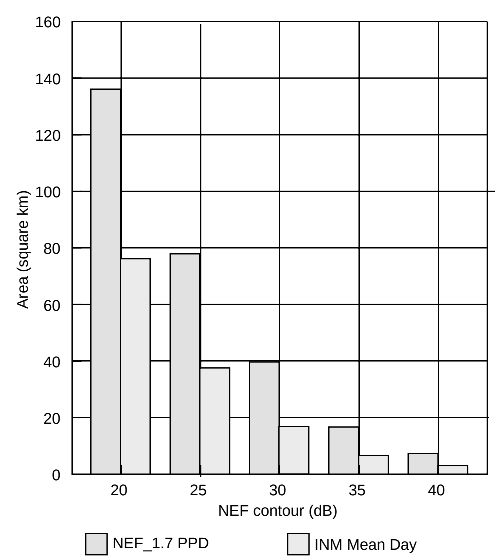


Figure 4.18: Comparison of contour areas produced for Ottawa airport using the INM program for a mean planning day and the NEF_1.7 program for a PPD.

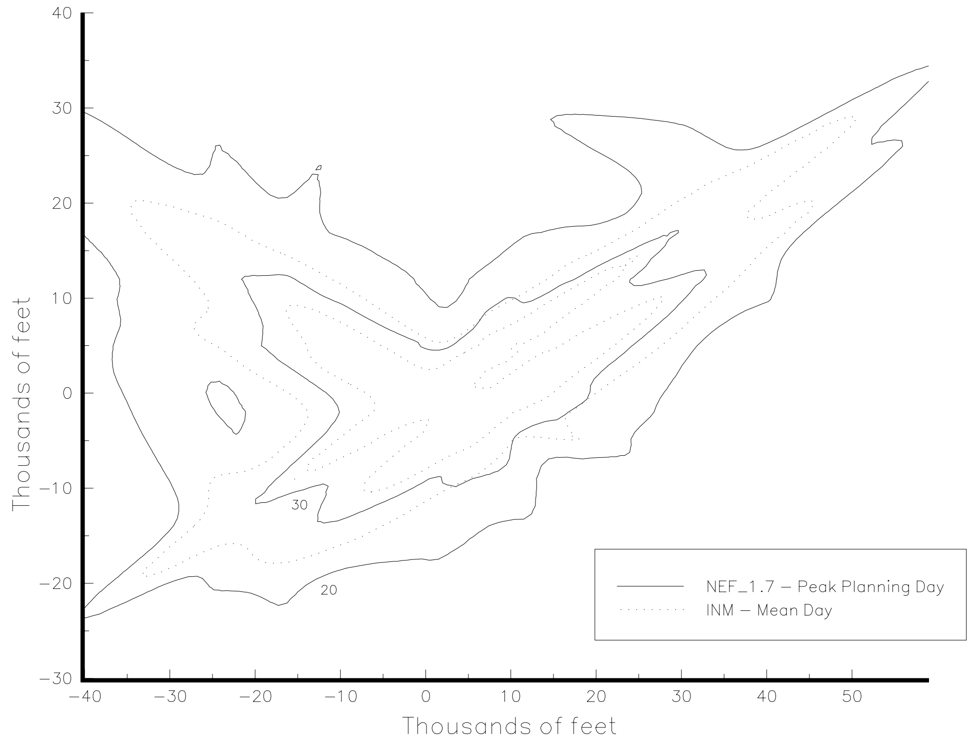


Figure 4.19: Comparison of NEF contours for Montreal airport using the INM program for a mean planning day and the NEF_1.7 program for a PPD.

Finally, the calculated contours for Montreal airport are compared in Figure 4.19. Both the NEF 20 and 30 contours are shown for the output of the NEF_1.7 program with PPD input and the INM program with mean day input. Figure 4.20 compares the areas of these contours. The contours produced by the NEF_1.7 program with PPD input were approximately 2.1 times larger than those produced by the INM program with mean day input.

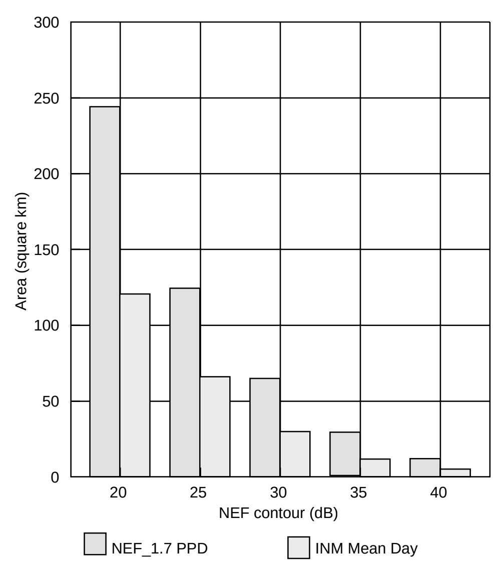


Figure 4.20: Comparison of contour areas produced for Montreal airport using the INM program for a mean planning day and the NEF_1.7 program for a PPD.

In section 4.1, the areas of contours produced by the INM program and the NEF_1.7 program with identical input were compared. On average, the contours produced by the NEF_1.7 program were approximately 1.7 times larger than the INM contours. In this section, the change from mean day to PPD produced an average increase of 1.3 times in the contour areas. If both the program and the number of operations are changed in going from the INM mean day contours to the NEF_1.7 PPD contours, there is an approximate increase in contour areas of 2.2 times. Thus, the two effects are independent and the combined effect can be obtained from the product of the individual effects (i.e. $1.7 * 1.3 \approx 2.2$).

The combined effect of the different computer programs and different basis for numbers of operations leads to substantial differences in the areas of the contours that would be calculated in the United States and Canada. The Canadian contours would typically be more than twice as large as the corresponding U.S. contours. The differences between the two computer programs are due to different approximations to modeling a complex system. Details of this process are discussed further in Chapter 6. The choice of a PPD rather than a mean day relates to the level of aircraft noise that is considered to be undesirable to residents near airports. This question will be discussed in a subsequent report.

5.0 SENSITIVITY ANALYSIS

There are various sources of error in the input data for airport noise contour predictions. This Chapter examines the sensitivity of the NEF_1.7 program to systematic variations in the major input variables. There is no reason to believe that other computer prediction programs would exhibit very different sensitivity to variations of the input data.

The principal input variable is the total number of aircraft operations for the planning day. In Chapter 3, the errors associated with predicting the total number of future operations and the additional errors associated with predicting the number of operations for the related PPD were examined. From the total number of operations for the future planning day, the user of an airport noise prediction program must estimate other aspects of the future planning day. One must estimate: how the total number of expected operations are distributed among aircraft types, the percentage of the operations that will occur during the night, the distribution of the operations among the runways, and the length of the various flights (i.e. the stage length). Each of these quantities was systematically varied a small amount to find the effect on NEF values within each contour interval and the effect on the contour areas. These results give an indication of the importance of errors in each of these input variables to the overall precision of the calculations.

Each of the five major input variables was systematically varied for the data from three airports. These were: Windsor 1996, Ottawa 1994, and Montreal 1989. These represent typical Canadian small, medium, and large airports. Thus, the sensitivity to errors in the input data can be examined as a function of airport size.

5.1 Noise Level Versus Contour Area Increments

Before discussing the effects of errors in each input variable, it will be helpful to quantify the relationship between small changes in NEF values and the related small changes in the contour areas. This will enable one to make approximate conversions between level and area changes in the following discussions.

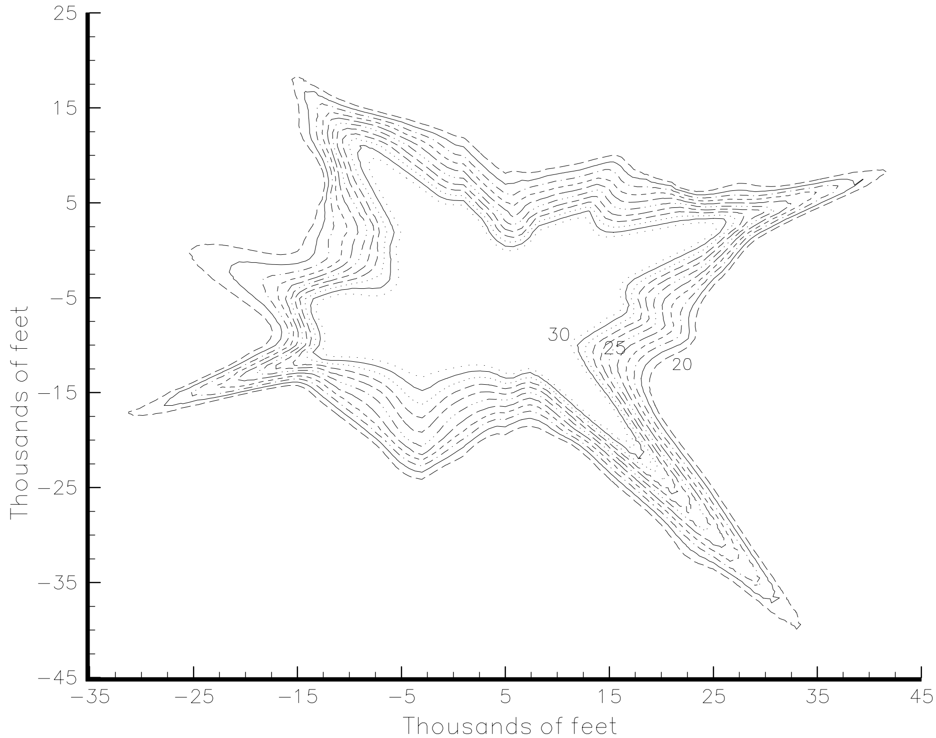


Figure 5.1: NEF contours for Ottawa airport in 1 NEF unit increments as calculated by the NEF_1.7 program.

An approximate relationship between increments in NEF values and increments in contour areas was obtained by calculating NEF contours in 1 NEF unit increments for Ottawa airport. Figure 5.1 shows the calculated NEF 20 to NEF 30 contours at Ottawa airport. Ottawa airport was used because it is an example of an intermediate sized airport and results for Ottawa airport should best approximate conditions at smaller and larger airports. The area of each contour was calculated and then these areas were plotted versus the contour NEF value as shown in Figure 5.2. The areas can be accurately related to the logarithm of the NEF values by the following regression equation,

$$\text{Area} = -438 \bullet \log(\text{NEF}) + 679, \ \text{km}^2$$

This regression equation is also shown on Figure 5.2.

It is more generally useful to express the relationship as the percentage change in area per increment in NEF value. This type of relationship was calculated for increments of 1, 2, and 3 NEF units. The resulting percentage change in contour areas are plotted as a function of NEF value in Figure 5.3. From this graph, one sees that at NEF 25 a 1 unit increment in NEF value would relate to approximately a 12%

change in contour area. For the same intermediate NEF 25 case, a 2 NEF unit increase would relate to a 21% change in contour area and a 3 NEF unit change would relate to a 33% change in contour area.

Although these results are based on data from Ottawa airport, they should be approximately valid for smaller and larger airports. Thus, one can make approximate conversions between changes in NEF values and changes in the related contour areas.

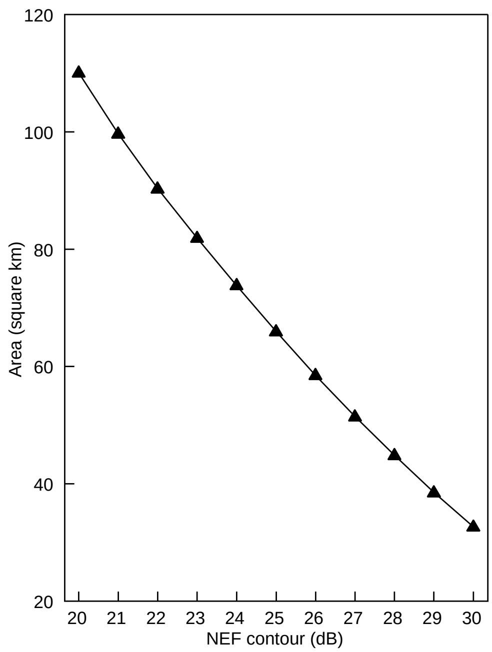


Figure 5.2: Contour areas versus NEF value for Ottawa airport from contours of Figure 5.1.

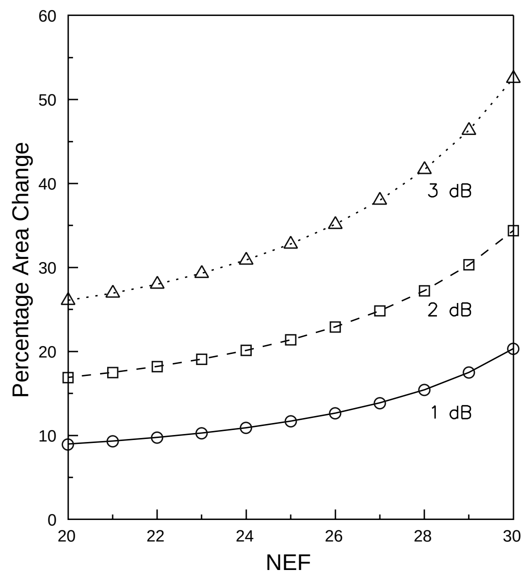


Figure 5.3: Percentage increase in area by NEF contour for 1, 2, and 3 dB NEF increments.

5.2 Total Number of Operations

In Chapter 3, it was seen that the average error in predicting future total annual numbers of operations is approximately 11% and that for a particular year the error could be as large as 21% (averaged over all large Canadian airports). The additional error associated with predicting the number of operations for a future PPD would add to this error. It varied among airports but could be in excess of 40 operations/day (Figure 3.11). In a worst case, these two sources of error could be multiplicative and the combined error in the estimated number of operations for a PPD could be over 30%. To examine the effect of errors in the total number of operations for a PPD, errors of +20% and -20% were considered. Such errors are by no means a worst case and are likely to occur reasonably frequently.

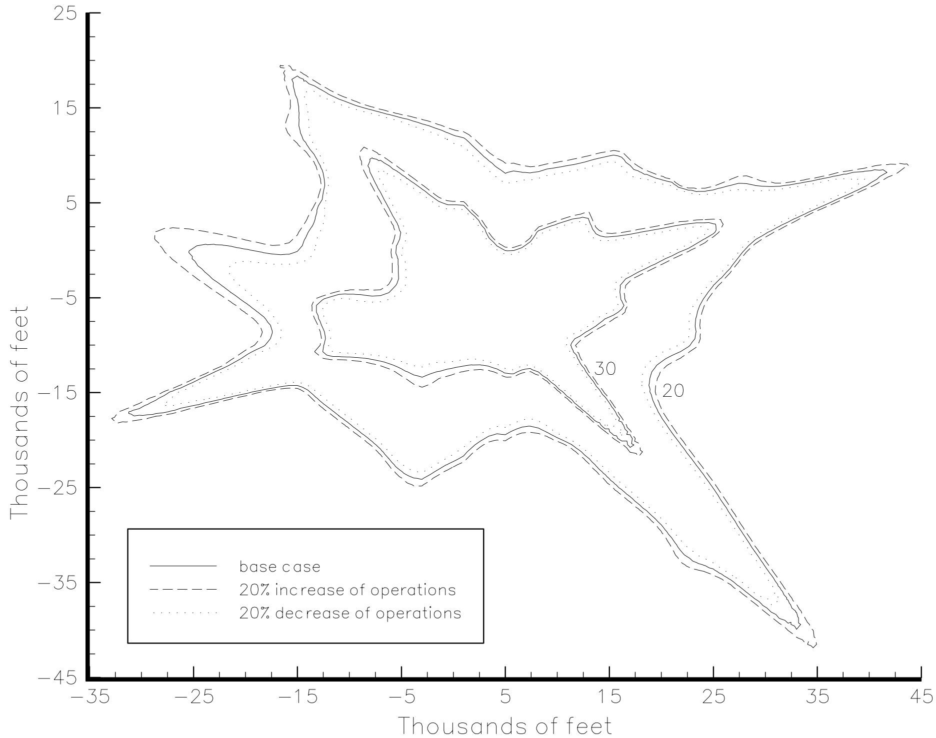


Figure 5.4: Example of effect of 20% increase and decrease in the number of operations on contours at Ottawa airport.

As an example Figure, 5.4 shows the resulting contours for both a 20% increase and a 20% decrease in total operations at Ottawa airport. The effects of the change in the total number of operations per PPD were examined in terms of both NEF level changes and changes in contour areas. For each contour interval (20-25, 25-30, 30-35, and 35-40 NEF) of the base case, the average of the point by point changes in NEF values were determined. The average changes in NEF values within each contour interval were quite similar for a given change in the input data so are presented here as a single average change for all contour intervals.

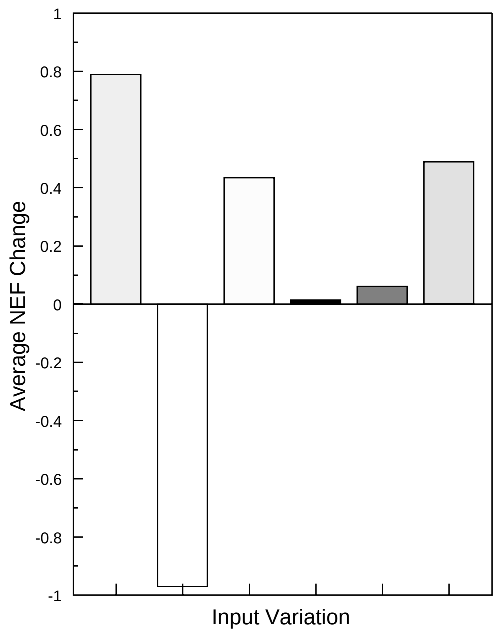


Figure 5.5: Average change in NEF values for various changes in the input data at Windsor airport.

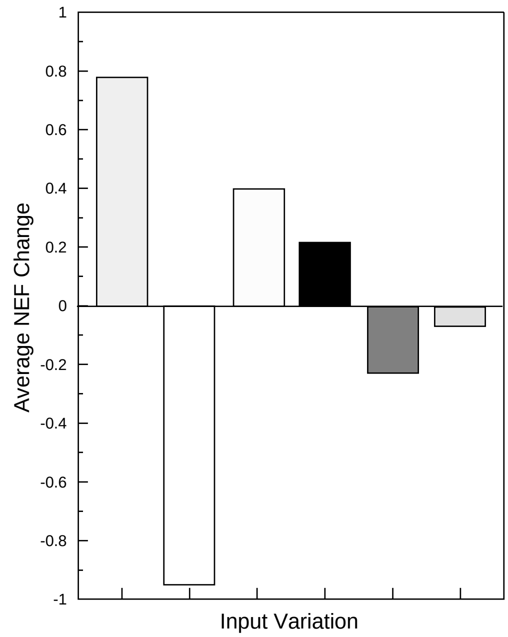


Figure 5.6: Average change in NEF values for various changes in the input data at Ottawa airport.

20% increase of ops
20% decrease of ops
20% increase of night ops
increase of stage length by 1
20% increase of Chapter 3 planes
20% increase of ops on specific runway

Figures 5.5, 5.6, and 5.7 show average NEF changes for Windsor, Ottawa, and Montreal, respectively. The left hand two bars of each graph are the resulting change in NEF values for a 20% increase and a 20% decrease in the total number of operations for the PPD. The changes for all three airports are almost exactly what one would calculate by increasing or decreasing the total number of operations in the formula defining the NEF measure (see equation A.20 in Appendix 1). That is, the average change in NEF values is proportional to 10 times the logarithm of the total number of operations. Thus, 20% errors in the

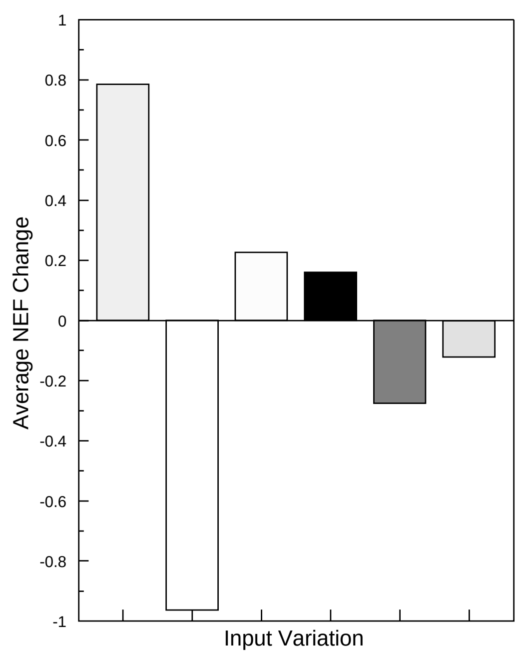


Figure 5.7: Average change in NEF values for various changes in the input data at Montreal airport.

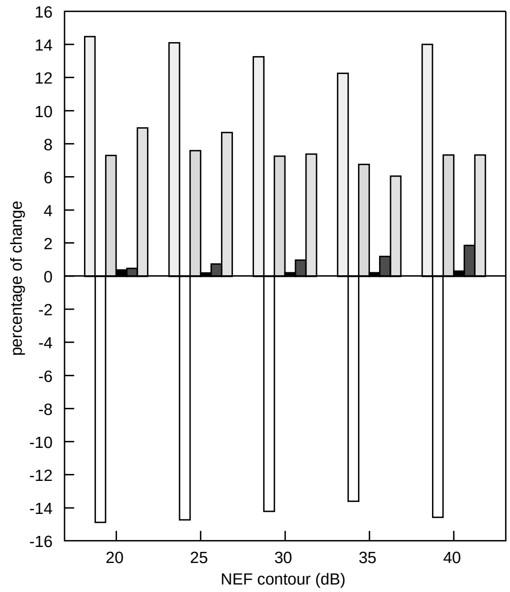


Figure 5.8: Percentage change in contour areas for various changes in the input data by NEF contour at Windsor airport.

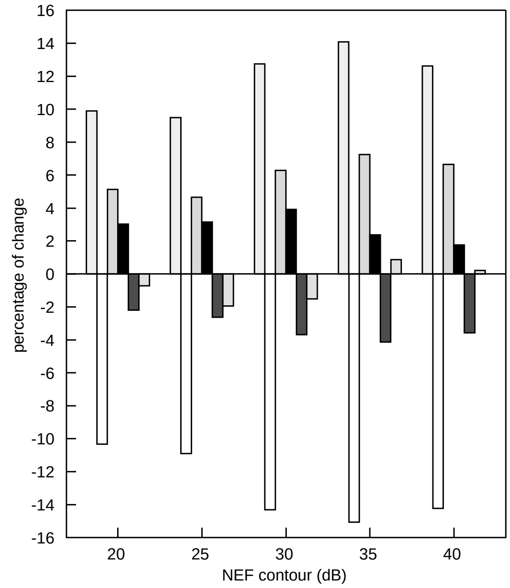
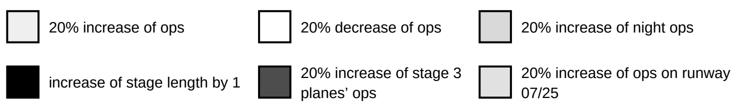


Figure 5.9: Percentage change in contour areas for various changes in the input data by NEF contour at Ottawa airport.



input number of operations will lead to errors in NEF values of approximately 1, and this magnitude of error is likely to occur quite frequently. An error of 1.5 units in the calculated NEF values would result from a 40% error in the total number of operations for PPD. Such an error would occur very infrequently and represents an estimated upper bound on the magnitude of this type of error.

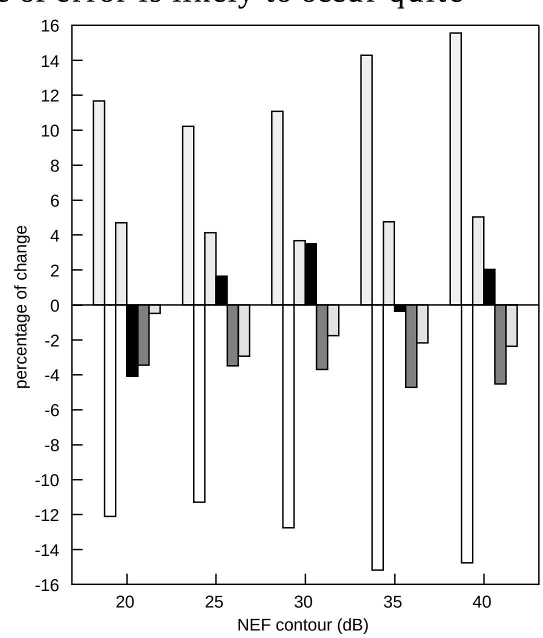


Figure 5.10: Percentage change in contour areas for various changes in the input data by NEF contour at Montreal airport.

The changes in contour areas are given in Figures 5.8, 5.9, and 5.10 for Windsor, Ottawa, and Montreal, respectively. There is some variation between airports and between contour intervals. For Ottawa and Montreal, the variations in contour areas tend to increase with contour NEF values. This is not true for Windsor where the variation is almost the same for all contour intervals. The changes in contour area, for a 20% increase or decrease in the total number of operations, vary from about 10% to 14%. Thus, changing the total number of operations by 20% led to average changes in contour areas of about 12%. This is similar to the relationship suggested by Figure 5.3, where a 1 unit increase in NEF at the intermediate NEF 25 contour would correspond to an approximate 12% change in contour area. It was suggested above that the maximum likely error in the total number of operations of approximately 40% would correspond to a 1.5 unit change in NEF. From Figure 5.3, this maximum likely error would relate to an approximate 16% contour area change.

