SEA-TAC COMMUNITIES PLAN

Final Report

NOISE STUDY

Volume II

Prepared by:

MAN-Acoustics and Noise, Inc.
2105 North 45th Street
Seattle, Washington 98103

T. L. Hughes
J. E. Mabry
H. J. Parry

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PORT OF SEATTLE
KING COUNTY

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September 1974

ACKNOWLEDGMENTS

The combined efforts of a large number of people are required in a program of this magnitude and the authors gratefully acknowledge their contributions. These personnel include members on the staffs of the King County Division of Land Use Management, Port of Seattle Department of Planning and Research, and the Airlines operating at SEA-TAC. Also, FAA personnel at Seattle-Tacoma Airport and from the Northwest Region office have been unusually helpful.

The authors wish to extend special thanks to Ken Whitehead and Dick Coykendall of United Airlines who aided the program in many ways.

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NOISE EVALUATION UNITS

Literally dozens of different noise evaluation units have been developed over the past 50 years. In 1970, Young (Reference 1) noted that he had identified sixty-some evaluation units as of that time, and others have been proposed since. However, a consensus seems to be emerging from this vast lore that a suitable noise evaluation unit for transportation systems, and for aircraft in particular, must account for the combination of time varying noise and complex frequency weighting.

Some noise evaluation units, like maximum sound level-A as measured directly on a sound level meter, do provide for frequency weighting, but not for the time varying characteristic of the noise or for the presence of discrete tones as produced by aircraft engine compressors. Human response to all of these aspects is well documented (Reference 2). Thus, a unit that accounts for all the characteristics is most desirable. Such a unit is effective perceived noise level (EPNL). A-weighted sound levels are also used to obtain time integrated units, such as the noise pollution level (L_{NP}) and the equivalent noise level (L_{eq}), and are in some ways equivalent to EPNL except for pure tone corrections that are necessary to account for increased human sensitivity to tones.

As shown in Figure A, EPNL accounts for human response, and for the noise characteristics of level, spectrum, tones and duration. It is the only such measure in common use today.

HUMAN RESPONSES
NOISE CHARACTERISTICS
LEVEL
SPECTRUM — EPNL
TONES
DURATION — NEF and ANE
OPERATION CONSIDERATIONS
NUMBER OF OPERATIONS
MIX OF AIRCRAFT
FLIGHT PATHS
SCHEDULES

FIGURE A - Factors accounted for in noise exposure evaluation units

SOUND NOISE EXPOSURE LEVEL - A CUMULATIVE MEASURE OF NOISE

Since EPNL is a measure that accounts for the total accumulation of noise for a single noisy event, it is called a sound exposure level. In contrast to a maximum sound level, sound exposure levels represent the summation of the sound energy during an entire event. Thus, even though the noise level may fluctuate up and down, the sound exposure level is always increasing. In principle, one could measure the sound exposure levels as the sum of sound energy received during a very long period, like the lifetime of a man. Many important sounds, however, are of significant magnitude only during a much shorter time, like a few seconds. Hence, the sound exposure level of an aircraft flyover may practically be measured during the 10 or 20 seconds for which the sound level is within 10 decibels of the maximum level. An aircraft with a relatively long duration flyover noise has an EPNL value greater than for an aircraft with a shorter duration noise if the maximum sound levels are the same.

In general then, for a noise at a constant level, the sound exposure level in decibels will exceed the maximum sound level by ten times the logarithm of the duration of the time interval in seconds. Some sound exposure scales are normalized by a specified reference time. For EPNL, the reference time is 10 seconds. For example, the average sound level for a constant sound of 60 decibels observed for either 10 or 100 seconds will be 60 decibels in both cases, but the sound exposure levels for the same conditions normalized to 10 seconds would be, respectively, 60 and 70 decibels.

Basic certification measurements for aircraft subject to Federal Aviation Regulation (FAR) Part 36 certification rules (Reference 3) are reported in terms of effective perceived noise level (EPNL) units of EPNdB. Unlike most other kinds of sound exposure level units, EPNL has a provision for assessing a numerical penalty for the presence of pronounced tonal components in the spectrum.

The numerical differences between EPNL and other sound level or sound exposure level units are thus a function of aircraft type, engine power setting, and distance from the aircraft since air absorption affects the spectral distribution of the noise signal. In general, EPNL will be numerically greater than sound exposure levels based on sound level-A values. Typical values of this difference, for takeoff power settings, are from 1 to 5 dB. The difference at approach power settings ranges typically from 2 to 8 dB. However, if maximum sound levels are compared with sound exposure