Thus, frequently occurring errors in the total number of operations would lead to modest errors in NEF values and NEF contour areas, but larger errors of up to 2 NEF units and 21% errors in contour area are possible.

5.3 Number of Night-time Operations

To examine the effect of errors in the number of night-time operations, calculations were performed with the number of night time operations at each of the three airports increased by 20%. The percentage of operations that are expected to occur during the night time hours, are usually estimated to be the same as current conditions. There is no information available to indicate the likely errors in estimating the numbers of future night-time operations. The 20% error example seems like a reasonable estimate of the magnitude of likely errors in this quantity. As seen in Figures 5.5, 5.6, and 5.7, this resulted in average increases in NEF values of 0.2 to 0.4 dB. The effect was largest at the smallest airport (Windsor).

Figures 5.8, 5.9, and 5.10 show that the same 20% increase in the number of night time operations would lead to increases in contour area of between 4 and 7%. The effect varies between airports and between contour intervals. The increase in contour areas is greatest at Windsor and Ottawa airports. Presumably the aircraft operating at night at these airports are more representative of the noisier aircraft at these two airports and hence slightly larger contour area increases are found.

5.4 Stage Length

Aircraft taking off for longer flights are assumed to be heavier and to climb more slowly. Longer flights (referred to as longer stage lengths) thus lead to larger noise contours. In predicting future conditions at an airport, one must predict the expected stage length of each aircraft. Stage length can vary from 1 to 7. To examine the likely errors associated with this prediction, all stage lengths in the original airport data were increased by 1.

The increase of all stage lengths by 1 led to very small average increases in NEF values at Windsor (Figure 5.5) and average increases of about 0.2 in the NEF values at Ottawa and Montreal airports (Figures 5.6 and 5.7). The changes in contour areas shown in Figures 5.8, 5.9, and 5.10 vary between airports and between contour intervals. At Windsor, only very small increases in contour areas were calculated. At Ottawa airport, contours increased by 2 to 4% depending on the contour interval. At Montreal, the NEF 20 contour decreased by approximately 4% and the other contours increased by approximately 2 to 4%. Thus, these average errors seem to be most important at medium and larger airports.

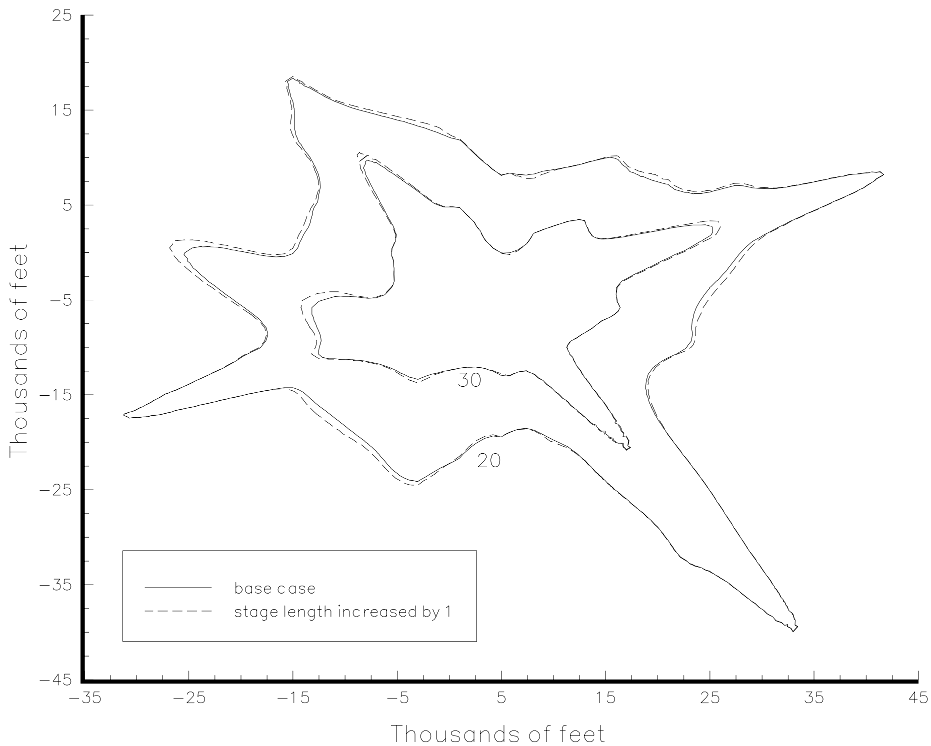


Figure 5.11: Example of changes in calculated contours when aircraft stage lengths were increased by 1, at Ottawa airport.

However, the changes can vary from position to position around an airport. Figure 5.11 shows the effect of the increase of all flights by one stage length on the NEF contours at Ottawa airport. At most locations there was very little change in the calculated contours. However, at some locations the NEF contour is moved by as much as 1000 ft. Thus, one cannot completely understand these types of errors by examining only average effects for the entire airport.

5.5 Number of Chapter 3 Aircraft

In order to simulate an error in the distribution of the operations among aircraft types, the number of Chapter 3 aircraft operating at each airport was increased by 20%. The total number of aircraft operations was kept constant so that the increase in Chapter 3 aircraft was compensated for by an equivalent decrease in the numbers of other aircraft operations. Chapter 3 aircraft are on average quieter than Chapter 2 aircraft so that increasing the proportion of Chapter 3 aircraft was expected to decrease noise levels. ('Chapter 2' and 'Chapter 3' are classifications of civil aircraft according to their certification noise levels as specified by ICAO [1]). As seen in Figures 5.5, 5.6, and 5.7, NEF values decreased by 0.2 to 0.3 dB for the Ottawa and Montreal airport cases. These airports have a large amount of commercial jet aircraft traffic and the average NEF levels decreased as expected. For the smaller Windsor airport, increasing the proportion of Chapter 3 aircraft produced a very small increase in average NEF values. This is because the Chapter 3 aircraft are among the noisier aircraft at this airport and most of the aircraft are quieter propeller aircraft.

The related effects on contour areas are shown in Figures 5.8, 5.9, and 5.10. At Windsor airport, the 20% increase in Chapter 3 aircraft caused the contour areas to increase by up to 2%. At the other two airports, the contour areas decreased by approximately 2 to 4%. The effects of the increased proportion of Chapter 3 aircraft are small and tend to be largest at larger airports where there are more noisier Chapter 2 jet aircraft.

Representing errors in predicting the future distribution of aircraft types by an increase in Chapter 3 aircraft is close to a worst case. Many such errors would be among aircraft types that are more equally noisy. Changing aircraft from Chapter 3 to Chapter 2 on average represents a relatively large change in source noise levels. Thus, it is thought that the 20% increase in Chapter 3 aircraft is a safe estimate of the likely errors in predicting the distribution of aircraft types.

5.6 Runway Use

When predicting future noise contours, one must decide how the aircraft operations are to be divided among the various runways. Errors in estimating the distribution among runways would also contribute to errors in the resulting NEF contours. To estimate the sensitivity of the

NEF_1.7 model to this type of error in the input data, the number of operations on one runway were increased by 20% while keeping the total number of operations constant. Of course, the effect would depend somewhat on the choice of runway, but these examples give some indication of the importance of this type of error.

At Windsor, increasing the number of operations on runway 07/25 by 20% led to an average increase in NEF values of approximately 0.5 dB. At Ottawa and Montreal, increasing the number of operations on one runway (07/25 at Ottawa and 06R/24L at Montreal) led to very small decreases in average NEF values (see Figures 5.5, 5.6, and 5.7). Similarly, the contour areas change more for the Windsor airport example, as illustrated in Figures 5.8, 5.9, and 5.10. At Windsor, the 20% increase in the use of one runway led to increases in contour areas of between 6 and 9%. At Ottawa and Montreal, areas increased slightly or decreased by amounts of up to 3%.

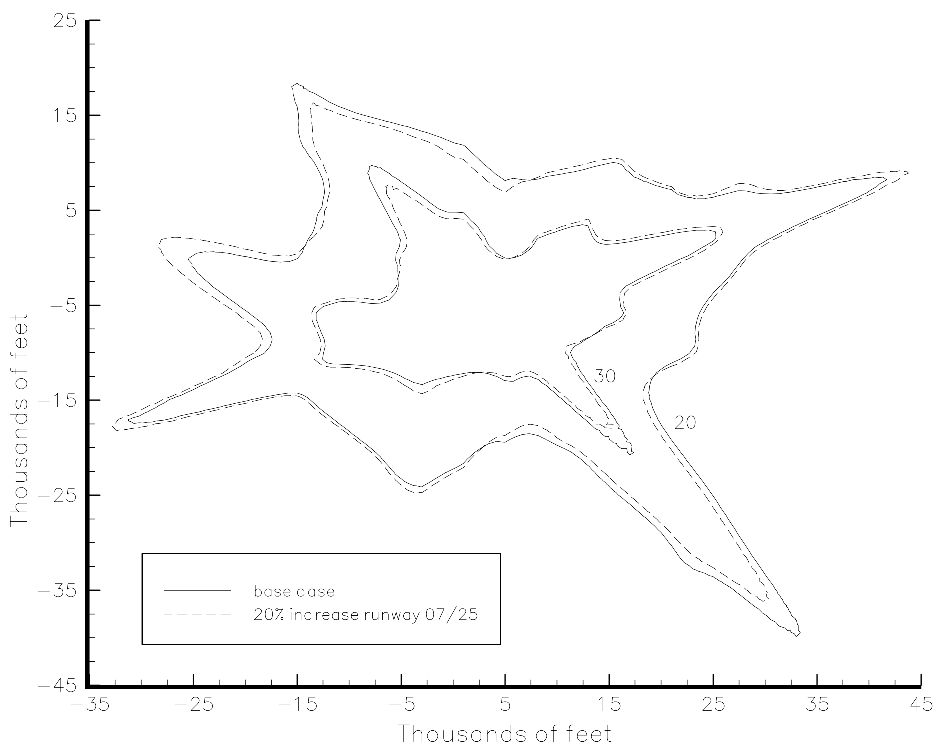


Figure 5.12: Example of changes in calculated contours when the number of operations on runway 07/25 were increased by 20% at Ottawa airport.

Looking at only the average effects of increasing operations on one runway can be misleading. Noise levels and contours should increase near the one runway but decrease near the other runways. Figure 5.12 is an example for Ottawa airport of the effect of a 20% increase in the use of one runway. At particular points, NEF values would change by approximately 1 dB. At some locations there would be increases and at others there would be decreases. Thus, for particular residents the effect of a 20% change in runway use could be similar in magnitude to a 20% error in the total number of operations.

5.7 Summary

Overall, the various types of errors in input data were seen to produce changes in average NEF values and contour areas that varied in detail with the NEF contour and the airport. Errors in the expected number of total aircraft operations per PPD produce the largest errors in NEF values and contour areas. Errors in the total number of operations would typically lead to errors of 1 NEF unit or approximately 12% in contour areas. These errors are at least double the magnitude of other possible sources of errors. However, errors from this source could on occasion be a little larger (up to 1.5 NEF units and 16% changes in contour area).

Errors in estimating the various input data values would be expected to be independent of each other. Thus, it would be very unlikely that combinations of errors would combine to produce very much larger total errors. That is, one input data error might lead to an increase in NEF values while another might lead to decreases. It is difficult to estimate the combined effect of the various input errors because in most cases we have no information on how likely they are to occur. The upper limit for the effects of errors in the total number of operations given above (up to 1.5 NEF units and 16% in contour area) probably represents a reasonable estimate of the maximum likely errors.

REFERENCE

1. International Civil Aviation Organization, “International Standards and Recommended Practices - Aircraft Noise, Annex 16” (1971).

6.0 EFFECTS OF DETAILS OF THE CALCULATION PROCESS

Many details of computer prediction programs such as the NEF_1.7 program are intended to approximate the actual movements of aircraft and the radiation of noise from them. For example, one can only approximate the nominal flight path of a particular aircraft. Similar aircraft following the same nominal path will in practice deviate from this nominal path. The different computer programs have different levels of complexity for approximating the nominal path of an aircraft and typical deviations from this path. The stage length influences the take-off weight of an aircraft which also affects its rate of climb and hence the resulting noise contours. Each computer program includes different approximations to model these effects. When an aircraft is close to the ground, the interaction of the sound with the ground causes an attenuation of the sound propagating away from the aircraft. This complex phenomenon is usually modeled by quite simple approximations in airport noise prediction programs.

This Chapter considers the details of a number of these approximations. Their influence is examined in terms of the resulting changes to calculated noise contours. Thus, the differences between the three prediction programs compared in Chapter 4 (NEF_1.7, INM, NoiseMap) are examined using further more specific comparisons.

6.1 Turn Rate Versus Turn Radius

After taking off, most aircraft turn to follow a path towards their destination. In the NEF_1.7 program, these turns can be specified in two different ways: (1) in terms of a turn rate (e.g. in degrees per second) as originally specified in the input data, or (2) in terms of a turn radius. If the turn radius approach is used, then the aircraft path in the turn follows part of a circle with a specified radius. If the speed of the aircraft is increasing during a turn, then its path will probably be better approximated by the turn rate procedure. Using this technique, the radius of the turn will increase as the aircraft speed increases.

The two American programs describe turns in terms of a turn radius. Thus, to perform the comparisons in Chapter 4, all turn rate information had to be converted to turn radius values. In this section, the effect of these approximate conversions are examined. These results give an indication of the importance of the turn specification procedure on the resulting noise contours.

The effects of these two possible procedures were examined by re-calculating the Windsor and Ottawa airport data for both procedures.

Figure 6.1 compares NEF 20 contours at Windsor airport for both turn calculation procedures. For this airport, there was a significant change to one part of the NEF 20 contour. To help explain this change, several flight tracks are also plotted on this graph for both turn procedures. For some aircraft, the flight tracks in this figure deviate significantly between the turn-rate and turn-radius calculation procedures and cause differences in the calculated contours. However, for most aircraft the two procedures lead to very similar flight tracks.

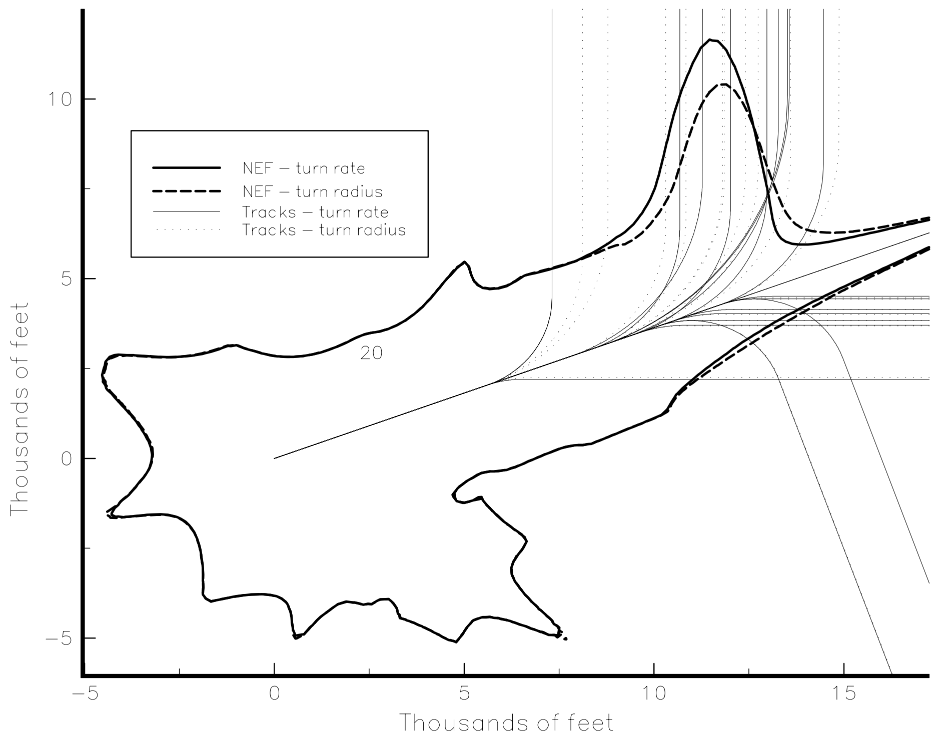


Figure 6.1: Comparison of NEF 20 contours for aircraft turns according to the turn radius, or turn at specified rate procedures for Windsor airport using the NEF_1.7 program.

Similar comparisons were made for the Ottawa airport data. The resulting NEF contours showed only very small differences that would not be of any practical significance. For both airport examples, the average change in NEF values and the average change in contour areas were very small.

The turn calculation procedure seems to be potentially more influential at smaller airports. Thus, when comparing different prediction programs at smaller airports, it is particularly important to use the same turn calculation procedure. The turn-rate procedure that is only implemented in the NEF_1.7 program would appear to be inherently more correct.

6.2 Turn at a Distance Versus Turn at an Altitude

There are also different procedures for deciding when a turn is to be initiated. The turn can be initiated either: (1) after a particular distance, or (2) when the aircraft reaches a particular altitude as in the original data. To examine the effects of these two different procedures, calculations using the NEF_1.7 program were repeated using both procedures at Windsor and Ottawa airports, by using average conversions for each flight track.

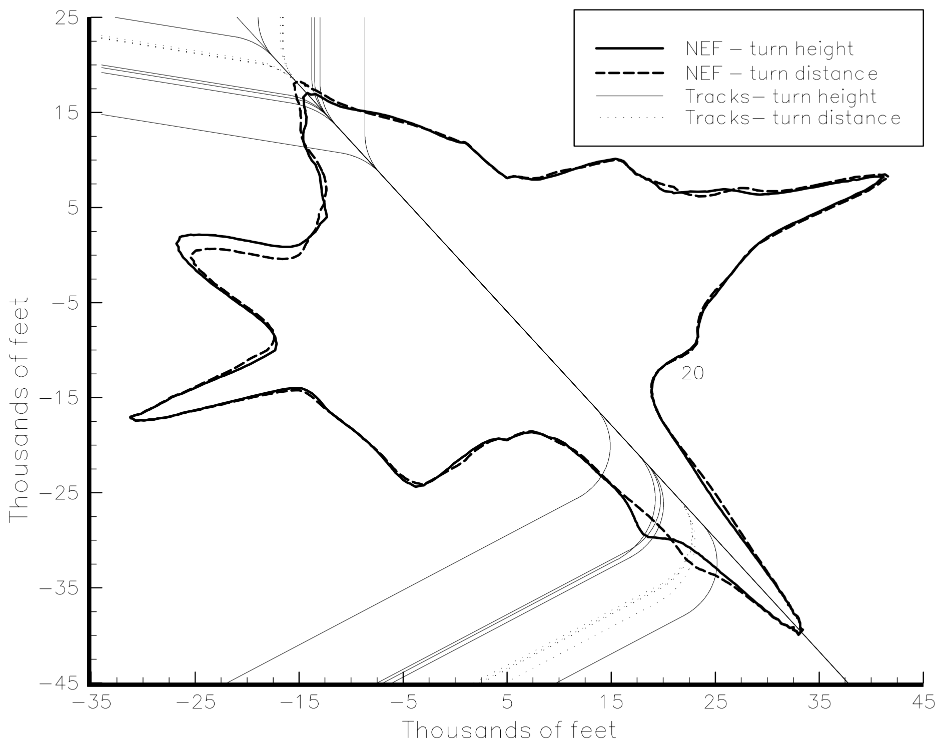


Figure 6.2: Comparison of NEF 20 contours at Ottawa airport for aircraft turns: at a specified distance, or at a specified altitude using the NEF_1.7 program.

At both airports small changes in the noise contours were observed. As an example, Figure 6.2 illustrates the Ottawa airport results for the calculated NEF 20 contours. Some selected flight tracks are also shown to help explain the cause of the changes in the NEF 20 contours. While some flight tracks changed, many did not.

At both airports the average changes in NEF values and NEF contour areas were very small. Thus, there was no average change of practical importance, but there were localized changes in the contours which could be important to specific groups of residents near airports. Again, when comparing programs it is important to use exactly the same calculation procedure.

The choice of procedure must depend on which method best approximates real flight conditions. An additional advantage of the turn at a specific altitude procedure is that it tends to increase the horizontal dispersion of the flight tracks. This is because different aircraft, or the same aircraft for different stage lengths, climb at different rates and reach a particular altitude at different distances from the start of take-off.

6.3 Horizontal Dispersion

Most prediction programs assume that all aircraft exactly follow the nominal flight track. In actual practice, aircraft deviate from the nominal track and in some cases the deviations can be quite large [1,2]. Figure 6.3 shows radar tracks of aircraft at Zurich airport. There is clearly quite a wide dispersion about the flight tracks at this airport. Similar results are to be expected at other airports, but are usually not published.

Figure 6.3: Radar flight tracks at Zurich airport showing the horizontal dispersion of flight tracks.

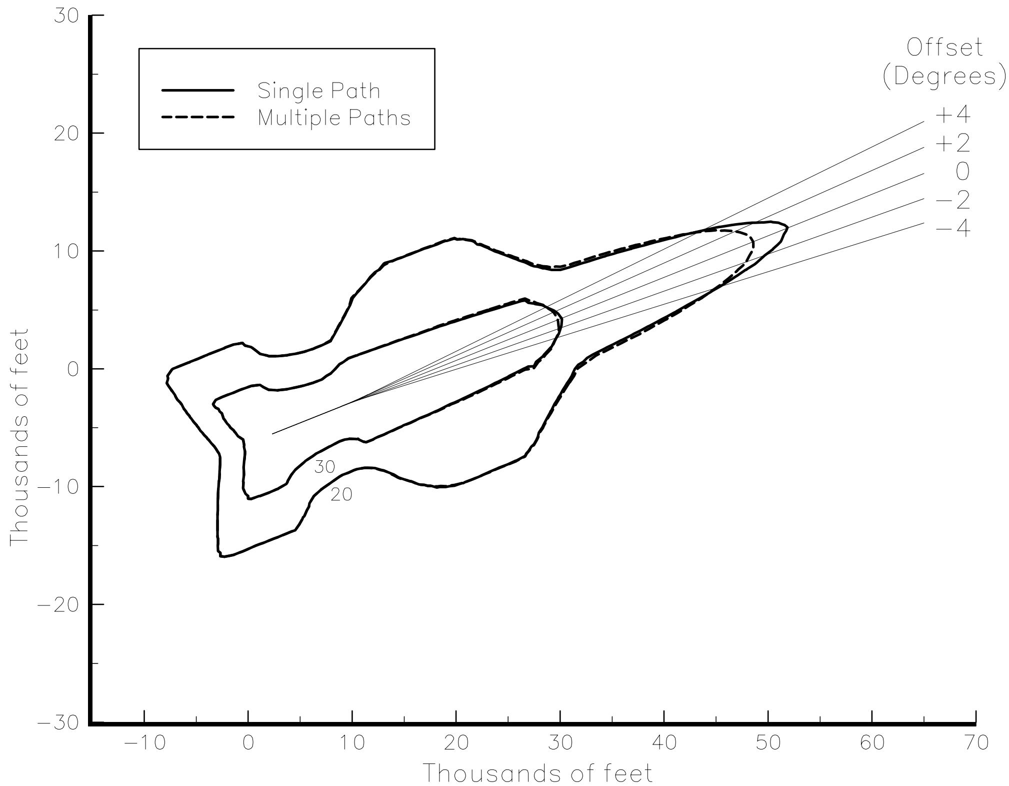


Figure 6.4: Calculated NEF 20 and 30 contours for 100 take-offs of a 727-200 aircraft with and without simulated horizontal dispersion up to ±4°.

Horizontal dispersion of aircraft flight tracks will systematically change the shape of the resulting noise level contours. To illustrate these effects, NEF contours were calculated for 100 aircraft of the same type (727-200/JT8D15) taking off on a straight departure path without turns. Then, to simulate horizontal dispersion the contours were re-calculated with the same aircraft distributed over five different flight tracks. The central track of the five was the original straight track; the others were displaced a small amount either side of this central straight track. Figure 6.4 illustrates the results when the side tracks were spread up to 4 degrees either side of the centre straight path. Figure 6.5 shows the effect of wider horizontal dispersion with the side tracks up to 8 degrees either side of the centre straight track.

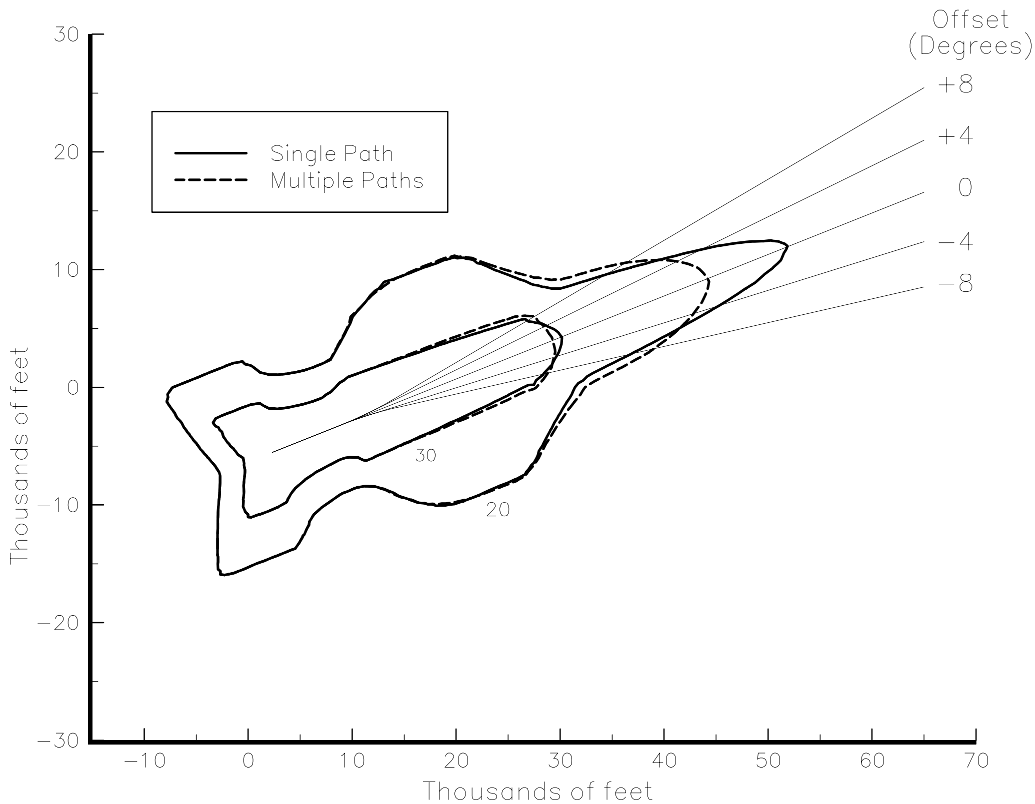


Figure 6.5: Calculated NEF 20 and 30 contours for 100 take-offs of a 727-200 aircraft with and without simulated horizontal dispersion up to ±8°.

As one would expect, added horizontal dispersion causes levels to decrease under the central flight track and to increase at points to the side of the centre straight track. The changes to the NEF contours will depend on the amount of horizontal dispersion in the flight tracks, but it is clear that the NEF 20 contours could easily move by several thousand feet. However, the impact is smaller for the contours commonly used for land-use planning, such as NEF 30. In Figure 6.4, the end point of the contour under the central flight track moves by approximately 3000 ft. In Figure 6.5, the same point moves approximately 8000 ft. when horizontal flight track dispersion is simulated.

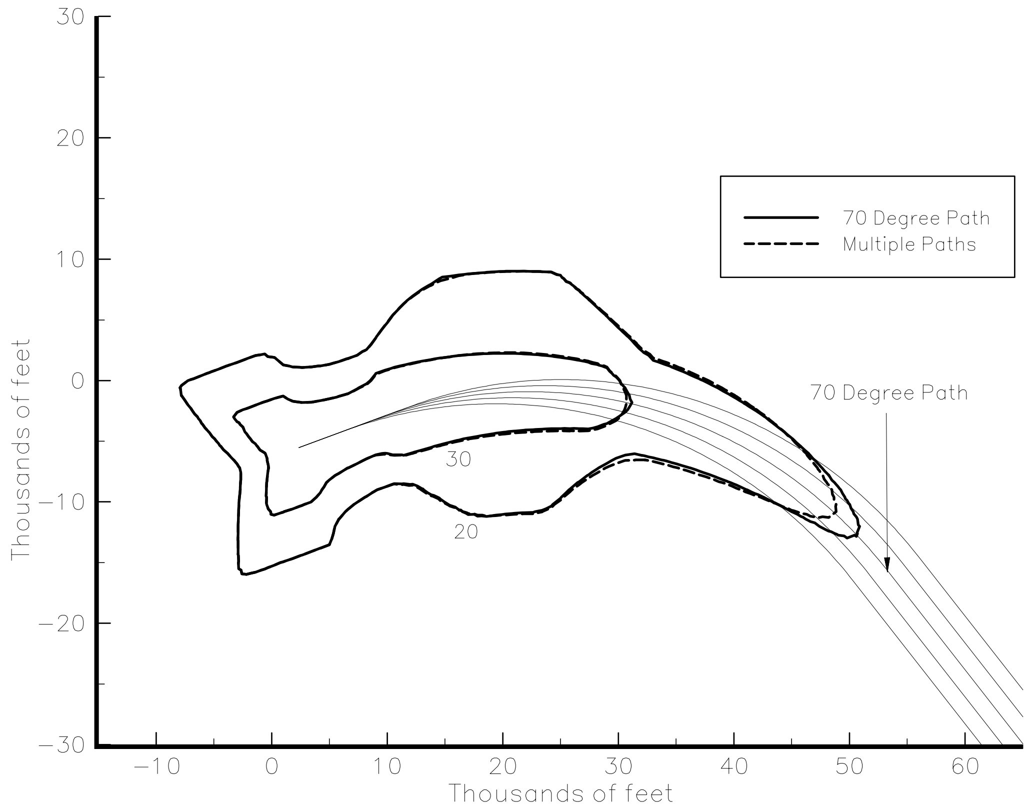


Figure 6.6: Calculated NEF 20 and 30 contours for 100 take-offs of a 727-200 aircraft with and without simulated horizontal dispersion for a flight track with a 70° turn.

Figure 6.6 illustrates the effect of added dispersion for a turning flight track. The amount of horizontal dispersion in this figure is relatively small and the results are similar to Figure 6.4. Much greater dispersion could occur on turning flight tracks if the turns were initiated at slightly different distances from the start.

Horizontal dispersion appears to be an important factor that should be included in airport noise prediction programs. None of the three programs used in this study (NEF_1.7, INM, and NoiseMap) include horizontal dispersion. Some programs in other countries do include horizontal dispersion [3].

6.4 Flight Profiles and Vertical Dispersion

In addition to specifying the horizontal flight track of each aircraft, one must also describe the vertical profile of each take-off. The INM program database has quite detailed, up to 10 segment, vertical profiles for each aircraft type by stage length. NoiseMap has similar detailed profiles. The NEF_1.7 program uses simplified profiles that are three segment approximations to the INM profiles.

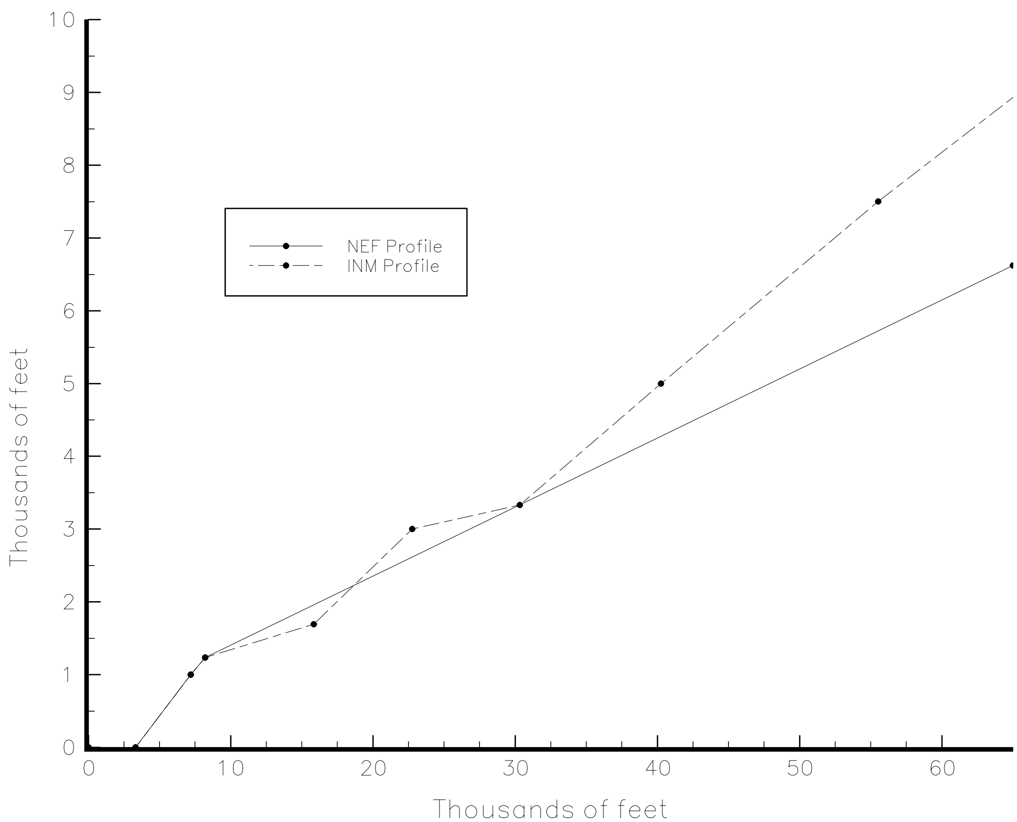


Figure 6.7: Comparison of vertical take-off profiles for a 767-CF6 aircraft for the INM and NEF_1.7 programs.

Figure 6.7 and 6.8 compare the three-segment profiles for the NEF_1.7 program with the more detailed profiles from the INM program. Figure 6.7 compares the vertical profiles for a 767-CF6 aircraft for a stage length 1 take-off profile. The NEF_1.7 profile is a good approximation to the more important initial part of the take-off but becomes increasingly less accurate to the right of this figure. Figure 6.8 gives a similar comparison for a 747-SP aircraft for a stage length 1 take-off profile.

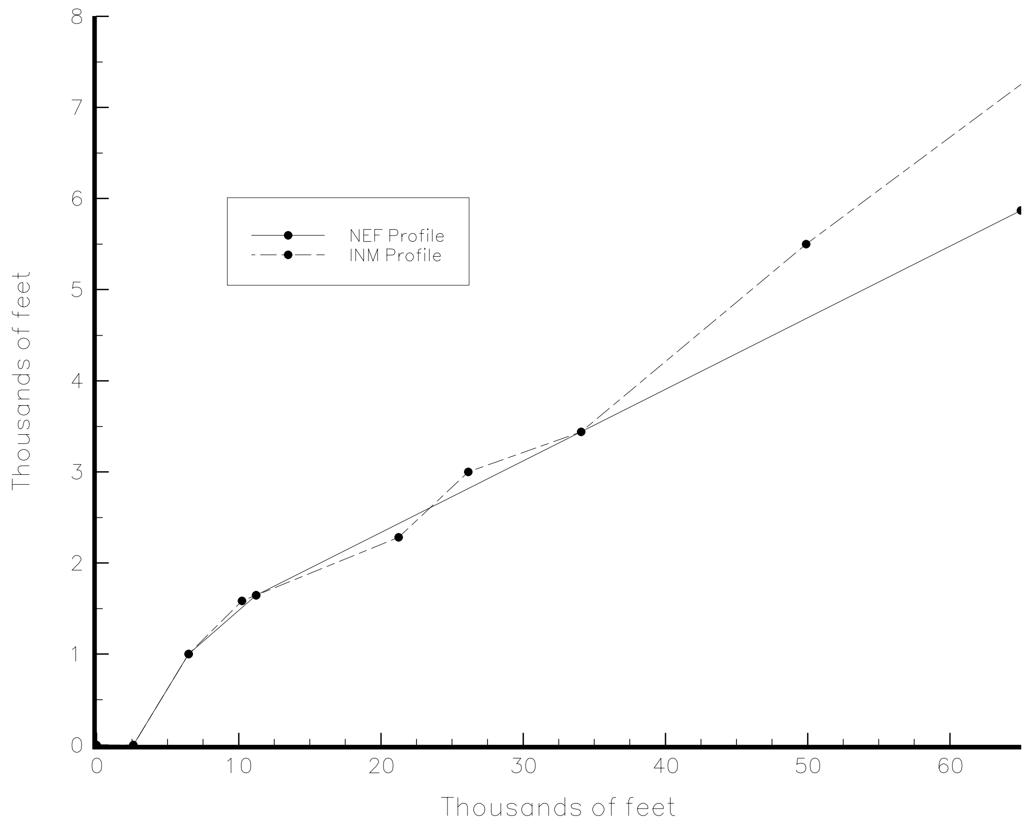


Figure 6.8: Comparison of vertical take-off profiles for a 747-SP aircraft for the INM and NEF_1.7 programs.

In these two figures, the INM take-off profiles are too complicated to be accurately modeled with a three-segment profile. It is important to most accurately represent the profile for the initial parts of the take-off. At this part of the take-off, the aircraft is closer to the ground and therefore is producing higher sound levels on the ground. The NEF_1.7 approximations do this well. However, as illustrated in these two figures, they do not always accurately represent the later parts of the take-off profile. Thus, at points further from the runway, there will be significant errors in noise levels. In Figure 6.7, at a distance of 60,000 ft from the start of the runway, the aircraft height is 8,200 ft according to the INM profile and only 6,100 ft according to the NEF_1.7 profile. Directly under the flight track at this distance, one can calculate an expected difference in maximum sound levels of 2.5 dB between the two profiles.

One could also consider vertical dispersion in the take-off profiles similar to the horizontal dispersion in the previous section. To some extent this is included by the different profiles for different stage lengths. (This is discussed further in section 6.7.)

The two examples given here show that three-segment take-off profiles cannot always accurately represent the more detailed profiles of actual take-offs. Where these errors occur, sound levels from these particular aircraft can be significantly in error. It was not possible to compare take-off profiles for all aircraft included in these computer programs, and so it is not possible to say how frequently these errors occur. Adding even one more segment to the take off profiles used by the NEF_1.7 program could considerably reduce these differences in take-off profiles.

6.5 Grid Spacing and Orientation

The NEF_1.7 program can calculate NEF values for a grid of up to 100 by 100 points. Of course, choosing a grid of fewer and more widely spaced points would speed up the calculations. However, one must decide how coarse a grid can be used without degrading the accuracy of the results. To check the effect of grid spacing, the NEF contours for Windsor and Ottawa given in Chapter 4 of this report were re-calculated with double the original grid spacing. NEF contours were originally calculated for Windsor airport with a 250 ft grid spacing. These calculations were repeated with a 500 ft grid spacing. Similarly, the Ottawa airport contours were re-calculated with a 2,000 ft grid spacing in place of the original 1,000 ft spacing. Figure 6.9 illustrates the two sets of contours for Ottawa airport.

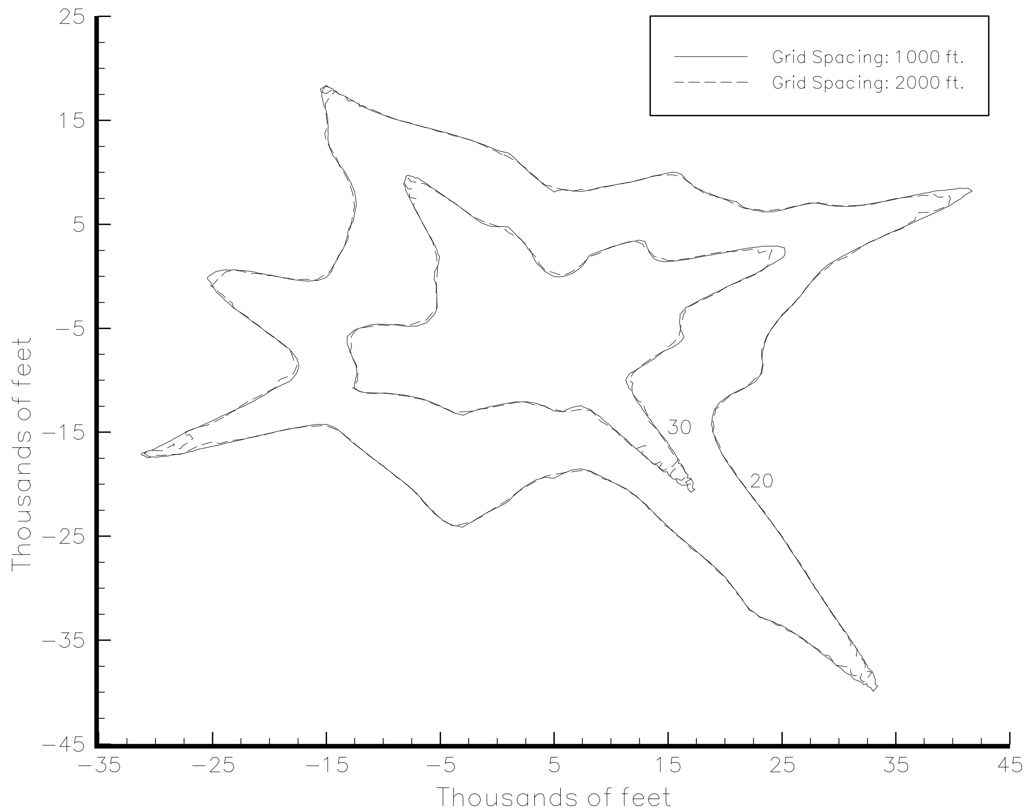


Figure 6.9: Comparison of NEF 20 and 30 contours at Ottawa airport for grid spacings of 1,000 and 2,000 ft without contour smoothing.

For both airports, the contours with the increased grid spacing included some small irregularities from their originally smooth shapes. However, these were relatively minor and the contour areas did not change significantly. One could probably minimize these irregularities by introducing some smoothing into the calculation of the contours. This would, of course, produce other small changes in the contour shapes and so was not done in this study.

Changing the grid spacing of the points at which NEF values are calculated therefore has no systematic effect on the overall contour shapes. If the grid spacing is too large, some small irregularities will be introduced into the contour fitting process.

It had been suggested that the noise prediction program results might vary with the orientation of the airports relative to the grid of calculation points. This proved to be completely false. Calculations of the Windsor and Ottawa airports cases were repeated with the airport runways rotated 45 degrees from the actual positions. Exactly the same

NEF contours were produced with exactly the same contour areas for the NEF_1.7, INM and NoiseMap programs.

6.6 Ground Attenuation

Predicting the attenuation of aircraft noise propagating close to the ground is one of the more difficult and more important problems associated with airport noise prediction programs. It is probably the major cause of differences between the NEF_1.7 program and the INM and NoiseMap programs. Excess ground attenuation is included in sound level predictions when the aircraft is close to the ground. For these situations, aircraft noise is considerably attenuated due to the interaction of the propagating noise with the ground surface. In detail it is a very complex phenomenon including the interaction of spherical sound waves from the aircraft and the complex acoustical impedance of the ground as well as meteorological effects.

The combination of the direct sound and the ground reflected sound result in a complex frequency response that will change from moment to moment as the aircraft moves. The whole process is further complicated by meteorological effects that will become increasingly important at larger distances from the source. That is, wind and temperature gradients will cause sound waves to propagate in curved and not straight lines. Further, turbulence in the air will tend to reduce the interference effects when direct and ground-reflected paths are combined. The problem is further complicated by the fact that the aircraft is moving and most aircraft noise measures are an integration over a complete pass-by of the aircraft. Thus, one is interested in the attenuation of the total integrated noise energy from the complete fly-by.

Airport noise prediction programs use various procedures to approximate these complex phenomena. They calculate the attenuation in excess of the normal decreases due to spherical spreading of the noise energy with increasing distance from the source. Often the problem is broken up into separate ground-to-ground propagation and air-to-ground propagation algorithms. Approximate relationships are produced for each case and a procedure for combining them allows the inclusion of intermediate situations. Frequently the differences between the attenuation with distance from a single fixed source and the attenuation with distance of the integrated noise measures are ignored.

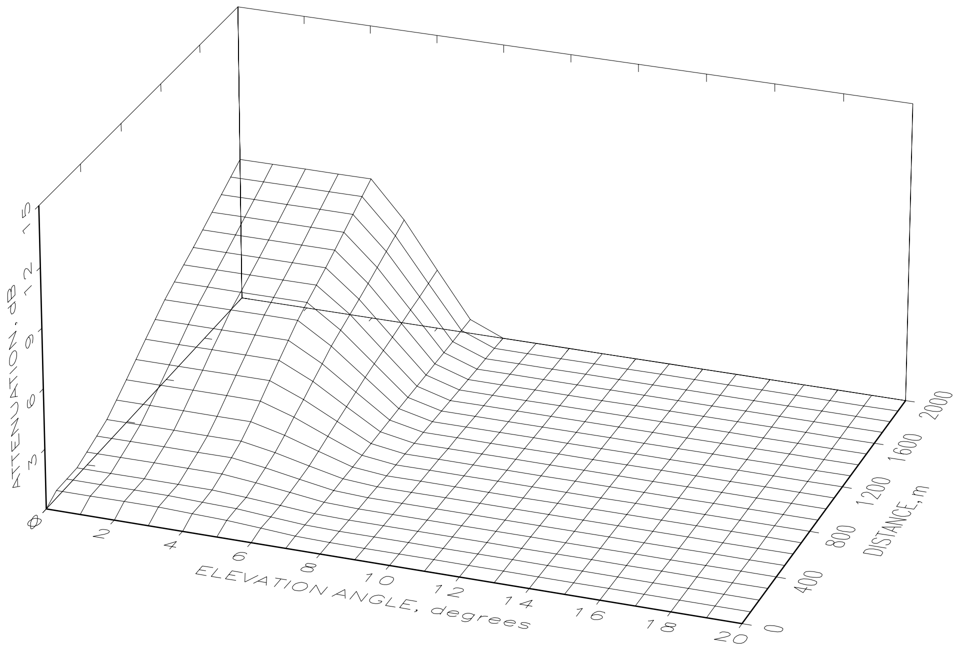


Figure 6.10: Excess ground attenuation incorporated in the NEF_1.7 program as a function of both distance and the elevation angle.

6.6.1 NEF_1.7 Method

The ground-to-ground excess attenuation included in the NEF_1.7 program [4] is illustrated by the 0 degree elevation angle line of Figure 6.10. This attenuation increases with distance from close to 0 dB to approximately 7 dB at a distance of 2,000 m. This attenuation is completely applied for locations where the vertical elevation angle of the aircraft is no greater than 4.3°. For vertical elevation angles of greater than 7.2°, excess ground attenuation is assumed to be zero. For angles between 4.3° and 7.2°, the excess ground attenuation is determined by linear interpolation between the 4.3° and the 7.2° cases for the particular distance in question. The combined effects of both distance from the flight track and the elevation angle of the aircraft are shown in Figure 6.10.

6.6.2 SAE Method

The SAE procedure [5] is used in the current versions of both the INM and NoiseMap programs. (In NoiseMap, the SAE procedure is only used for civil aircraft.) There are again separate algorithms for the excess attenuation for over-ground propagation (i.e. the ground-to-ground propagation case) and for air-to-ground propagation. Again, these are the excess attenuation in addition to inverse square law spherical spreading. For cases where both the source and receiver are on the ground, only ground-to-ground attenuation is considered. At larger distances when the aircraft is in the air, only the air-to-ground attenuation needs to be considered. For intermediate conditions, both attenuations can be combined.

For ground-to-ground attenuation with source-to-receiver distances of up to 904 m (3000 feet), the following equation is used to predict excess attenuation as a function of distance, l, in metres,

$$G(l) = 15.09 \bullet (1 - e^{-0.00274 \bullet l}), \text{ dB} \qquad [6.1]$$

For distances greater than 904 m., G(l) = 13.86 dB.

This relationship is largely based on Parkin and Scholes [5] measurements of the noise from a fixed ground based jet engine. It does not represent the attenuation from a moving source and the original data will not represent the noise spectra of modern high by-pass ratio jet engines. The procedure is applied identically to both SEL and EPNL values.

When the source is above the ground, the resulting excess attenuation depends on the source height. For elevated sources and large source-to-receiver distances, the following equation relates excess attenuation to the elevation angle, β, of the source,

$$A(\beta) = 3.96 - 0.066 \bullet \beta + 9.90 \bullet e^{(-0.13 \bullet \beta)}, \text{ dB} \quad \text{where } 0° \le \beta \le 60° \qquad [6.2]$$

For larger angles $A(\beta) = 0$ dB.

Equations 6.1 and 6.2 are based on curve fits to measured data for these specific limiting conditions. For the more general case (the transition region), little data were available and the following is assumed to represent the combined attenuation.

$$A(\beta,l) = (G(l) \bullet A(\beta))/13.86, \text{ dB} \qquad [6.3]$$

This combined ground attenuation is illustrated in Figure 6.11 as a function of both distance and vertical elevation angle. Equation 6.1 above is illustrated by the 0 degree elevation angle line on this plot. Equation 6.2 is illustrated by the line at a constant distance of 2000 m.

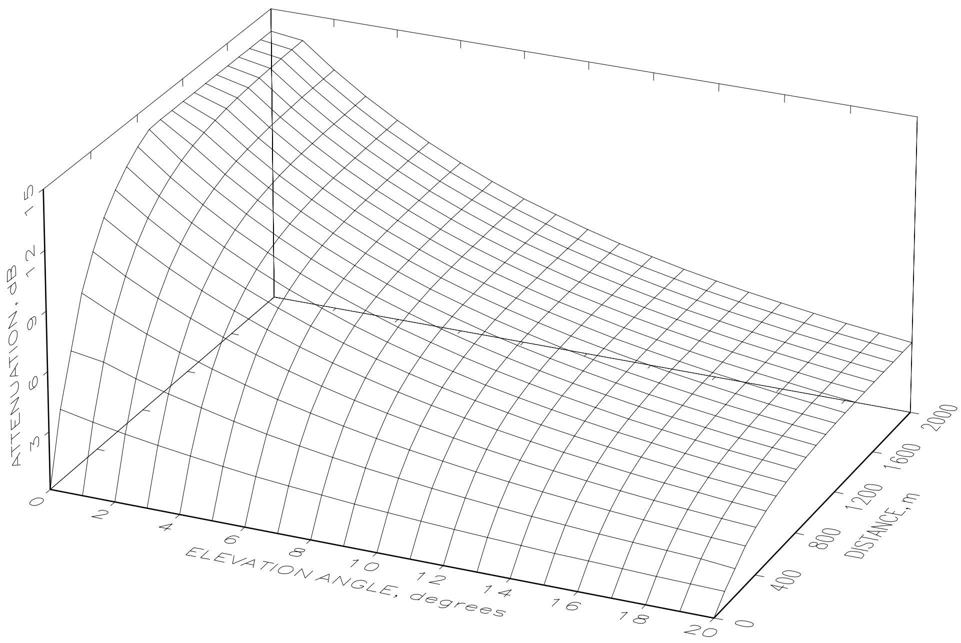


Figure 6.11: Excess ground attenuation using the SAE procedure incorporated in the INM program as a function of both distance and the elevation angle.

The SAE procedure is limited for several reasons. It is based on curve fits to old measured data of aircraft spectra that would not represent modern high by-pass ratio jet engine noise spectra. There is little experimental verification that equation [6.3] correctly predicts the combined effects. There seems to be little evidence concerning the accuracy of representing the excess ground attenuation of both SEL and EPNL by the same equations. It is not clear how the fixed source attenuations of Parkin and Scholes have been adapted to integrated measures of a complete aircraft pass-by. Integrated levels such as SEL should vary with distance more like sound levels from a line source rather than those from a single fixed source. Thus, one would expect SEL values to vary less rapidly with distance than the levels from a single fixed source.

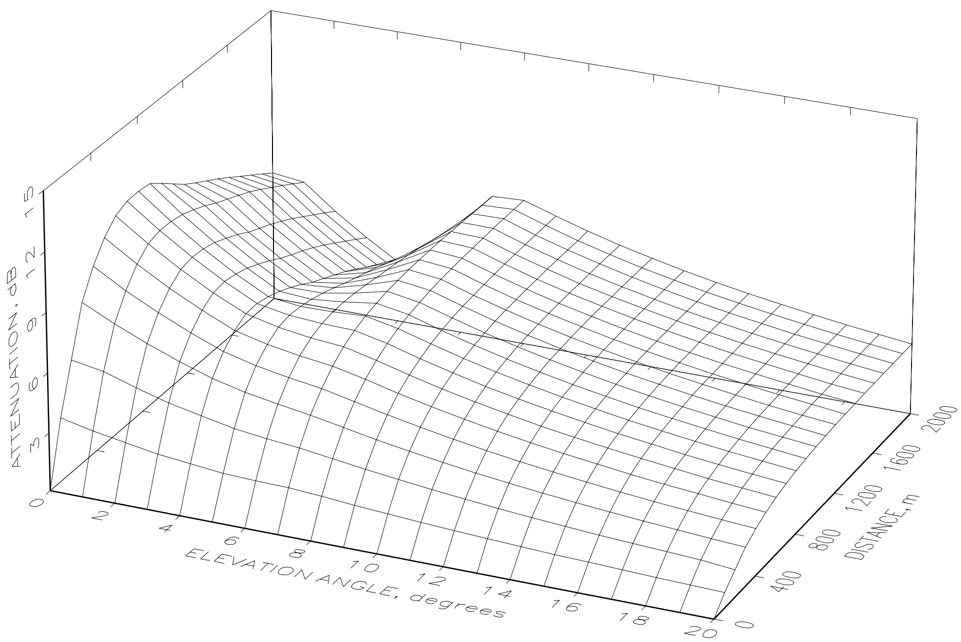


Figure 6.12: Difference in excess ground attenuation between the INM and NEF_1.7 programs (INM - NEF_1.7) as a function of both distance and the elevation angle.

6.6.3 Comparison of the NEF_1.7 and SAE Methods

The SAE procedure leads to considerably greater excess ground attenuation than the procedure in the NEF_1.7 program. Figure 6.12 illustrates these differences as a function of both distance and angle of elevation of the aircraft. Differences as large as 11 dB are found in this figure. The average difference for all distances and angles shown in this figure is 4.85 dB (i.e. distances of 0 to 2000 m and angles of 0 to 20 degrees). If one includes all elevation angles up to 60 degrees, the average difference reduces to 2.45 dB. From figure 5.3 one can estimate that a 3 dB change in NEF could lead to errors of over 50% in the area of an NEF 30 contour. Larger differences are readily possible between the two procedures. Figure 5.3 indicates that a larger area change would result for a 3 dB change of the NEF 35 contour. In regions where smaller elevation angles predominate, the differences in resulting NEF values could be considerably greater than 3 dB and hence the related contour area differences would also be much greater. Thus, the differences in the two excess ground attenuation algorithms easily explain most of the differences observed between the contours from the three programs compared in Chapter 4.

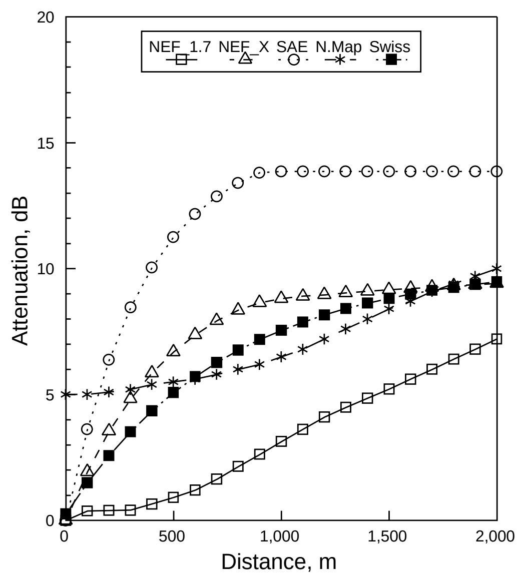


Figure 6.13: Comparison of excess ground-to-ground attenuation from several sources.

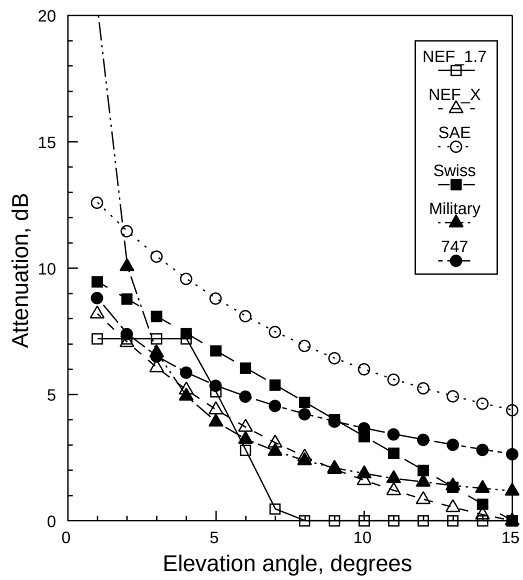


Figure 6.14: Comparison of excess air-to-ground attenuation from several sources.

6.6.4 Comparisons with Other Results

(a) Proposals by Transport Canada

Work by Kelly and Nitschke at Transport Canada [4] produced a suggestion for changing the excess ground attenuation procedure in the NEF_1.7 program. Although this work was most concerned with producing a better ground-to-ground attenuation algorithm, it also introduced a modified air-to-ground calculation. The modified ground-to-ground attenuation was based on an average of three different results. One was the calculated attenuation for one aircraft type at 125 Hz from the ISO attenuation procedure. The other two were modifications of the SAE and Noise Map procedures that approximated downwind conditions. The resulting average curve is shown in Figure 6.13. For the air-to-ground attenuation, the SAE relationship (equation 6.2) was used by subtracting 4.4 dB from it so that at large distances it matched the ground-to-ground attenuation. This curve is shown in Figure 6.14.

(b) Old Noise Map

Figures 6.13 and 6.14 also show the relationships that were used in older versions of NoiseMap. In Figure 6.13, the old NoiseMap curve indicates more attenuation with distance than the NEF_1.7 curve. The old NoiseMap variation of excess ground attenuation with elevation angle is exactly the same as the current NEF_1.7 program, shown in Figure 6.14.

(c) Comparisons with Measurements

There is very little experimental data of excess ground attenuation for modern commercial aircraft with high by-pass ratio jet engines. However, one study [6] made extensive measurements of the excess ground attenuation of the noise from a Boeing 747 aircraft. The best fit relationship to measured EPNL levels from this study is also included in Figure 6.14. The measurements of the excess ground attenuation versus elevation angle for the Boeing 747 aircraft were similar for both A-weighted and PNLT-weighted measures with the PNLT attenuations approximately 0.5 dB less. The attenuation versus angle was larger for EPNL values of the Boeing 747 pass-by but this difference was not discussed.

The measured excess attenuation data of the Boeing 747 aircraft were less than the SAE procedure curve (equation 6.2) by 2 to 4 dB depending on the elevation angle. Thus, noise contours produced using the SAE procedure (e.g. using the INM program) would be much smaller than the Boeing 747 aircraft measurements would suggest are correct. The Boeing 747 measured data are closer to the curve suggested by Kelly and Nitschke (see Figure 6.14). For some angles, the current procedure in the NEF_1.7 program would reasonably approximate the measured data.

(d) Comparisons with Measurements of Military Aircraft

Recent results by Speakman and Berry [7,8] from measurements of military aircraft produced a different air-to-ground attenuation curve as a function of the vertical elevation angle, β,

$$\text{Attenuation} = 20.49/\beta - 0.1818, \text{ dB} \qquad [6.4]$$

This equation is recommended to be used for vertical angles from 1 to 45 degrees and is the curve labeled 'Military' on Figure 6.14. For less than 1 degree, an excess attenuation of 20.3 dB is recommended. There is no suggestion that this applies to civil aircraft. This equation was a best fit curve to data from both the U.K and the U.S.A. and there was considerable scatter about this best fit line. For angles of 2 degrees and larger, it is similar to the Boeing 747 measurements and the NEF_X curve.

(e) Swiss Model

Another excess ground attenuation calculation procedure has been recently developed in Switzerland [9]. It is similar to the procedure used in Germany. An excess ground attenuation equation was developed empirically from a large number of aircraft pass-by recordings at Zurich airport. The following equation was obtained for attenuation as a function of both elevation angle, β, and distance, l,

$$A(\beta,l) = (1-3.8637 \bullet \sin(\beta)) \bullet (10.1451-9.90 \bullet e^{(-0.00134 \bullet l)}), \text{ dB} \qquad [6.5]$$

This equation is also included in Figures 6.13 and 6.14. In Figure 6.13, the excess ground attenuation calculated using equation [6.5] is plotted versus distance for an elevation angle of 0°. The result of the Swiss equation is very similar to the Kelly and Nitschke suggestion for ground-to-ground attenuation and is intermediate to the SAE procedure and to the procedure in the current NEF_1.7 program. A curve of ground-to-ground attenuation versus distance used in Germany [10] is very similar to this Swiss curve.

In Figure 6.14, the results of equation 6.5 are plotted for a distance of 2,000 m versus elevation angle. The result is a straight line decreasing from about 10 dB at an angle of 0° to 0 dB attenuation at 15°. Again, the Swiss procedure yields lower attenuation than the SAE method and it is also a good approximation to the measured data for a 747 aircraft.

There is a growing consensus that the attenuation of the SAE procedure is larger than found from measurements. The suggestion by Kelly and Nitschke and the Swiss and German methods are closer approximations to the Boeing 747 data than the SAE procedure and would lead to excess ground attenuations that are 2 to 4 dB less than the SAE procedure. Again, Figure 5.3 can be used to estimate that this would lead to very large differences in contour areas.

6.6.5 Effect of Ground Attenuation on Single Aircraft Contours

Calculated noise contours for a single aircraft type on a simple straight take-off path were compared to illustrate the effects of the different ground attenuation algorithms. It was assumed that the difference in ground attenuation calculation procedures was the major difference between the prediction programs. Contours were generated using the INM program, NoiseMap, and the NEF_1.7 program. In addition, an experimental version of the NEF program incorporating Kelly and Nitschke's suggestions was also used. This NEF_X program was said to be identical to the NEF_1.7 program except for different ground attenuation and aircraft directivity algorithms.

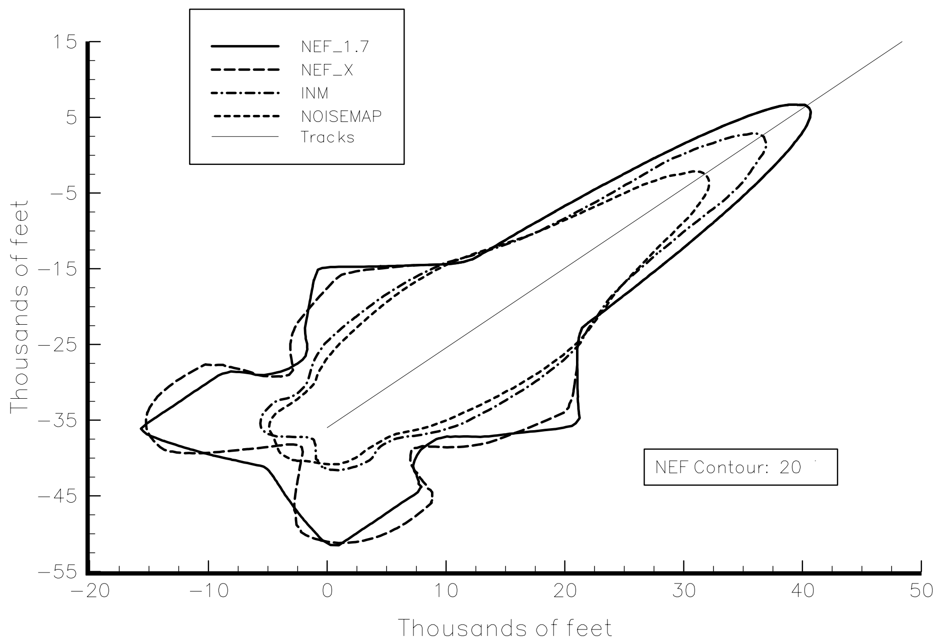


Figure 6.15: Comparison of NEF 20 contours for 100 take-offs of a 737-D17 aircraft for four different computer programs incorporating different ground attenuation calculations.

Figure 6.15 compares the calculated NEF 20 contours from the four prediction programs for 100 operations of a 737-D17 aircraft. The areas of these NEF 20 contours, as well as those of the NEF 25, 30, 35, and 40 contours are shown in Figure 6.16. From these two figures the NEF_1.7 and NEF_X programs are seen to produce similar area contours which are larger than the contours produced by the INM and NoiseMap programs.

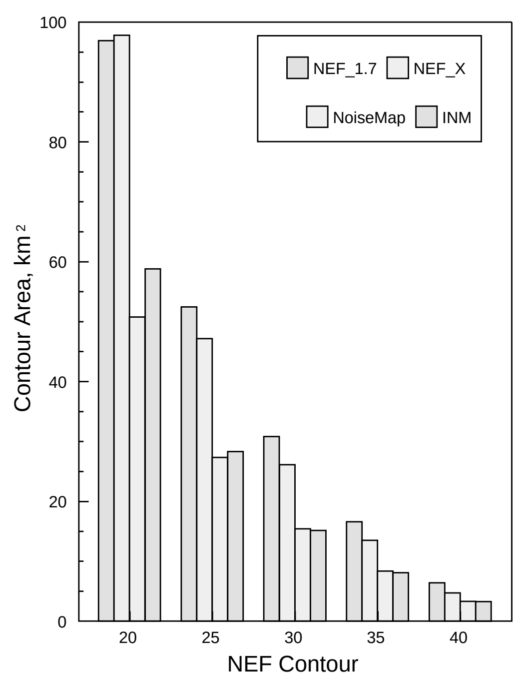


Figure 6.16: NEF contour areas for 100 take-offs of the 737-D17 aircraft calculated by four computer programs.

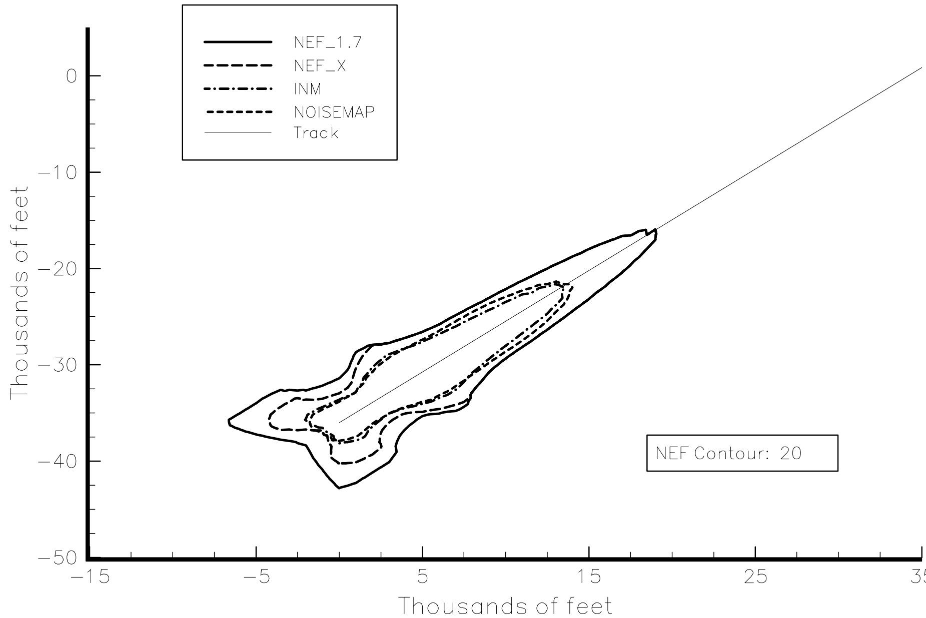


Figure 6.17: Comparison of NEF 20 contours for 100 take-offs of a 767-CF6 aircraft for four different computer programs incorporating different ground attenuation calculations.

Similar comparisons were made for 100 operations of a 767-CF6 aircraft. Figure 6.17 compares the four calculated NEF 20 contours and Figure 6.18 compares the areas of five different NEF contours. Here the NEF_1.7 program again produced larger area contours than the INM and NoiseMap programs. However in this case the NEF_X program produced contours with areas intermediate to the larger NEF_1.7 contours and the smaller INM and NoiseMap contours.

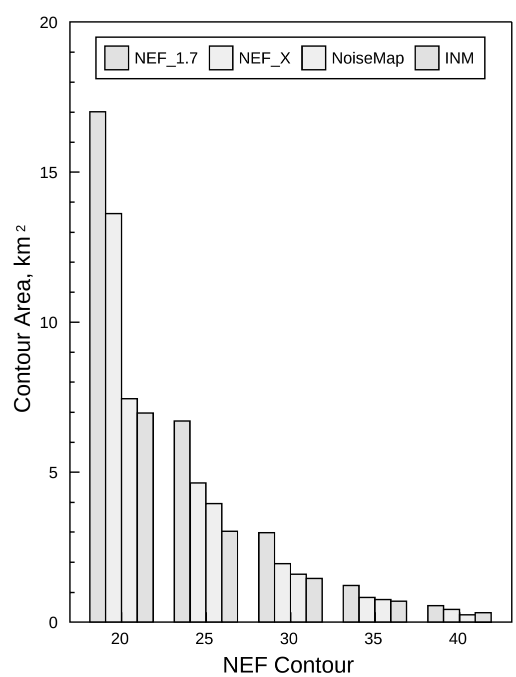


Figure 6.18: NEF contour areas for 100 take-offs of the 767-CF6 aircraft calculated by four computer programs.

For both the 767-CF6 and 737-D17 aircraft examples the NEF_1.7 contours were approximately double the area of the INM and NoiseMap contours. The NEF_X contours were approximately 40 to 60% larger in area than the INM and NoiseMap contours. However, when these results are examined in detail there are a number of differences on the effects of ground attenuation on contours, between aircraft types and among the computer prediction programs.

6.6.6 Effect of Ground Attenuation on Overall Airport Contours

Because the NEF_1.7 and NEF_X programs are the same except for differences in ground attenuation and directivity algorithms, they were also used to examine the effect of these differences on the complete contours of typical Canadian airports. Data for the Windsor, St. John's, Ottawa, and Montreal airports that were included in the Chapter 4 results were again used. Complete sets of NEF contours were calculated for these four airports using both the NEF_1.7 program and the experimental NEF_X program.

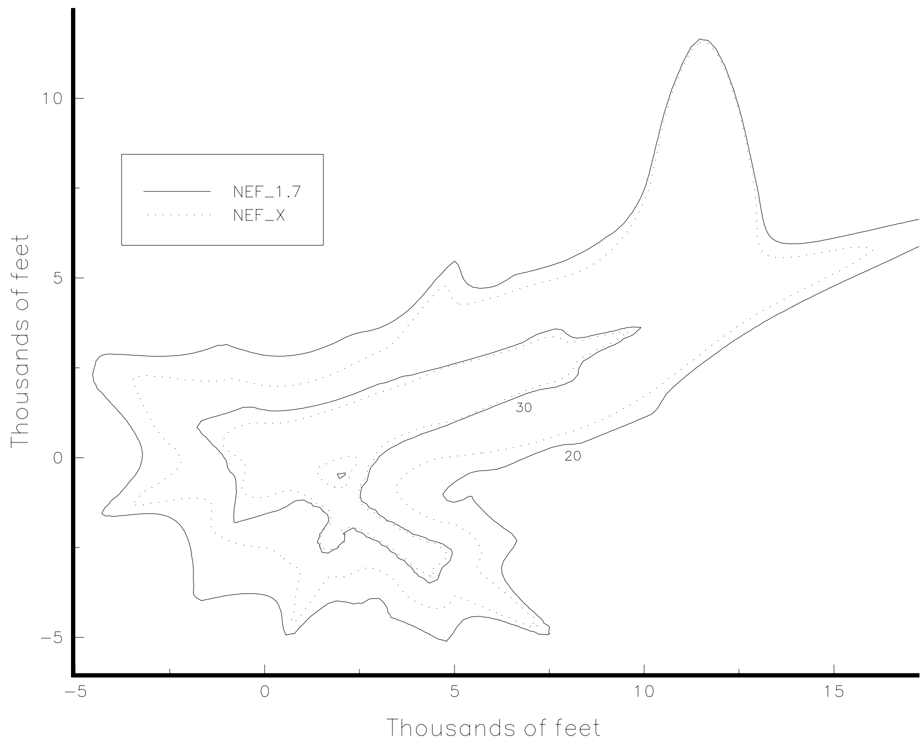


Figure 6.19: Comparison of NEF 20 and 30 contours at Windsor airport calculated by the NEF_1.7 and NEF_X programs.

Figure 6.19 compares the calculated NEF 20 and 30 contours for Windsor airport. For this airport, the areas of the two sets of contours were quite different and these differences tend to decrease with increasing NEF, as illustrated in Figure 6.20. For the NEF 20 contours, the NEF_1.7 result was more than 30% larger in area than the NEF_X contour.

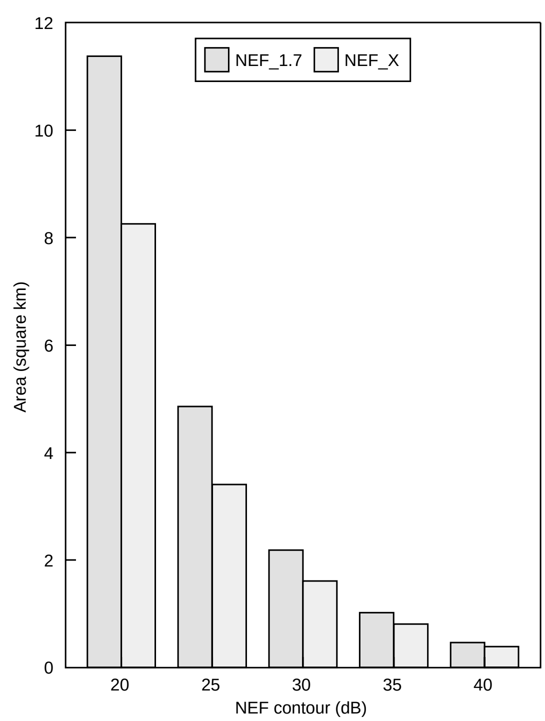


Figure 6.20: Comparison of the areas of contours produced by the NEF_1.7 and NEF_X programs for Windsor airport.

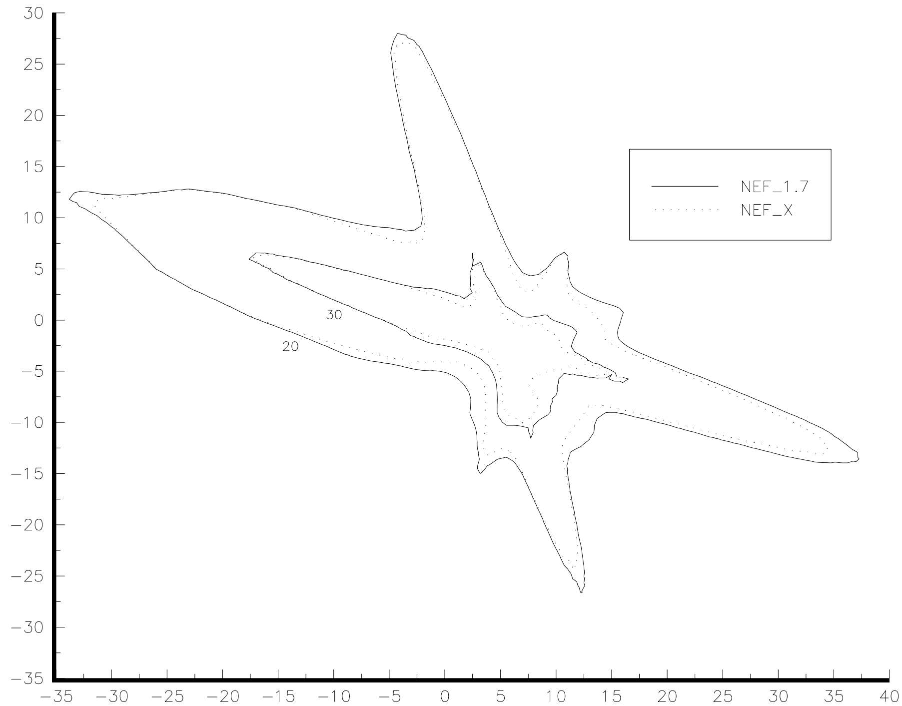


Figure 6.21: Comparison of NEF 20 and 30 contours at St. John's airport calculated by the NEF_1.7 and NEF_X programs.

The NEF 20 and 30 contours calculated by the two programs are compared for St. John's airport data in Figure 6.21. The differences between the area of the two sets of contours are smaller than for the previous example. As illustrated in Figure 6.22, these area differences vary with contour interval.

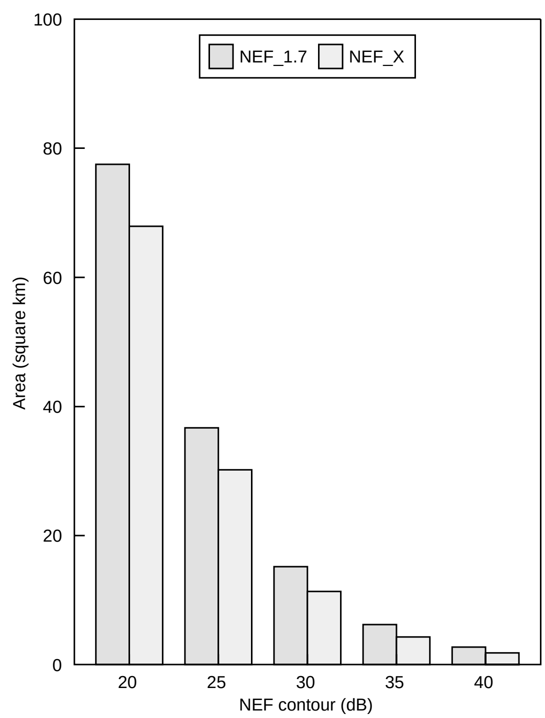


Figure 6.22: Comparison of the areas of contours produced by the NEF_1.7 and NEF_X programs for St. John's airport.

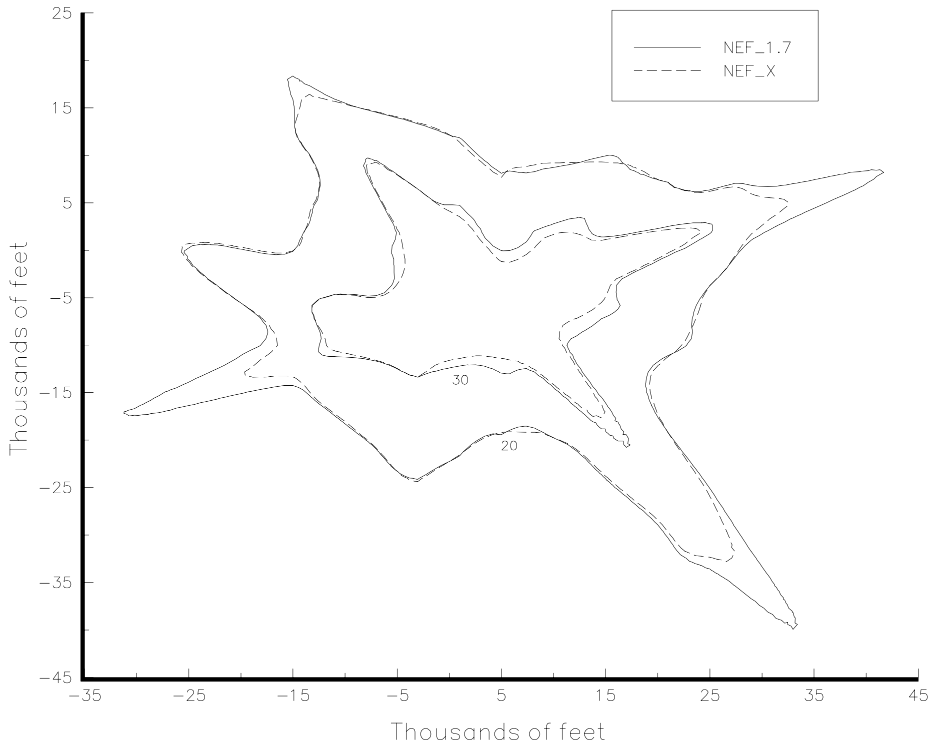


Figure 6.23: Comparison of NEF 20 and 30 contours at Ottawa airport calculated by the NEF_1.7 and NEF_X programs.

The calculated NEF 20 and 30 contours are compared for Ottawa airport data in Figure 6.23 and in Figure 6.25 for the Montreal airport data. There is a trend that the differences in NEF 20 and 30 contour areas decrease with increasing airport size. Thus, for the Ottawa airport data, the contours have only small area differences and for the Montreal results the contour areas are approximately the same. The contour areas for Ottawa are given in Figure 6.24, and for Montreal in Figure 6.26.

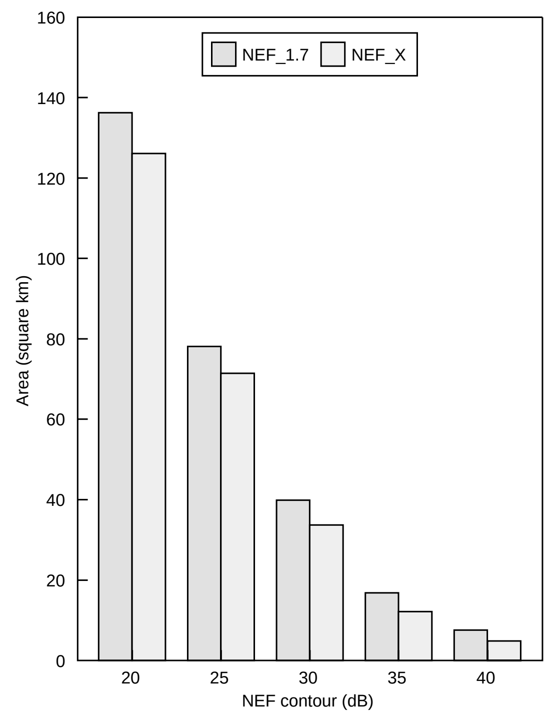


Figure 6.24: Comparison of the areas of contours produced by the NEF_1.7 and NEF_X programs for Ottawa airport.

Figure 6.25: Comparison of NEF 20 and 30 contours at Montreal airport calculated by the NEF_1.7 and NEF_X programs.

Thus, the intermediate ground attenuation algorithm(NEF_X), when compared to the algorithm used in the NEF_1.7 program, has quite different effects as a function of airport size. For airports with large numbers of daily operations such as Montreal, these ground attenuation differences are of little practical significance. For small airports such as Windsor, very significant changes in contour areas are produced by the two different approaches to calculating the effect of excess ground attenuation. Thus, without incorporating an improved algorithm into an airport noise prediction program, it would be quite difficult to estimate the overall effect on typical airport noise contours.

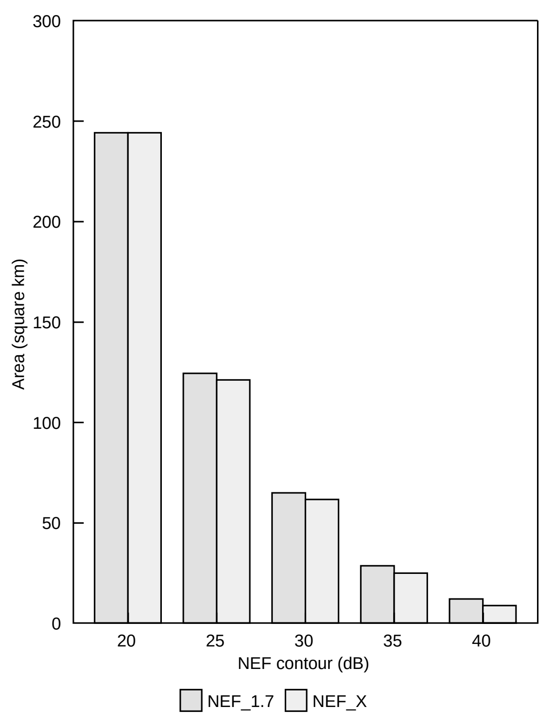


Figure 6.26: Comparison of the areas of contours produced by the NEF_1.7 and NEF_X programs for Montreal airport.

Comparisons with measurements and other recent work on ground attenuation suggest that the excess ground attenuation algorithm in the NEF_1.7 program leads to overestimations of the calculated NEF contours. Similar U.S. calculation programs appear to underestimate NEF contours. The effects of the experimental algorithms in the NEF_X program vary with airport size. Thus, it is quite likely that the effects of improved ground attenuation routines will vary from airport to airport.

6.7 Stage Length

Departing aircraft are classified according to stage lengths depending on how long their flight is to be. Stage lengths vary from 1, for shorter flights, to 7, for the longest flights. Not all aircraft are capable of all lengths of flights. Aircraft taking off for a longer flight are assumed to be heavier because of the extra fuel that is required. Because of the extra weight, the vertical profile of the take-off flight path is modified and for a given distance from the runway heavier aircraft will be closer to the ground and hence produce higher levels of noise. These effects are assumed to be insignificant for smaller aircraft and they are assumed to follow the same vertical take-off profile for all destinations.

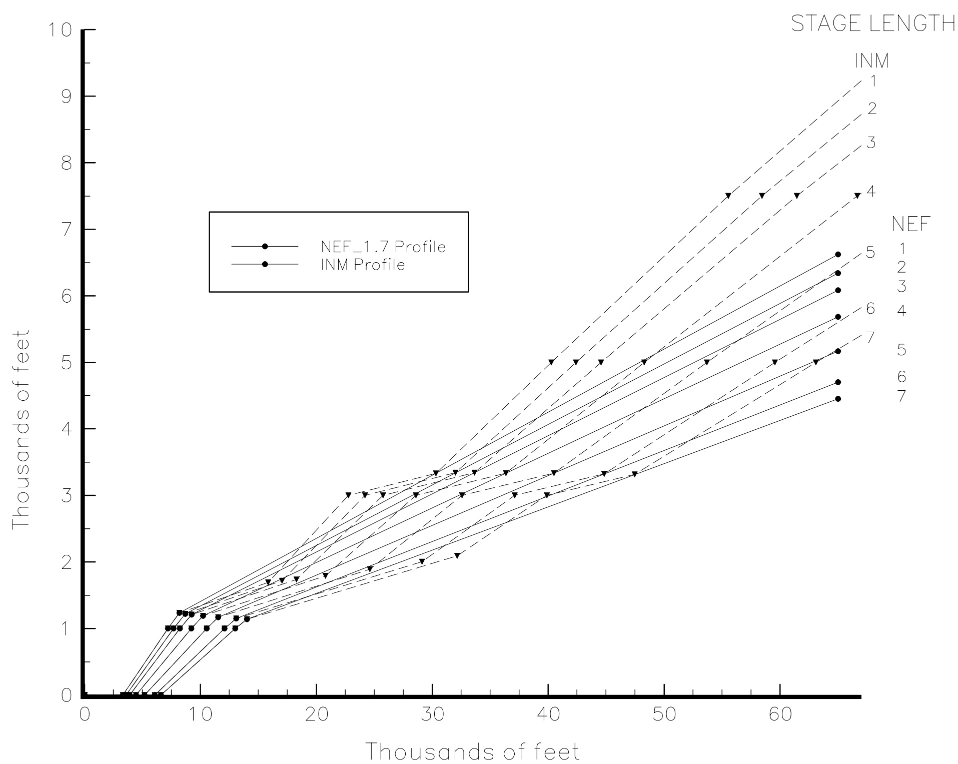


Figure 6.27: Comparisons of vertical take-off profiles by stage length for the INM and NEF_1.7 programs for a 767-CF6 aircraft.

As discussed in section 6.4, the NEF_1.7 program approximates the more complex vertical profiles of the INM model by simpler three-segment vertical profiles. Figures 6.27 and 6.28 compare the take-off profiles by stage length for two different aircraft. Figure 6.27 is for a 767-CF6 aircraft. As discussed in section 6.4, the schemes of the two programs are in reasonable agreement for locations closer to the runway, but they differ by increasing amounts further from the runway. In addition, the differences between the two programs at large distances vary with stage length. Figure 6.28 shows somewhat similar results for a 747-200 aircraft.

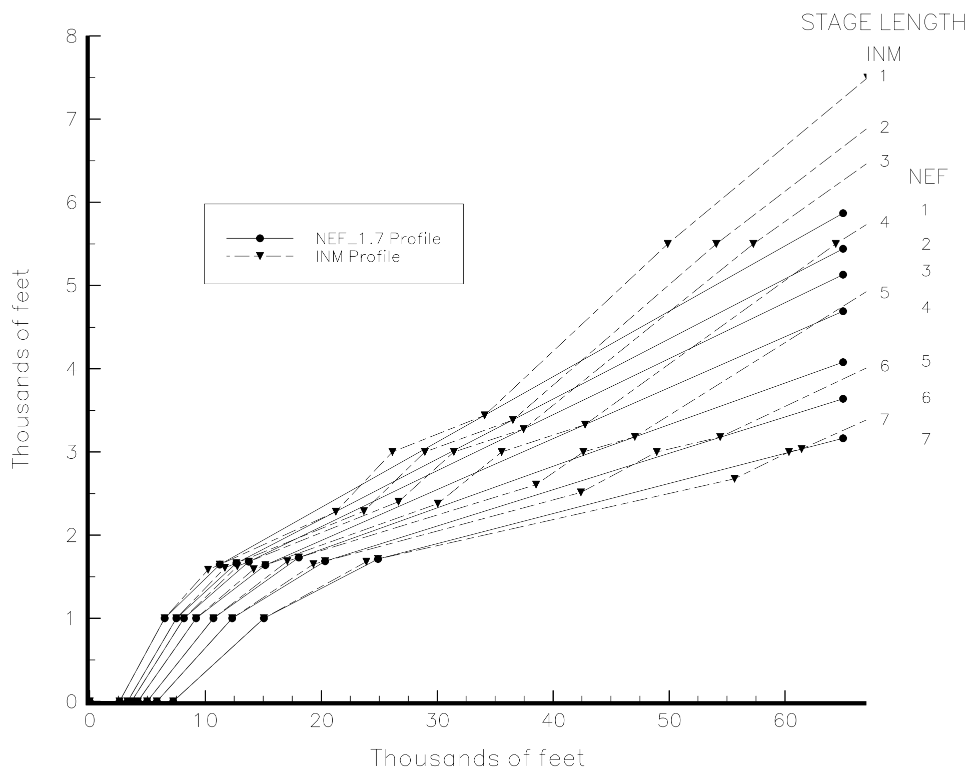


Figure 6.28: Comparisons of vertical take-off profiles by stage length for the INM and NEF_1.7 programs for a 747-200 aircraft.

Comparing the vertical profiles of both programs shows differences as both a function of distance from the runway and with stage length. Thus, one must expect differences between the programs concerning how modifications in stage length influence the resulting NEF contours.

The influence of stage length on the NEF contours was examined by calculating NEF contours for 100 operations of a single aircraft type using both the NEF_1.7 program and the INM program. These were repeated for four different types of aircraft chosen from those capable of flights of up to stage length 7. The aircraft chosen were: 747-200, 767-

CF6, 707-320, and a 747-SP. As one example of the results of these calculations, Figure 6.29 compares the areas calculated for the 767-CF6 aircraft for the NEF 30 contours as a function of stage length for both computer predictions. The two programs produce contours of different areas and these differences increase with stage length. Similar comparisons were made for all four aircraft types and for the NEF 20, 25, 30, 35, and 40 contours.

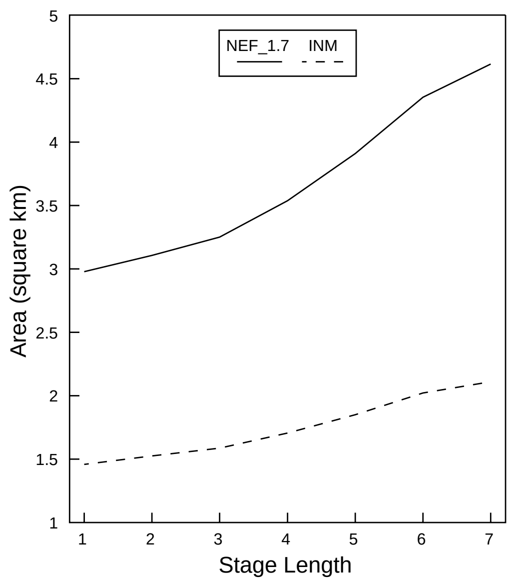


Figure 6.29: Comparison of NEF 30 contour areas versus stage length for 100 take-offs of a 767-CF6 aircraft using both the INM and NEF_1.7 programs.

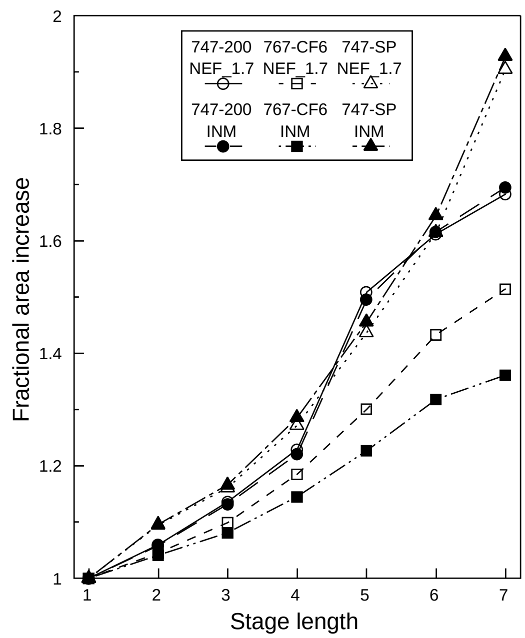


Figure 6.30: Fractional contour area increases, averaged over all NEF contours, calculated by both the INM and NEF_1.7 programs for three aircraft types.

In many cases, the fractional increase in contour areas did not vary much between NEF contours. Accordingly, the average fractional increases in contour areas were calculated for each aircraft type and for each prediction program. Figure 6.30 shows these average fractional increases in contour area as a function of stage length. This shows that for the 747-200 aircraft and the 747-SP aircraft, the NEF_1.7 and the INM programs produce very similar fractional increases in contour areas as a function of aircraft stage length. For the 767-CF6 aircraft, the NEF_1.7 program produced on average larger increases in contour areas than the INM program.

Averaging over the results for various NEF contours hides a number of other differences between the two prediction programs. Figure 6.31 compares the fractional increase in the areas of the NEF 30 contours. For this specific case, the two programs produce differences for all three aircraft types included in this graph. Other such particular differences were noted, but it was not possible to consider the many other aircraft types that are included in the data bases of the prediction programs.

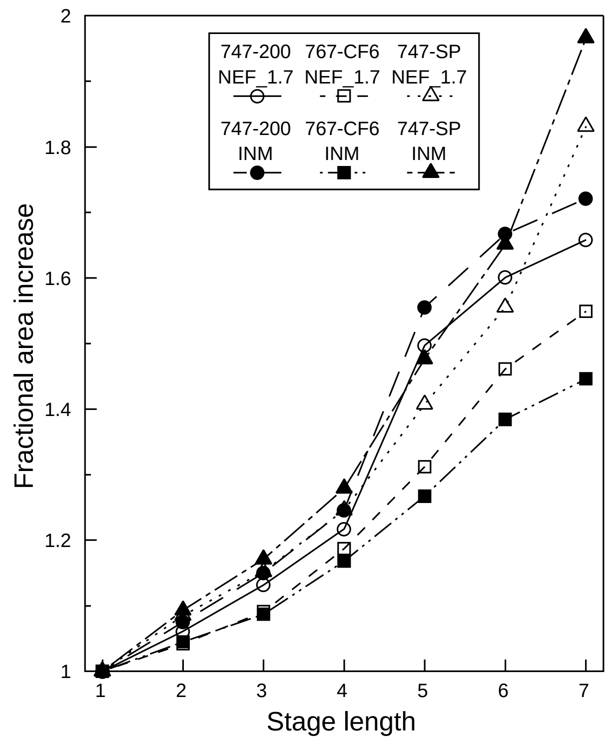


Figure 6.31: Fractional NEF 30 contour area increases calculated by both the INM and NEF_1.7 programs for three aircraft types.

Clearly, the influence of aircraft stage length on the resulting NEF contours is a very complex relationship that varies with: aircraft type, noise contour level, and prediction program. The NEF_1.7 program starts from more approximate vertical flight profiles. This should contribute to a less accurate modeling of the effect of aircraft stage length on the resulting noise level contours.

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7.0 COMPARISON OF SINGLE EVENT AND MULTIPLE EVENT NOISE CONTOURS

7.1 Procedure for Relating Single Event and Multiple Event Measures

Noise measures that have been developed to assess overall airport noise in various countries are almost always integrated measures that sum the contributions of all aircraft typically over a complete day. The NEF and L_{dn} measures are two examples of such integrated measures. In certain particular situations, it is often argued that single event measures should also be considered. For example, at small airports with mostly quieter smaller aircraft but with a few very noisy commercial jet aircraft, single event measures might be useful. Integrated measures such as NEF might not change much due to the presence of a few noisy aircraft, but during the times when they fly over, noise levels would be as high as near some much larger airports. Therefore, it is sometimes argued that a supplementary single event measure should be used to limit such infrequent excesses. Such single event measures could be a maximum A-weighted level (L_{max}) or an integrated single event level such as the sound exposure level (SEL).

To be able to consider the application of such a single event measure, one needs a procedure for relating single event measures and integrated measures as a function of the total number of operations at an airport. Thus, this Chapter first develops a procedure for comparing single event and integrated measures. In developing this procedure, it is assumed that single event levels at smaller airports should not exceed those typically experienced at larger airports.

The sound exposure level (SEL) is the result of integrating the sound energy from one complete aircraft fly-by and calculating the sound level that would give the same total energy with a duration of 1 second. The SEL is theoretically related to the maximum pass-by level L_{max} and the effective pass-by duration t_e by the following,

$$SEL = L_{max} + 10 \log(t_e) \qquad [7.1]$$

Data in reference [1] for measurements at a distance of 1,000 ft from the flight track fits the relationship, $SEL = L_{max} + 7$. This corresponds to t_e being 5 seconds. One can show that t_e will approximately double for each doubling of the distance from the flight track. (This is only strictly correct when there is no excess attenuation in addition to spherical spreading.) Thus, at a distance of 2,000 ft, t_e will have a value of 10 seconds. This is often taken as a representative value for locations around airports and is used in the following calculations. Of course, other values could be readily substituted to represent particular situations.

SEL is an integrated measure and can be approximately converted to other integrated measures such as L_{dn}, L_{eq}, or NEF. A 24-hour L_{eq} is an integration of the noise energy over 86,400 seconds, or 24 hours. Thus, the sound exposure level SEL of one aircraft could be converted to a 24 hour L_{eq} by subtracting 49.4 dB. (i.e. 10 log(86,400) = 49.4 dB). That is,

$$L_{eq}24 = SEL - 49.4 \qquad [7.2]$$

L_{dn} and NEF can be approximately related to $L_{eq}24$ (see also Appendix 1).

$$L_{dn} \approx L_{eq}24 + 2$$

$$NEF \approx L_{dn} + 35$$

Therefore,

$$L_{dn} \approx SEL - 47.4 \qquad [7.3]$$

$$NEF \approx SEL - 82.4 \qquad [7.4]$$

Using equations 7.3 and 7.4 with equation 7.1, one can relate L_{max} or SEL values to either NEF or L_{dn} values as a function of the total number of operations. These were performed by assuming various numbers of operations of one "typical" aircraft type. The "typical" aircraft is intended to represent an average aircraft.

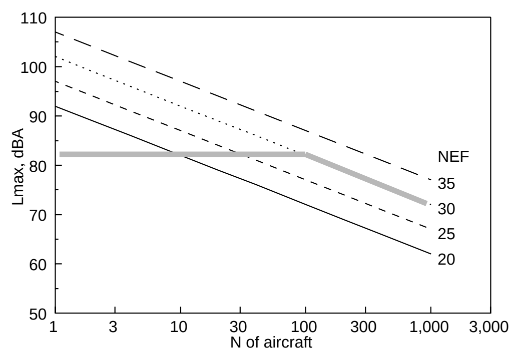

Figure 7.1: Estimated L_{max} values for N equal aircraft by NEF value. Thick line shows example of procedure for deriving an L_{max} single event limit.

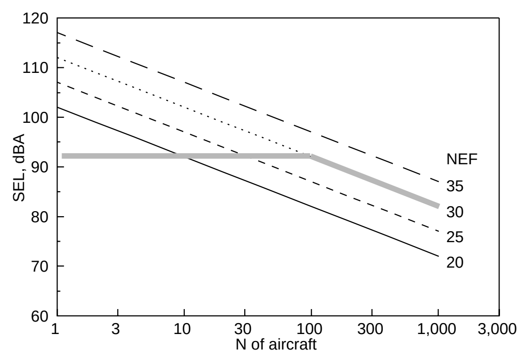

Figure 7.2: Estimated SEL values for N equal aircraft by NEF value. Thick line shows example of procedure for deriving an L_{max} single event limit.

Figure 7.1 relates L_{max} values to NEF values and Figure 7.2 relates SEL values to NEF values as a function of the total number of operations per day. These relations are calculated for NEF values of 20, 25, 30, and 35. These would be closely equivalent to L_{dn} values of 55, 60, 65, and 70 dBA. Figure 7.1 illustrates that, for a constant NEF value as the number of operations decrease, the related maximum pass-by level, L_{max}, increases. Thus, maximum levels at the NEF 30 contour near a small airport would be much higher than near a busier airport.

The thick line on each of Figures 7.1 and 7.2 represents one approach for devising a scheme to include supplementary single event limits. For larger numbers of operations per day, the thick line follows the NEF 30 line which is frequently used as the limit of acceptability for residential development. At some point, a maximum acceptable single event limit is reached and the thick line then horizontally follows this limit. In these two examples, 100 operations per day was taken as the limit below which airports could be considered small and single event limits might be required. This leads to a maximum level, L_{max}, of 82 dBA and an SEL of 92 dBA. Of course, for a real airport with a variety of aircraft, these limits would represent only the average of all aircraft.

This is intended as an example of how such calculations can be performed, but the actual limits would have to consider the results of studies of the negative effects of aircraft noise on people. These figures allow one to compare conditions at airports of various sizes.

7.2 Example Comparisons of Single Event and Multiple Event Contours

To further illustrate the relationships between single event and multiple event noise measures, noise contours for both types of measures were calculated and compared. Data from the four Canadian airports used in Chapter 4 were again used. Results of the INM model calculations were plotted in terms of L_{dn} values. These were compared with the SEL contours of two different smaller commercial jet aircraft. SEL contours were used because they have more commonly been used to describe single event levels in previous studies. EPNL and NEF contours could be similarly compared. One aircraft, a 737-D17, was a Chapter 2 aircraft; the other was a much quieter Chapter 3 aircraft, a 737-3B2. These two aircraft represent smaller commercial jet aircraft that are likely to be present at both smaller and larger airports and together represent a wide range in noise levels.

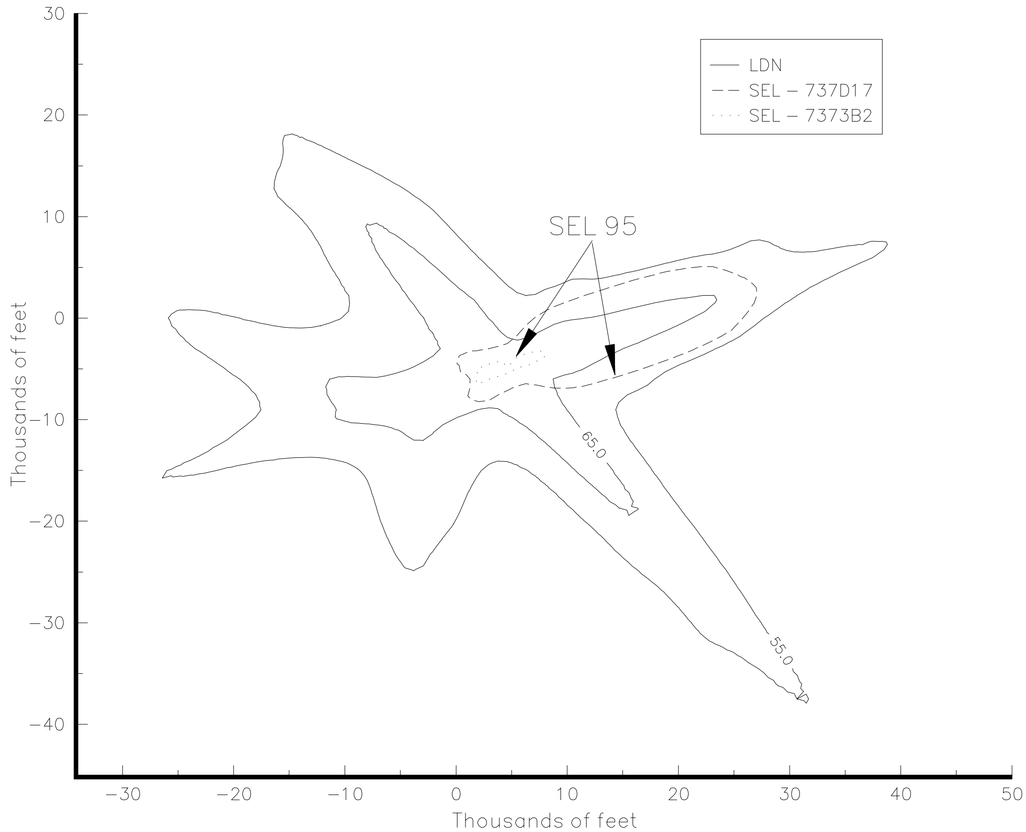

Figure 7.3: Comparison of L_{dn} 55 and 65 contours with SEL 95 contours for 737-D17 and 737-3B2 aircraft at Ottawa airport.

Figure 7.3 compares the calculated L_{dn} 55 and 65 contours at Ottawa airport with the SEL 95 contours for the two example aircraft. These L_{dn} contours would be approximately the same as the NEF 20 and 30 contours. The SEL 95 contours for the two aircraft are very different in areas. The SEL 95 contour for the noisier aircraft, the 737-D17, fits inside the L_{dn} 55 contour. Thus, for a number of locations around Ottawa airport, the SEL 95 contour of this aircraft is almost equivalent to the L_{dn} 55 contour (NEF 20).

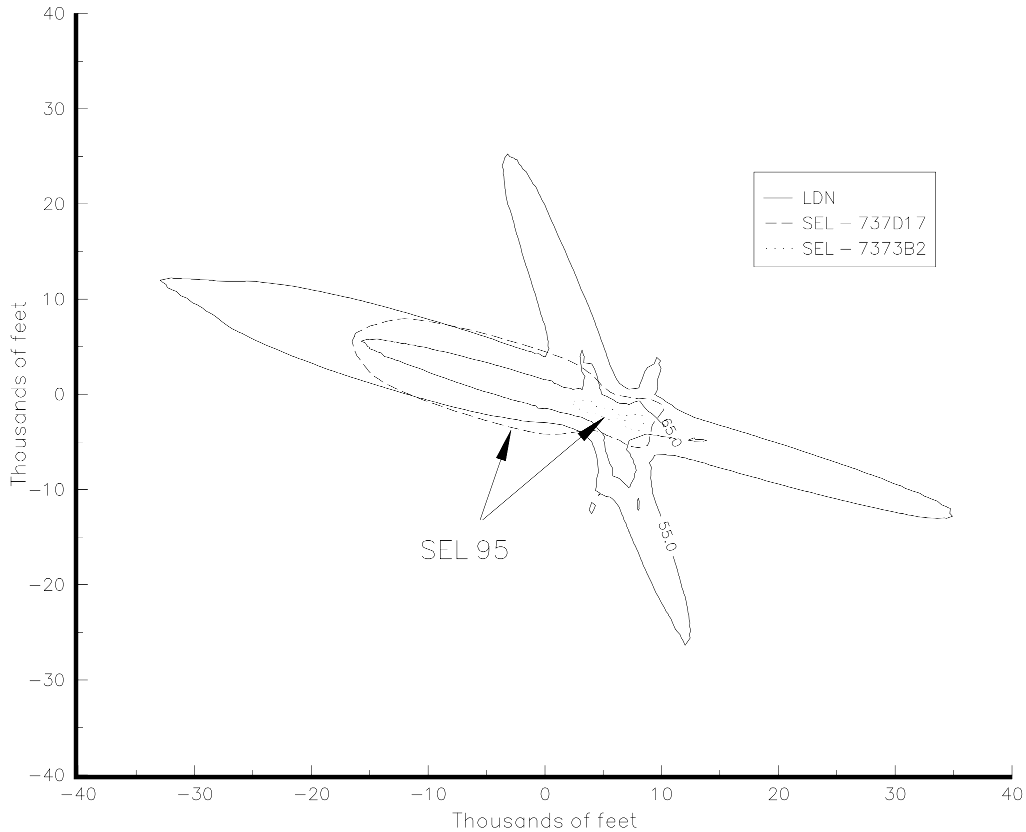

Figure 7.4: Comparison of L_{dn} 55 and 65 contours with SEL 95 contours for 737-D17 and 737-3B2 aircraft at St. John's airport.

Similar comparisons are made for the St. John's airport data in Figure 7.4. Again the 737-D17 SEL 95 contour approximately corresponds to the L_{dn} 55 contour for a number of locations around this airport. The SEL 95 contour for the quieter 737-3B2 aircraft is much smaller than both L_{dn} contours.

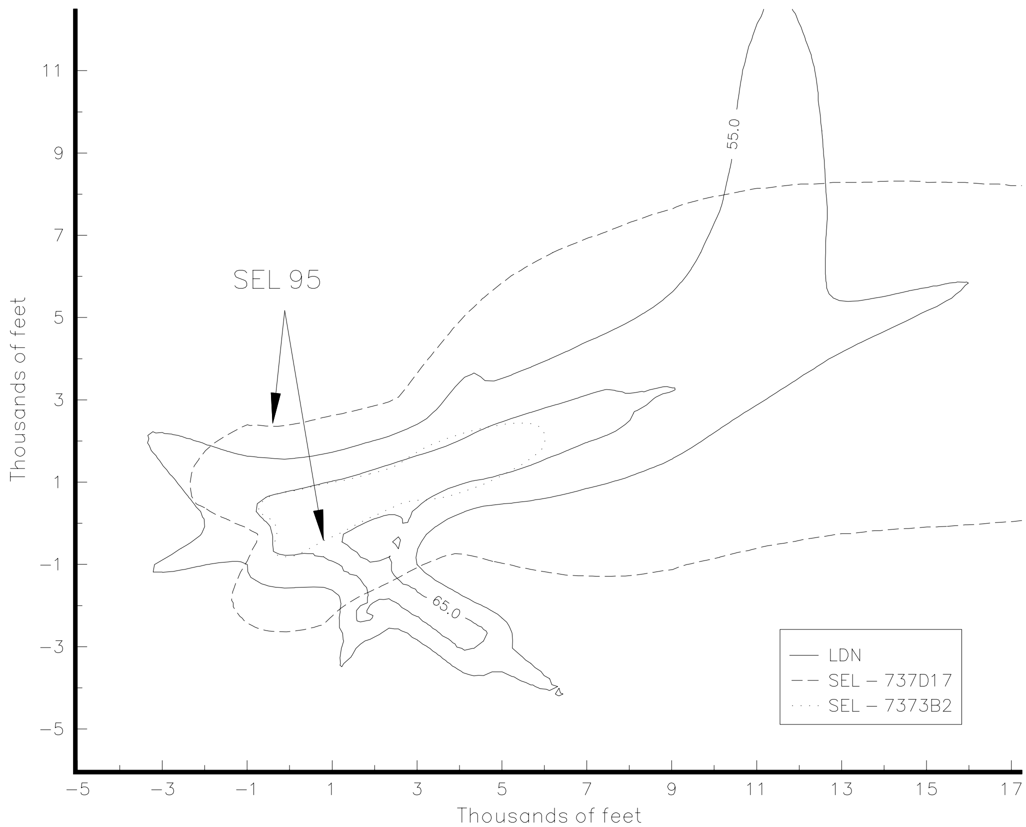

Figure 7.5: Comparison of L_{dn} 55 and 65 contours with SEL 95 contours for 737-D17 and 737-3B2 aircraft at Windsor airport.

The comparison is much different for the Windsor airport data shown in Figure 7.5. Here the SEL 95 contour for the 737-D17 is much larger than the L_{dn} 55 contour (NEF 20) and the SEL 95 contour for the 737-3B2 aircraft is similar to the L_{dn} 65 contour (NEF 30).

These three plots demonstrate that the relationship between single event measures such as SEL and multiple event measures such as L_{dn}, vary in a complicated manner depending on the size of the airport, the type of aircraft considered for the single event calculations, and the runway used. The L_{dn} contours shown in these figures are based on the same data used in Chapter 4 of this report and so represent realistic mixes of both Chapter 2 and 3 aircraft. Because of the mixture of aircraft types in the present complete airport data, the Chapter 3 aircraft SEL contours seem unusually small and the Chapter 2 aircraft SEL contours seem unusually large. It would be preferable to compare the SEL contour of the quieter Chapter 3 aircraft with future airport situations with only Chapter 3 aircraft in operation.

The analysis in section 7.1 provides a procedure for deriving special single event limits for airport noise. The comparison of the SEL contours of particular aircraft with the combined noise level (L_{dn} or NEF) contours permits one to validate the success of a proposed single event limit for particular airport situations. For example, if an additional single event limit of SEL 95 were created, this would have little effect at Ottawa and St. John's airports. However, at Windsor airport such an additional limit would considerably expand the noise contour areas.

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8.0 COMPARISON OF A-WEIGHTED AND EPNL BASED MEASURES

The NEF measure, used to predict airport noise in Canada, is derived from EPNL values of individual aircraft. A number of airport noise measures used in other countries are derived from A-weighted measures of individual aircraft noise. It is clearly of interest to assess the relationship between aircraft noise levels using the two different frequency weightings. This can be done by comparing the SEL and EPNL values for individual aircraft or by comparing overall integrated airport noise measures such as NEF and L_{dn}. Comparing SEL and EPNL measures should reveal the effects of just the different frequency weightings. Comparing NEF and L_{dn} values should indicate the combined effects of the different frequency weightings and the different time of day weightings in these two integrated noise measures. Both types of comparisons are made in this Chapter.

8.1 SEL Versus EPNL Values

The SEL and EPNL measures were compared using the aircraft noise data in the INM input database. This database gives tables of SEL and EPNL values for each aircraft as a function of distance and power settings. Data were extracted from this database; initially, SEL and EPNL values were plotted versus distance separately for each engine type and each power setting. These plots showed that the data for various power settings clustered together to fit a single relationship with distance.

As a second step, the EPNL values were plotted versus SEL values for each of the 28 engine types in the INM database. For each of these plots, a best fit linear regression line, correlation coefficient, and the standard error about the regression line were calculated. For all but one engine type, the R^2 values were greater than 0.99. The one exception was for JT15D engine which is a smaller engine typically used on business jets. For the Chapter 2 engines, the standard errors varied from 0.75 to 1.89 EPNdB. For the Chapter 3 engine types, the standard errors varied from 0.78 to 2.86 EPNdB.

When all Chapter 2 aircraft were combined into one group and EPNL values were again plotted versus SEL values, the related R^2 value was 0.991 and the standard error 1.87 EPNdB. This relationship is shown in Figure 8.1. The corresponding plot for Chapter 3 aircraft led to an identical R^2 value and an almost identical standard error of 1.86 EPNdB. When considered by engine type, the largest standard errors were associated with the smaller engines used on business jets. At airports with significant amounts of commercial jet aircraft traffic, business jets would normally not contribute very significantly to the overall noise climate. Thus, further comparisons were made with the business jets excluded. The resulting standard errors were then 1.78 EPNdB for Chapter 2 aircraft and 1.60 EPNdB for Chapter 3 aircraft. All R^2 values were greater than 0.99. When both groups were combined into one group, the associated standard error was 2.00 EPNdB.

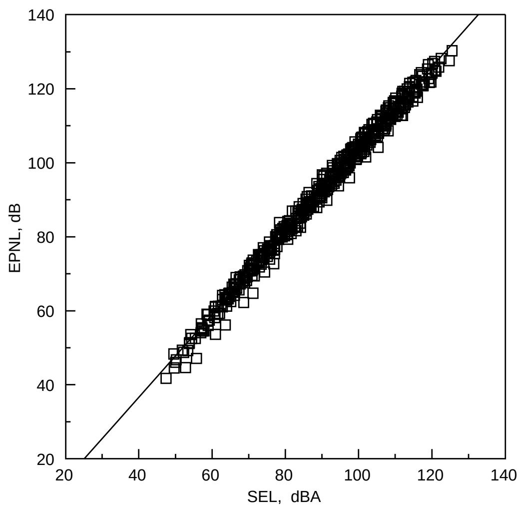

Figure 8.1: Plot of EPNL values versus SEL values for Chapter 2 aircraft data from the INM database. (R^2 = .991, Standard error = 1.87 EPNdB.)

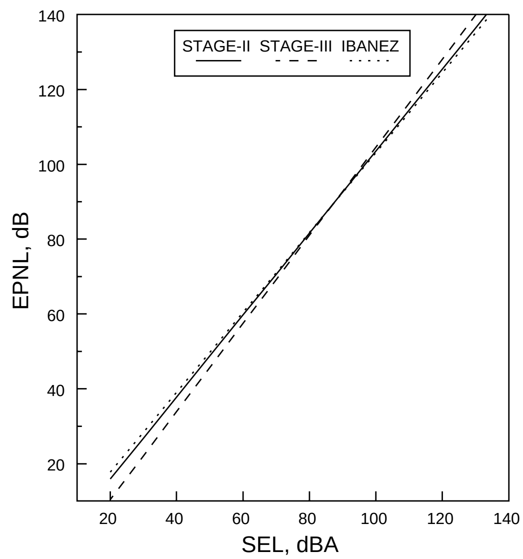

Figure 8.2: Regression lines to plots of EPNL values versus SEL values for Chapter 2 and 3 aircraft data from the INM database and measurement results by Ibanez.

One can therefore expect current EPNL values to relate to SEL values with an error of approximately ±2.0 EPNdB. Some time in the future, when only Chapter 3 aircraft are in use at Canadian airports, this would be expected to reduce to the 1.6 EPNdB figure given above. Thus, it is possible to convert between the two frequency weightings without large errors.

The regression equations that were derived were as follows,

$$EPNL = 1.0953 \bullet SEL - 5.986, \text{ for Chapter 2 engines} \quad [8.1]$$

$$EPNL = 1.1772 \bullet SEL - 13.167, \text{ for Chapter 3 engines} \quad [8.2]$$

These two regression lines are very similar, as is illustrated in Figure 8.2. Ibanez et al. [1] made similar comparisons of EPNL and SEL values from their own measurements. From 74 pairs of measured EPNL and SEL values, they calculated the following regression line,

$$EPNL = 1.067 \bullet SEL - 3.391 \quad [8.3]$$

All three regression lines are compared in Figure 8.2. It is not known what types of aircraft were included in the measurements of Ibanez et al., but with a 1985 publication date one can assume mostly Chapter 2 aircraft. The regression line calculated by Ibanez et al. agrees very closely with the regression line for Chapter 2 aircraft derived here. Thus, the measured results of Ibanez et al. confirm the current analyses based on data from the INM database.

8.2 L_{dn} Versus NEF Values

Comparisons of L_{dn} and NEF values were made using the INM program to predict both measures for three Canadian airports. These were the Windsor 1994, Ottawa 1992, and the Montreal 1989 data that were used in Chapter 4 of this report. For each airport, the INM model was used to calculate a 100 by 100 grid of NEF and L_{dn} values. Then, for each airport L_{dn} values were plotted versus NEF values, for all locations where the NEF ≥ 20.

The resulting plots are shown in Figures 8.3, 8.4, and 8.5 for Windsor, Ottawa, and Montreal airports, respectively. In each case, a best fit linear regression was also calculated. These are shown on each plot and their equations are as follows,

$$L_{dn} = 0.951 \bullet NEF + 36.432, \quad \text{Windsor} \quad [8.4]$$

R^2 = 0.981, Standard deviation = 0.874, dBA

$$L_{dn} = 0.958 \bullet NEF + 36.636 \quad \text{Ottawa} \quad [8.5]$$

R^2 = 0.979, Standard deviation = 0.782, dBA

$$L_{dn} = 0.955 \bullet NEF + 36.832 \quad \text{Montreal} \quad [8.6]$$

R^2 = 0.983, Standard deviation = 0.811, dBA

The scatter about these regression lines is quite small and the standard deviations of the points about the best fit regression lines given above were always less than 1 dBA. Again, the two different measures can be quite accurately related to one another.

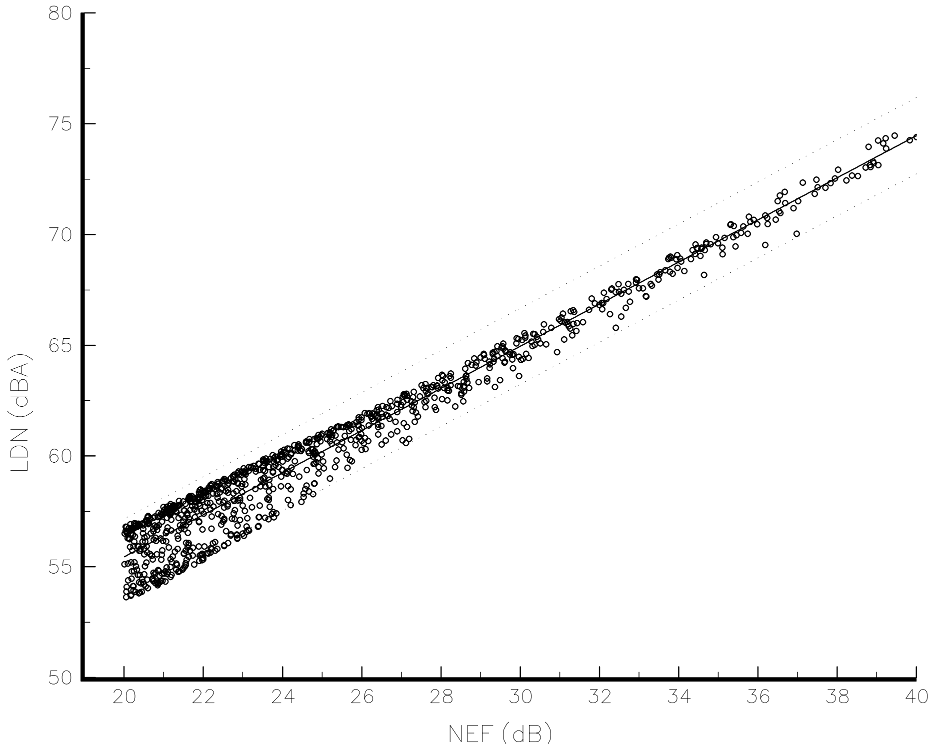

Figure 8.3: Calculated L_{dn} values versus NEF values using the INM program and Windsor airport data (R^2=0.981, σ=0.874).

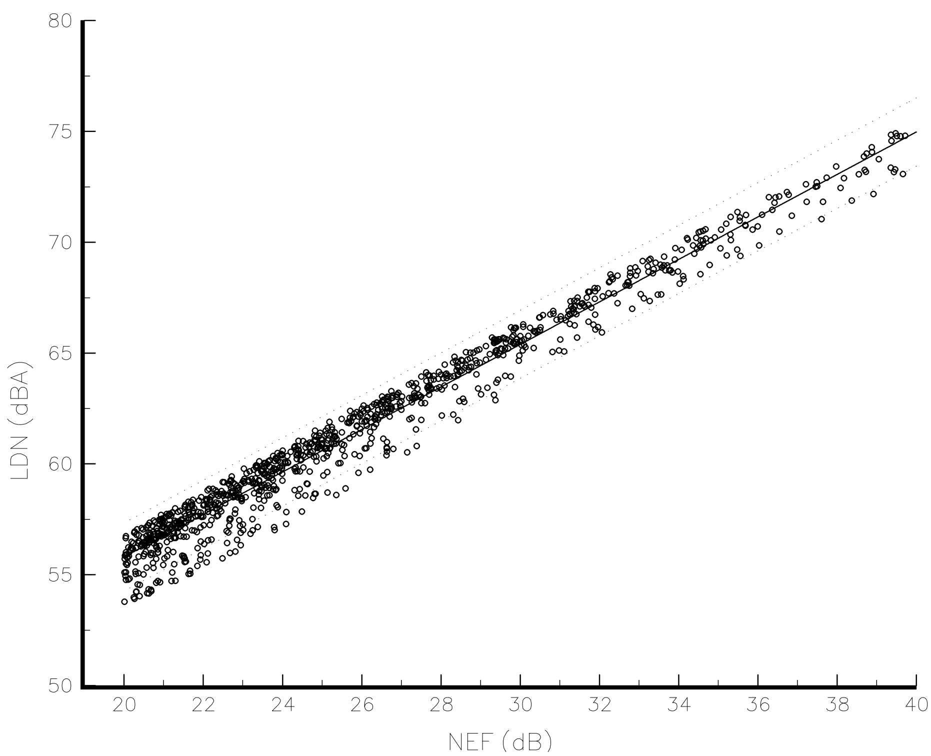

Figure 8.4: Calculated L_{dn} values versus NEF values using the INM program and Ottawa airport data (R^2=0.979, σ=0.782).

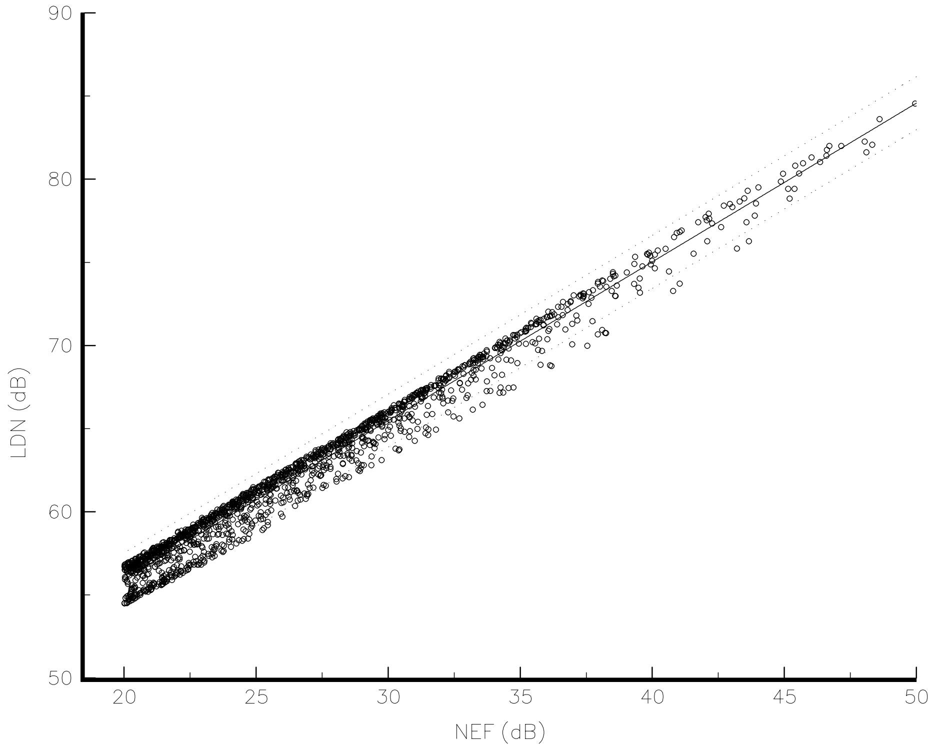

Figure 8.5: Calculated L_{dn} values versus NEF values using the INM program and Montreal airport data (R^2=0.983, σ=0.811).

These regression lines are very similar to the relationship between L_{dn} and NEF calculated in Appendix 1. They are also almost indistinguishable from the simple relationship,

$$L_{dn} = NEF + 35.0 \qquad [8.7]$$

which is also included in Appendix 1. Thus, this is not only a convenient simple relationship, but it is also apparently a quite accurate average trend based on the calculations at these three quite different airports.

REFERENCE

1. Ibanez, B.F., Belenguer, H.F., and Diac, E.G., "Relationship Between EPNL and SENEL Parameters in Aircraft Noise", Noise Control Engineering Vol., 25, No., 2, pp. 80-82 (1985).

9.0 CONCLUSIONS

This report has examined the NEF_1.7 airport noise prediction program in some detail. In these conclusions, it is hoped to summarise these analyses and to put them into some perspective.

The NEF_1.7 program is similar to other older airport noise prediction programs such as the Integrated Noise Model and NoiseMap programs used in the United States. However, the NEF_1.7 program uses simpler descriptions of aircraft flight paths and uses a different procedure to calculate the expected excess ground attenuation. These methodological differences lead to significant differences in the calculated airport noise contours. While there are differences, it is not clear which result is likely to be more valid. It is most probable that measured noise levels would lie somewhere in between the results of these three programs.

In Europe, several more modern airport noise programs are being developed that use a simulation approach. These are potentially more accurate, but require considerably longer computation times and sometimes more sophisticated input data.

For all computer models, the problem of predicting the numbers of future operations is a major source of errors. Errors of up to 21% can be expected in predicting the annual numbers of future aircraft operations. Further errors are incurred in trying to estimate the number of operations for a peak planning day, PPD. This report recommends a new simpler and more accurate procedure for predicting the number of operations per PPD.

Detailed comparisons of the contours calculated by the NEF_1.7 program, the Integrated Noise Model, and the NoiseMap program showed quite large differences in contour areas and calculated NEF values. On average for the same aircraft operations, the NEF_1.7 contours were 60 to 80% larger, and at particular points NEF values were 3 to 4 dB higher. The two American programs tend to produce quite similar contours.

A PPD typically includes 1.4 times the number of operations of a mean day. This difference between a mean day and a PPD resulted in an approximately 1.5 dB increase in NEF values and an increase in contour areas by a factor of approximately 1.3.

Comparing the approach used in the United States, using the number of operations for a mean day and the INM program, with NEF_1.7 program and the number of operations for a PPD, produced even larger differences. The Canadian approach produced contours that were approximately 2.2 times larger than the U.S. approach. Thus, the two countries use quite different approaches and one must be very careful in making comparisons between results without complete documentation concerning the calculation procedures.

The prediction programs seem to be most sensitive to changes in the estimated total number of aircraft operations. Errors of this type could commonly lead to 1 dB errors in calculated NEF values and 12% errors in contour areas. Predicting the number of operations during the night-time hours would lead to further errors in the NEF contours that would typically be about half as large as for the total number of operations. Errors due to predicting the stage length of aircraft, aircraft types, and runway use would lead to smaller average errors. However, in some cases such as for predicting runway use, localized effects can be quite large. It is estimated that the combined effect of errors in the input data would normally lead to errors in calculated contours of up to 1.5 dB in NEF values and up to 16% in contour areas.

A number of the details of the airport noise program calculations were seen to significantly influence the calculated contours. The expected horizontal dispersion of actual aircraft movements about the nominal flight track was shown to significantly change contours. The NEF_1.7 program does not include such effects and hence would be expected to incorrectly model real situations. Similarly, the simplified descriptions of flight tracks and vertical profiles used by the NEF_1.7 model would not permit accurate modeling of all real situations. The effects of aircraft stage length are not modeled in exactly the same way by the NEF_1.7, INM, and NoiseMap programs. This is partly due to the simplified vertical profiles used in the NEF_1.7 program

The major cause of differences between the NEF_1.7 program and the two programs used in the United States is the different algorithms for excess ground attenuation. The INM and NoiseMap programs both use the SAE procedure for civil aircraft operations. This procedure predicts greater ground-to-ground and air-to-ground attenuation than the procedure used by the NEF_1.7 program. Comparisons with procedures used in Switzerland and Germany, as well as with measurements of a Boeing 747 aircraft in the U.S., suggest that a better estimate of excess ground attenuation would be intermediate to the SAE procedure and the current NEF_1.7 procedure.

Determining a better method for estimating excess ground attenuation is an essential first step to producing improved estimates of aircraft noise contours. This would probably require extensive measurements of actual aircraft fly-bys of civil jet aircraft types in use today. Performing calculations in octave bands would make it possible to better model sound propagation phenomena. The expected changes to excess ground attenuation calculations would lead to very significant changes in contour areas.

Procedures were developed to relate measures of single aircraft fly-bys, such as SEL and L_{max}, to combined measures of many aircraft such as L_{dn} and NEF. These procedures make it possible to systematically develop secondary single event measures for special situations where measures such as L_{dn} and NEF may not be completely adequate.

Comparisons of A-weighted and PNL-weighted aircraft noise measures showed that the two different frequency weightings could be related with an error of ±2 dB depending on the mix of aircraft types, and that this error would decrease in the future with only chapter 3 aircraft present. Similarly, NEF values (based on EPNL values) were shown to relate to L_{dn} values (based on SEL values) with an error of less than ±1 dB.

A systematic set of approximate conversions between the various aircraft noise measures used in the major industrialized countries was produced. With a single approximate conversion from PNL to A-weighted levels, many of these measures could be related within an error ±1 dB. Different time of day weighting schemes were seen to have a significant effect on these relationships. Of all the measures considered, the NEF measure has the highest night-time weighting. Differences between A-weighted and PNL weighted measures would also have significant effects on these relationships.

Because the NEF_1.7 program is such a critical part of the management of airport noise in Canada, it is extremely important that its validity and accuracy be as good as is reasonably possible. The use of millions of dollars of land at 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 procedure would considerably improve the NEF_1.7 program. It seems essential that the required continuing development of the NEF_1.7 program should receive the necessary financial and technical support.

APPENDIX 1. APPROXIMATE COMPARISONS BETWEEN AIRPORT NOISE MEASURES

A1.1 Calculation Procedures

Almost every country with one or more major airports has developed its own airport noise measure. The result is a confusing array of apparently different noise measures. When examined in more detail, many of these quantities are reasonably similar, and it is possible to make approximate conversions among most of them. In this Appendix, such approximate conversions among the major airport noise measures are calculated.

Conversions among the various measures were calculated for the simplified case of only one typical aircraft type with a single assumed maximum A-weighted level, L_{max}, for each aircraft fly-by. The effective duration, t_e, of a fly-by can vary with the distance of the receiving point from the aircraft flight track. For these calculations, the effective duration of each fly-by was assumed to be 10 s. (From the results of Chapter 7, this would correspond to a measurement point approximately 2,000 ft from the aircraft.) This could be changed but later results in this Appendix show that in cases where the value of t_e influences the calculated relationships between measures, its influence is easily estimated.

It is also necessary to make approximate conversions between A-weighted measures and measures based on Perceived Noise Levels (PNL). A conversion similar to that used by other groups was derived from the aircraft noise level database of the U.S. Integrated Noise Model.

Values of each noise measure were calculated by systematically varying the numbers of aircraft operations in day- and night-time hours. No attempt was made to model the distribution of aircraft operations within the day- or night-time periods.

The calculated relationships are based on the following five assumptions:

1. L_{max} = 75.0 dBA, was used as a typical maximum level for the starting point. (L_{max} is the maximum A-weighted sound level at the receiver point for an aircraft fly-by).

   All aircraft are assumed to be the same typical aircraft so that L_{max} and the mean for all fly-bys $<L_{max}>$ will be the same.

2. The effective duration, t_e, was taken to be 10 s.

   (The effective duration is the time which, when multiplied by the maximum pressure squared value, gives the total integrated sound exposure or in decibels the sound exposure level (SEL) for one fly-by).

3. $SEL = L_{max} + 10 \bullet \log(t_e)$ [A.1]

   (This follows from the definition of t_e).

4. $PNLT_{max} = L_{max} + 12,$ [A.2]

   That is, the tone corrected maximum Perceived Noise Level ($PNLT_{max}$) is typically 12 dB greater than the maximum A-weighted noise level, L_{max}.

   This is the same approximation used by the Swiss [1], but the Japanese [2] use the approximation $PNLT_{max} = L_{max} + 13$.

   The constant 12 was determined from EPNL and SEL values in the Integrated Noise Model database. Initially, the constant was given the value 'k',

   $PNLT_{max} = L_{max} + k$ [A.3]

   $EPNL = PNLT_{max} + 10 \bullet \log(t_e/10)$ [A.4]

   $= L_{max} + k + 10 \bullet \log(t_e/10)$

   but, $SEL = L_{max} + 10 \bullet \log(t_e)$ [A.5]

   Therefore,

   $EPNL = SEL + k - 10$ [A.6]

   The following regression equations were derived from the INM database (see also equations 8.1 and 8.2 in section 8.1).

   $EPNL = 1.0953 \bullet SEL - 5.986$ (Chapter 2 aircraft) [A.7]

   $EPNL = 1.1772 \bullet SEL - 13.167$ (Chapter 3 aircraft) [A.8]

   The average difference between EPNL and SEL values for all aircraft types in the range of SEL values between SEL 70 and 100 was 2.0.

Therefore, from equation A.6 the constant 'k' must equal 12.

(Matshcat et al. [3] have shown that the tone correction on average approximates 1 dB. That is, PNLT ≈ PNL + 1. In these approximate conversions, this 1 dB correction is ignored.)

5. Values of each airport noise measure were calculated for combinations of the numbers of operations per hour for both day and night time periods. This assumed that every hour of the day time had the same number of operations and similarly that all night time hours had identical numbers of operations. This simplification is only a problem for the airport noise measure used in the Netherlands that includes time of day weightings that vary according to the particular hour of the day.

   The following numbers of operations per hour were used to calculate values of the airport noise measures.

   n_d = 1, 2, 4, 8, 16, 32, or 64; the number of operations per hour in day-time.

   n_n =0, 1, 2, 4, 8, 16, 32, or 64; number of operations per hour during the night-time.

   The combination of these numbers of day and night operations resulted in 56 different values of each noise measure. Of course, some combinations are not very realistic. e.g. n_d=1, n_n=64.

Below each of the airport noise measures are defined.

1. L_{dn} (Day night sound level, U.S.A.)

   $N_d = n_d \bullet 15$ (07:00-22:00 hours)
   $N_n = n_n \bullet 9$ (22:00-07:00 hours)

   N_d is the total number of day time operations, and N_n is the total number of night-time operations.

   $$L_{dn} = 10 \bullet \log\{N_d \bullet 10^{(SEL/10)} + N_n \bullet 10^{(SEL+10)/10}\} \qquad [A.9]$$

2. L_{den} (Day evening night sound level, Denmark)

$N_d = n_d \bullet 12$ (07:00-19:00 hours)
$N_e = n_d \bullet 3$ (19:00-22:00 hours)
$N_n = n_n \bullet 9$ (22:00-07:00 hours)

$$L_{den} = 10 \bullet \log(N_d \bullet 10^{(SEL/10)} + N_e \bullet 10^{(SEL+5)/10} + 10^{(SEL+10)/10}) \quad [A.10]$$

3. $L_{eq}24$ (24 hour energy equivalent average sound level)

$N = n_d \bullet 15 + n_n \bullet 9$

$$L_{eq}24 = 10 \bullet \log(N \bullet 10^{(SEL/10)}) \quad [A.11]$$

4. $L_{eq}16$ (16 hour day-time L_{eq} value, United Kingdom)

$N_d = n_d \bullet 16$ (07:00-23:00 hours)

$$L_{eq}16 = 10 \bullet \log(N_d \bullet 10^{(SEL/10)}) \quad [A.12]$$

5. WECPNLj (Weighted Equivalent Continuous Perceived Noise Level, Japan). (This is an A-weighted approximation to the original WECPNL measure that was based on EPNL values.)

$N_w = n_d \bullet 12 \bullet 1 + n_d \bullet 3 \bullet 3 + n_n \bullet 9 \bullet 10$
day = 12 hours, weighting = 1 (07:00-19:00 hours)
evening = 3 hours, weighting = 3 (19:00-23:00 hours)
night = 9 hours, weighting = 10 (23:00-07:00 hours)

$$WECPNLj = <L_{max}> + 10 \bullet \log(N_w) - 27 \quad [A.13]$$

6. NNI (Noise and Number Index used in Switzerland, and formerly in the United Kingdom)

$N12 = n_d \bullet 12$ (U.K.) (06:00-18:00 hours)
$N16 = n_d \bullet 16$ (Swiss) (06:00-23:00 hours)

$$NNI_{UK} = <PNL_{max}> + 15 \bullet \log(N12) - 80, \quad \text{(U.K.)} \quad [A.14]$$
$$NNI_S = < L_{max} > + 15 \bullet \log(N16) - 68, \quad \text{(Swiss)} \quad [A.15]$$

7. B (Total Noise Load or Kosten Unit, the Netherlands)

$N_p = \Sigma N_{hi} \bullet w_i$, N_{hi} = number hours in time period
w_i = weighting of each time period

Times	N_{hi}	Weighting, w_i	
0 - 6	6	10	| night
6 - 7	1	8	|
7 - 8	1	4	+
8 - 18	10	1	+ day
18 - 19	1	2	+
19 - 20	1	3	+
20 - 21	1	4	+
21 - 22	1	6	+
22 - 23	1	8	| night
23 - 24	1	10	|

$$B = 20 \bullet \log(N_p \bullet 10^{(L_{max}/15)}) - 157 \qquad [A.16]$$

8. Q (Disturbance Index, Germany) (more recently referred to as aircraft noise equivalent level, LEQ(FLG))

(a) day time operations only calculation

$N_d = n_d \bullet 16 \bullet 1.5$ (06:00-23:00 hours)

$$Q(day) = 13.3 \bullet \log[(2 \bullet t_e \bullet N_d \bullet 10^{(L_{max}/13.3)}/86400)$$

(The duration is based on the 10 dB down points which they show [3] to be 2 times the effective duration, t_e).

(b) day and night operations day (06:00-23:00 hours)
night (23:00-06:00 hours)

$N_{dn} = n_d \bullet 16 \bullet 1 + n_n \bullet 8 \bullet 5$

(where 16 and 8 are the number of hours of day and night respectively, and 1 and 5 are weighting factors).

$$Q(24\ hr) = 13 \bullet \log[(2 \bullet t_e \bullet N_{dn} \bullet 10^{(L_{max}/13.3)}/86400) \qquad [A.18]$$

The equation giving the highest Q value is used. (Note, although this measure is now referred to as an equivalent level, this may lead to some confusion because it is not an 'energy' equivalent level).

9. I_p (Psophique Index, France)

$N_d = n_d \bullet 12$ (06:00-22:00 hours)
$N_n = n_n \bullet 8$ (22:00-06:00 hours)

$$I_p = 10 \bullet \log(N_d \bullet 10^{(PNL_{max}/10)} + N_n \bullet 10^{(PNL_{max}+10)/10}) - 32 \quad \text{[A.19]}$$

10. NEF (Noise Exposure Forecast, Canada)

$EPNL = PNLT_{max} + 10 \bullet \log(t_e/10)$
$N_d = n_d \bullet 15$ (07:00-23:00 hours)
$N_n = n_n \bullet 9$ (23:00-07:00 hours)

$$NEF = 10 \bullet \log(N_d \bullet 10^{(EPNL/10)} + 16.67 \bullet N_n \bullet 10^{(EPNL/10)}) - 88 \quad \text{[A.20]}$$

11. ANEF (Australian Noise Exposure Forecast, Australia)

$N_d = n_d \bullet 12$ (07:00-19:00 hours)
$N_n = n_n \bullet 12$ (19:00-07:00 hours)

$$ANEF = 10 \bullet \log(N_d \bullet 10^{(EPNL/10)} + 4 \bullet Nn \bullet 10^{(EPNL/10)}) -88 \quad \text{[A.21]}$$

12. NEF(A) (An A-weighted approximation to the NEF)

$N_d = n_d \bullet 15$ (07:00-23:00 hours)
$N_n = n_n \bullet 9$ (23:00-07:00 hours)

$$NEF(A) = 10 \bullet \log(N_d \bullet 10^{(L_{max}/10)} + 16.67 \bullet N_n \bullet 10^{(L_{max}/10)}) - 76 \quad \text{[A.22]}$$

This last equation can be developed as follows:

$$\begin{aligned} EPNL &= PNLT_{max} + 10 \bullet \log(t_e/10) \\ &= PNLT_{max}, \quad \text{(for } t_e = 10 \text{ s)} \\ &= L_{max} + 12, \quad \text{using the approximation from INM database} \end{aligned}$$

$$\begin{aligned} NEF(A) &= 10 \bullet \log[N_d \bullet 10^{(L_{max}+12)/10} + 16.67 \bullet N_n 10^{(L_{max}+12)/10}] - 88 \\ &= 10 \bullet \log[(N_d + 16.67 \bullet N_n) \bullet (10^{(L_{max}+12)/10})] - 88 \\ &= 10 \bullet \log[(N_d + 16.67 \bullet N_n) \bullet (10^{(L_{max})/10}) - 76 \end{aligned}$$

(If one used the Japanese approximation to convert PNL_{max} to L_{max}, the constant would be -75 instead of -76.)

A1.2 Comparisons for Full 24 Hour Periods

Although comparisons could be made for all combinations of the above 12 different airport noise measures, this is not necessary for the purposes of this report. Accordingly, the various measures were only compared with L_{dn} and NEF values. There are three major types of differences between the various measures that influence the comparisons.

First, they include two different types of frequency weighting of the airport noises: A-weighted levels and Perceived Noise Levels. One approximate conversion between the two frequency weightings was made which on average should be approximately correct, but this does not include the variability in this relationship due to spectral differences in individual aircraft sounds.

Second, there are differences in the time of day weightings in the various measures. These include different time periods and different weighting factors. The calculated comparisons explicitly include these differences, and the results correctly reflect the influence of these time-of-day weighting differences.

Third, there are differences in the portion of the day that is included in the calculation of airport noise measures. While most measures include the complete 24 hour period, others include only the day-time hours of each 24-hour period. For example, the United Kingdom uses a 16-hour L_{eq}. It is not possible to have a simple conversion from a day-time only measure such as $L_{eq}16$ to a 24-hour measure such as L_{dn}. These measures can only be compared for the day-time periods. For example, Figure A1 shows the plot of calculated $L_{eq}16$ values versus L_{dn} values. For a particular $L_{eq}16$ value, there is a wide range of possible L_{dn} values depending on the number of night-time operations. The measures: $L_{eq}16$, NNI_S, NNI_{UK}, include only day-time operations.

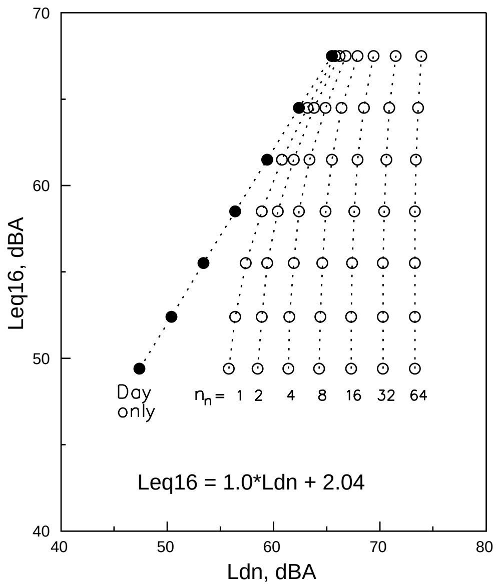

Figure A1: Calculated day-time $L_{eq}16$ values versus L_{dn} values for varied numbers of night-time operations per hour, n_n (regression equation is for the case n_n = 0).

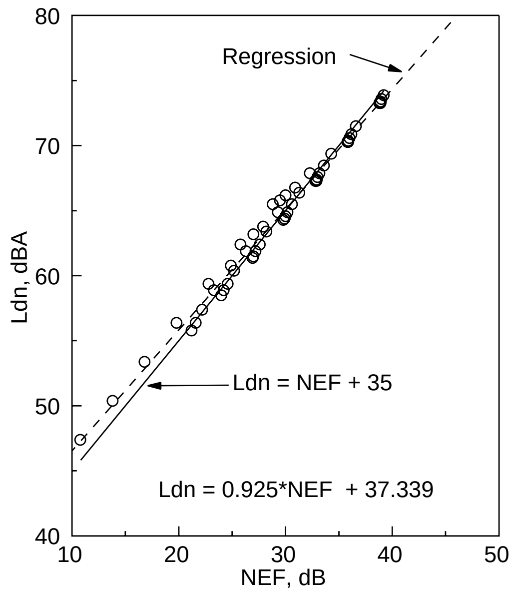

Figure A2: Calculated L_{dn} values versus NEF values, with best fit regression line and solid line representing an approximate relationship.

The measures that include operations from the complete 24-hour period are first plotted as a function of NEF values. Figure A2 plots calculated L_{dn} values versus calculated NEF values. This figure, and other subsequent figures, includes a best fit regression line with the associated standard error of the prediction and R^2 values (correlation coefficient squared). In this case, the R^2 value is quite high (0.990) and the standard error quite small (0.6 dBA). Thus, it is possible to make a reasonable estimate of an equivalent L_{dn} value from a known NEF value.

The regression equation in Figure A2 is the most accurate average conversion from NEF values to L_{dn} values from this analysis. A simpler, but more approximate, conversion was derived from the average differences between the NEF and L_{dn} values. This suggests that L_{dn} values can be estimated by adding 35 to NEF values. This approximate conversion is illustrated by the solid line on Figure A2. Similar conversions have been suggested by others, and this is probably sufficiently accurate for most needs (see also section 8.2).

The other measures are compared with calculated NEF values in a similar manner in the following plots. Figure A3 compares L_{den} values with NEF values. The extra evening weighting in the L_{den} measure introduces a little more scatter (standard error ±1.0 dBA) into the relationship and gives Lden values that are slightly larger than the corresponding L_{dn} values in the previous plot. Thus, L_{den} values can be approximated by adding 36 to NEF values, as illustrated by the solid line in Figure A3.

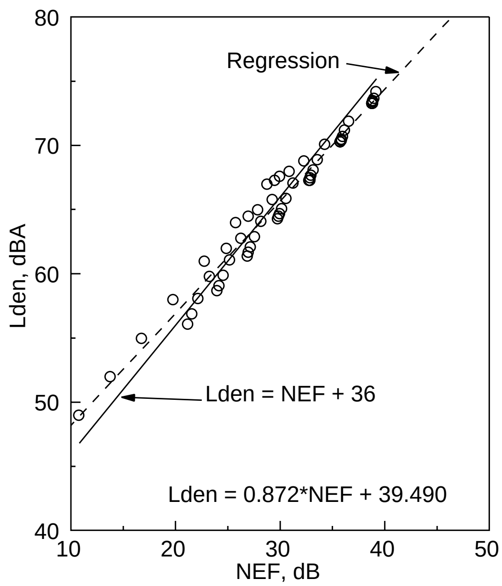

Figure A3: Calculated L_{den} values versus NEF values, with best fit regression line and solid line representing an approximate relationship.

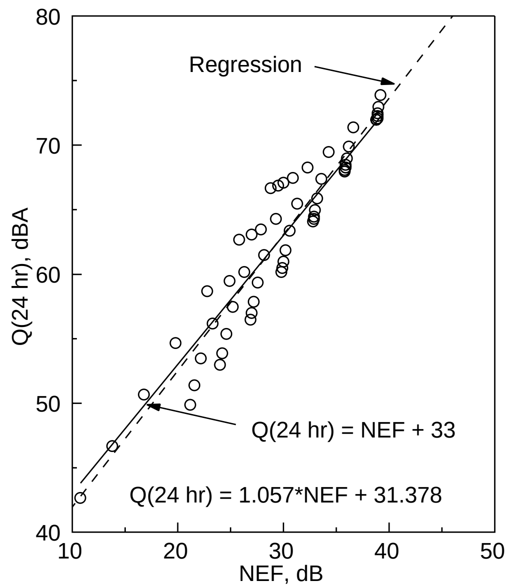

Figure A4: Calculated Q(24 hr) values versus NEF values, with best fit regression line and solid line representing an approximate relationship.

Figure A4 compares calculated Q(24 hr) values and calculated NEF values. There is increased scatter in this relationship (standard error ±2.2 dBA) compared to the previous plot and a reduced R^2. This is due to the larger differences in the night-time weighting schemes for NEF and Q(24 hr) measures. However, it is still possible to make approximate conversions from NEF values to Q(24 hr) values by adding 33 to NEF values.

The French Psophique Index, I_p, is compared with NEF values in Figure A5. Here, a more accurate conversion between the measures is found and the standard error is ±0.8 dBA. I_p values can be approximated by adding 54 to NEF values, as illustrated by the solid line in Figure A5.

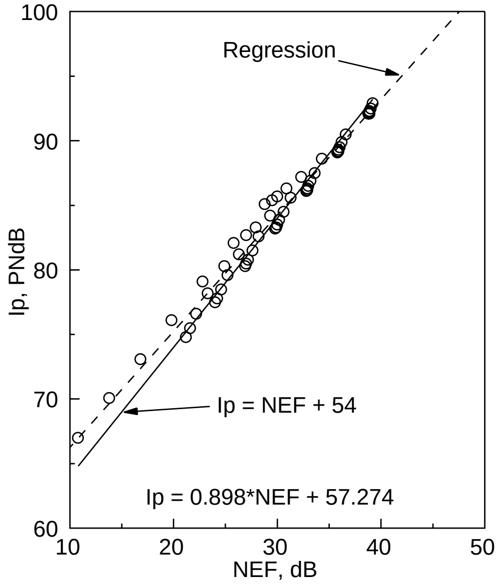

Figure A5: Calculated I_p values versus NEF values, with best fit regression line and solid line representing an approximate relationship.

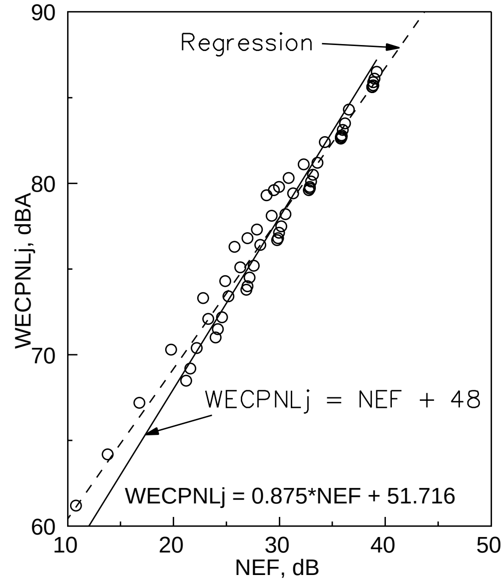

Figure A6: Calculated WECPNLj values versus NEF values, with best fit regression line and solid line representing an approximate relationship.

WECPNLj and NEF values are compared in Figure A6. The best fit regression equation to this data would allow one to predict WECPNLj values with a standard error of ±1.0 dB. WECPNLj values can be approximated by adding 48 to NEF values.

The Total Noise Load or Kosten Unit, B, is plotted versus NEF values in Figure A7. The scatter is quite large (standard error ±2.9 dBA), but one can use the regression equation in Figure A7 to predict B values from NEF values. The increased scatter in this relationship is due to the quite different time-of-day weightings in these two measures. It is not possible to use a simple average difference between these two quantities because the slope of the regression line is not close to 1.0. Because B values are influenced by the distribution of operations throughout the day and night periods, the relationship shown in Figure A7 may not represent typical conditions at real airports.

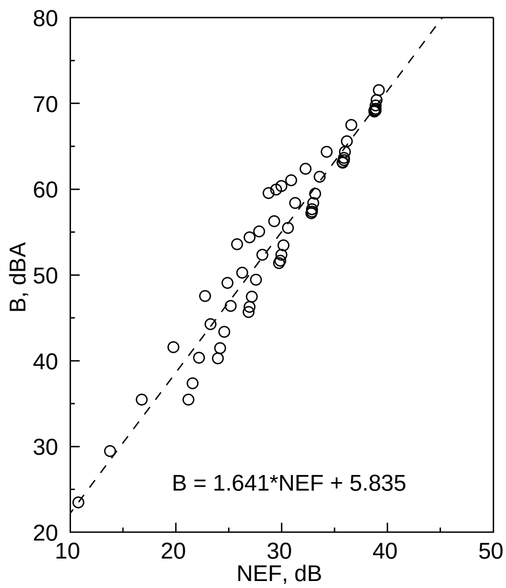

Figure A7: Calculated B values versus NEF values, with best fit regression line.

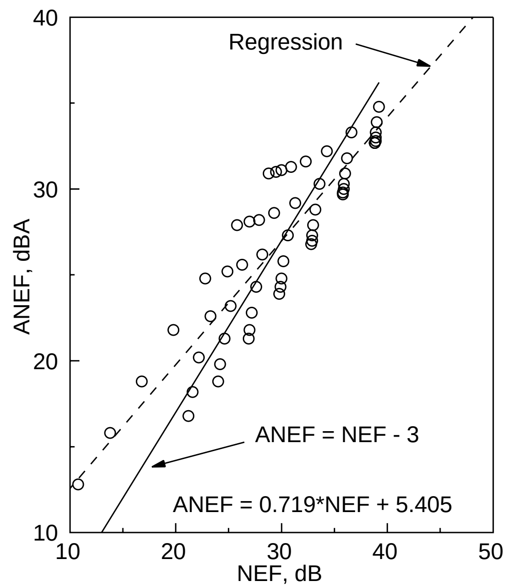

Figure A8: Calculated ANEF values versus NEF values, with best fit regression line and solid line representing an approximate relationship.

Figure A8 compares calculated ANEF and NEF values. The scatter in this relationship is quite large due to the quite different time of day weightings. The standard error about the best fit regression line is ±2.2 dBA. One can approximate ANEF values by subtracting 3 from NEF values.

Because the major differences between measures seem to be due to different time-of-day weighting schemes, an A-weighted equivalent of NEF was calculated with the same time-of-day weightings as the conventional NEF value. Figure A9 plots values of this A-weighted measure, NEF(A), versus NEF values. Because they have exactly the same night-time weighting scheme, the two measures agree perfectly. Of course, this is based on the assumption of a constant relationship between A-weighted levels and PNL values.

Figures A10 to A17 plot various calculated airport noise measures versus calculated L_{dn} values. L_{den} and L_{dn} values are compared in Figure A10. The added evening weighting in the Lden measure produces only small changes relative to L_{dn} values. There is a quite small amount of scatter in this relationship, (standard error ±0.5 dBA), and L_{den} values can be approximated by adding 1 to L_{dn} values.

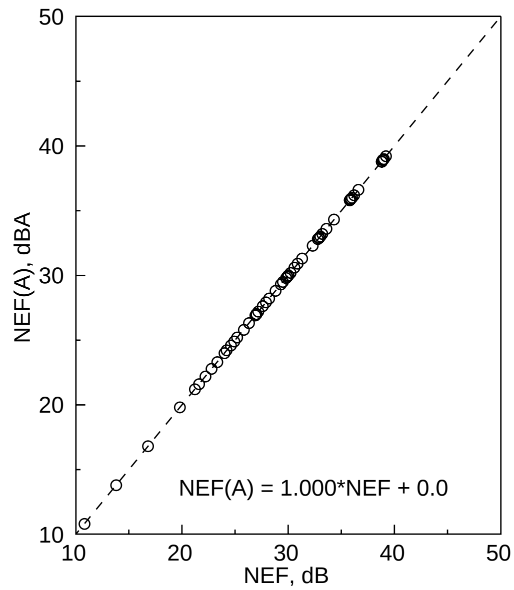

Figure A9: Calculated NEF(A) values versus NEF values, with best fit regression line.

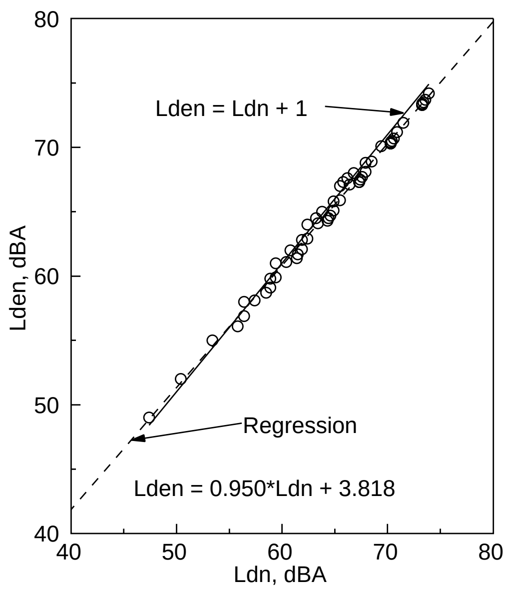

Figure A10: Calculated L_{den} values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

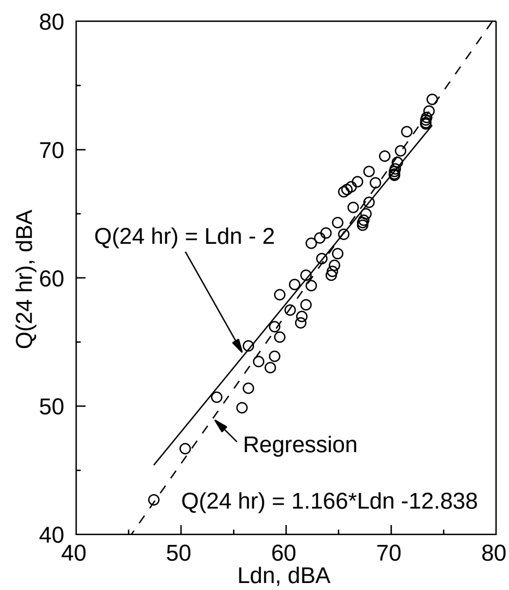

Figure A11: Calculated Q(24 hr) values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

Q(24 hr) values are plotted versus L_{dn} values in Figure A11. The standard error is ±1.5 dB which is larger than in the previous plot, but is smaller than in Figure A4 where Q(24 hr) values were plotted against NEF values. Thus, one can estimate Q(24 hr) values more accurately from L_{dn} values than from NEF values because of the more similar night-time weightings. Q(24 hr) values can be approximated by subtracting 2 from L_{dn} values.

Figure A12 shows that calculated I_p values and calculated L_{dn} values are very closely related with a standard error of only ±0.2 dB. I_p values can be approximated by adding 19 to L_{dn} values.

WECPNLj values are also quite closely related to L_{dn} values, as illustrated in Figure A13. The standard error in this figure is only ±0.4 dBA, and WECPNLj values can be approximated by adding 13 to L_{dn} values.

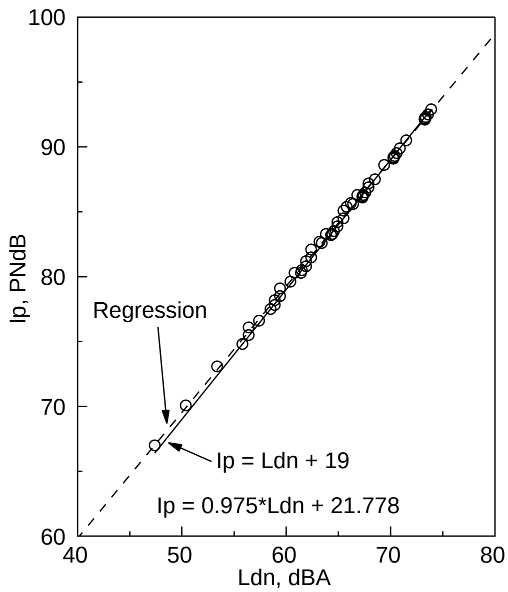

Figure A12: Calculated I_p values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

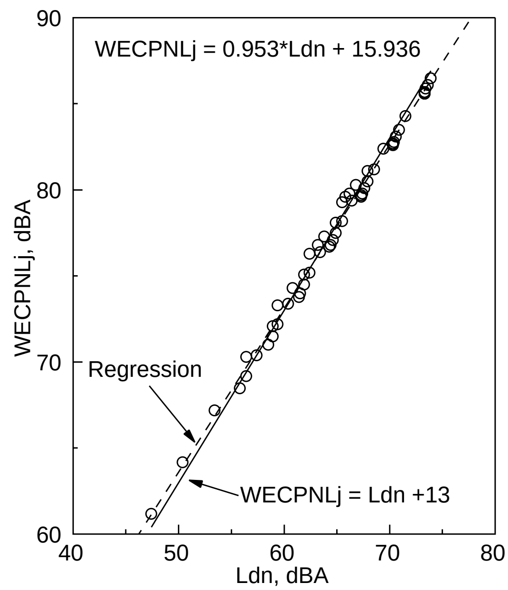

Figure A13: Calculated WECPNLj values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

Figure A14 is a plot of calculated NEF values versus calculated L_{dn} values. The standard error about the best fit regression line is ±0.6 dB. NEF values can be approximated by subtracting 35 from the associated L_{dn} value, similar to the inverse relationship in Figure A2.

Calculated values of the Kosten Unit, B, are plotted versus L_{dn} values in Figure A15. There is a moderate amount of scatter in this relationship with a standard error of ±1.8 dBA about the best fit regression line. It is not possible to use a simple average difference between these two quantities because the slope of the regression line is not close to 1.0. Again, it should be noted that actual B values will be influenced by the distribution of operations throughout the day- and night-time hours.

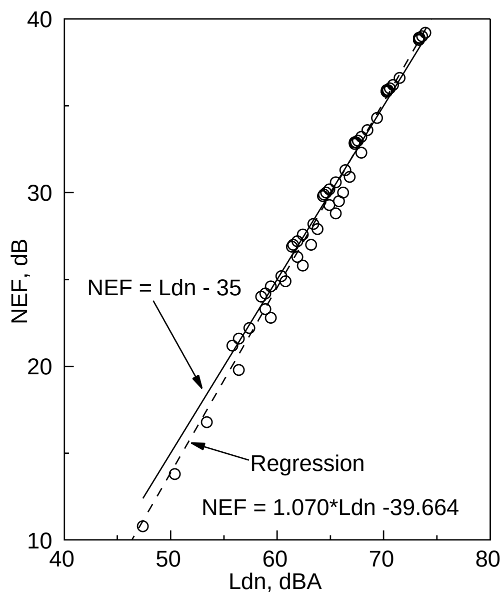

Figure A14: Calculated NEF values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

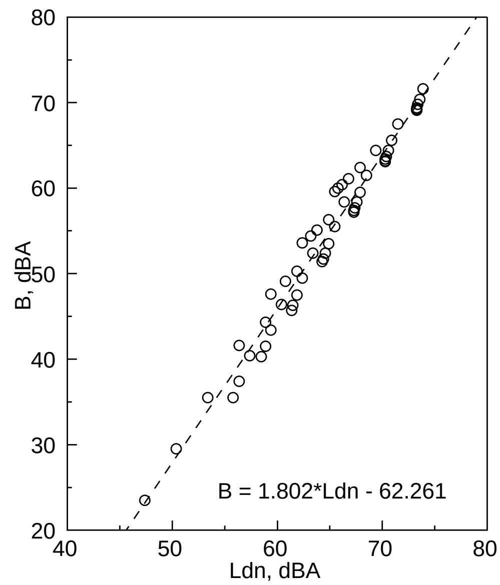

Figure A15: Calculated B values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

ANEF values are compared with L_{dn} values in Figure A16. There is more scatter than in the previous plots and the standard error is ±1.8 dB. ANEF values can be approximated by subtracting 38 from L_{dn} values.

Figure A17 compares calculated values of the A-weighted NEF approximation, NEF(A), with L_{dn} values. Although this measure agreed perfectly with NEF values (Figure A9), there is a small amount of scatter in the relationship with L_{dn} values because of the different night-time weighting schemes.

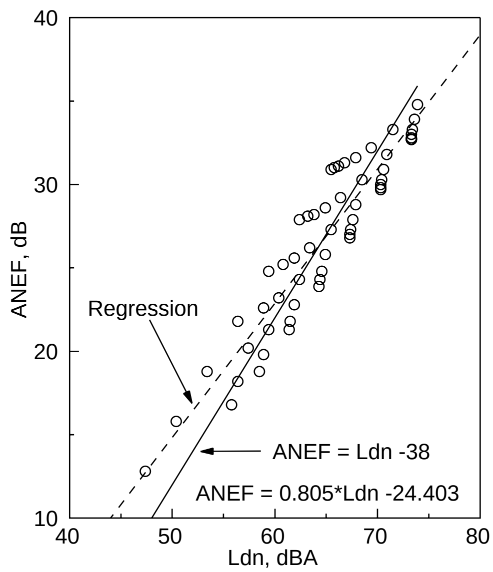

Figure A16: Calculated ANEF values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

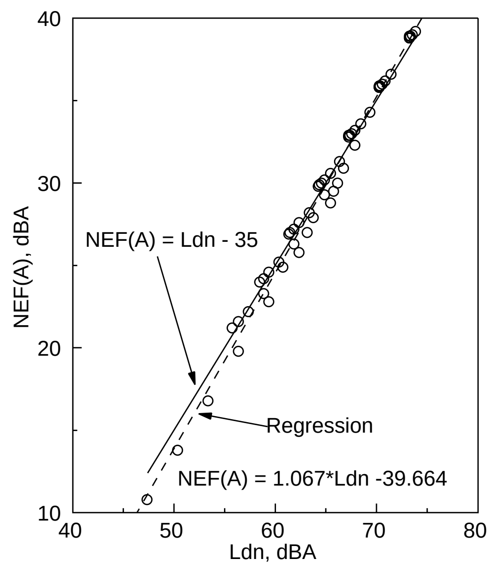

Figure A17: Calculated NEF(A) values versus L_{dn} values, with best fit regression line and solid line representing an approximate relationship.

Table A1 summarises the approximate relationships shown on the previous plots.

Table A1: Summary of approximate conversions.

Measure	re. L_{dn}	re. NEF
L_{dn}	-	NEF + 35
L_{den}	L_{dn} + 1	NEF + 36
Q(24 hr)	L_{dn} - 2	NEF + 33
I_p	L_{dn} + 19	NEF + 54
WECPNLj	L_{dn} + 13	NEF + 48
NEF	L_{dn} - 35	-
ANEF	L_{dn} - 38	NEF - 3
NEF(A)	L_{dn} - 35	NEF + 0.0

A1.3 Comparisons for Day Only

It is possible to compare L_{dn} and NEF values with measures that include only day-time hours by considering cases where there are no night-time aircraft operations. Further regression analyses were performed on the calculated measures for these day-time operations only cases. The resulting equations are given in Table A2.

Table A2. Equations of regressions versus NEF and L_{dn} for day-time operations only cases.

$L_{eq}24$	$= 1.00 \bullet NEF + 36.635$
$L_{eq}16$	$= 1.00 \bullet NEF + 38.676$
NNI_S	$= 1.50 \bullet NEF + 8.920$
NNI_{UK}	$= 1.50 \bullet NEF + 7.046$
Q(day)	$= 1.33 \bullet NEF + 30.693$
$L_{eq}24$	$= 1.00 \bullet L_{dn} + 0.0$
$L_{eq}16$	$= 1.00 \bullet L_{dn} + 2.041$
NNI_S	$= 1.50 \bullet L_{dn} - 46.032$
NNI_{UK}	$= 1.50 \bullet L_{dn} - 47.906$
Q(day)	$= 1.33 \bullet L_{dn} - 18.032$

A1.4 Influence of Effective Fly-by Duration

Most airport noise measures are based on the integration of the noise energy over a complete fly-by. In these calculations, this was approximated by the product of the maximum sound pressure squared and the effective duration of the fly-by. If the effective duration is changed, there may be very little change in the relationship between two measures because the effective duration is changed by the same amount in each quantity. Other airport noise measures are based on maximum levels and not integrated levels. Changes of the effective fly-by duration will affect comparisons of maximum level based measures and integrated level based measures.

Both L_{dn} and NEF are based on the integrated level of individual aircraft fly-bys. Thus, changing the effective duration, t_e, has a negligible effect on the relationship between L_{dn} and NEF. Similarly, the relationships between integrated level based measures such as: L_{den}, $L_{eq}16$, $L_{eq}24$ (for day only operations), Q(24 hr), L_{dn}, and NEF are not influenced significantly by changing t_e.

When other measures based on maximum fly-by levels are compared with L_{dn} or NEF values, the relationship will change with changes in t_e. Changing t_e does not affect the measures based on maximum levels but does affect L_{dn} and NEF and hence the relationship between the two types of measures. Some of the previous regression analyses were repeated for t_e increased from 10 s to 20 s. The resulting regression equations for both values of t_e are given in Table A3.

Table A3. Effect of t_e on regression analyses.

I_p	= 0.898•NEF + 57.274,	t_e = 10 s.
I_p	= 0.898•NEF + 54.570,	t_e = 20 s.
WECPNLj	= 0.875•NEF + 51.716,	t_e = 10 s.
WECPNLj	= 0.875•NEF + 49.080,	t_e = 20 s.
B	= 1.641•NEF + 5.835,	t_e = 10 s.
B	= 1.641•NEF + 0.896,	t_e = 20 s.
NNI_S	= 1.5•NEF + 8.920,	t_e = 10 s. (day only operations)
NNI_S	= 1.5•NEF + 4.405,	t_e = 20 s. (day only operations)

Changing the values of t_e changes the y-intercept of the regression equations but not the slopes. For a doubling of t_e, from 10 to 20 s, NEF values on the right side of these equations would increase by 3 dB. Thus, the changes in the other quantities shown in Table A3 depend on the slope of the regression equations. In many cases the slope is approximately 1.0 resulting in an approximate 3 dB change in the relationship with the other measures (e.g. Ip, Q(24 hr), WECPNLj). Where the slope is greater than 1.0, there is a larger change in the relationship (e.g. NNI_S, B). Thus, the result of changing the effective fly-by duration can be calculated from the slopes of the above regression equations.

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3. Matschat. K. and Müller, E-A, "Vergleich nationaler und internationaler Flugälarmbewertungsverfahren. Aufstellung von Naherngsbeziehen zwischen den Bewertungsmassen", Max Planck Institut Report, November (1981).

APPENDIX 2. SUMMARIES OF OTHER REPORTS

A2.1 NEF Validation Study: (2) Review of Aircraft Noise and its Effects

SUMMARY

This is a summary of the second of three reports containing the results of an NEF validation study for Transport Canada.

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.

This report reviews:

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

This is 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 considered issues related to the calculation of airport noise contours. The two reports will form the technical background for a final report to Transport Canada reviewing all aspects related to the use of the NEF measure.

Some of the major technical findings of this report are 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 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 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 outdoor 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 are 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 counter measures 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).

A2.2 NEF Validation Study: (3) Final Report

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

- Consider adopting an A-weighted NEF measure.
- 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.
- Upgrade (and provide ongoing support for) the continuing development of the NEF_1.7 program.
- Support updating of the CMHC document on new housing and aircraft noise.
- Establish and publish noise criteria for all major Canadian airports in terms of NEF values and supplementary single event noise criteria.
- Encourage 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} 40, limit for existing homes. (NEF_{CAN} refers to NEF values predicted 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 predictions.
- 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 responses as a function of noise levels.
- 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.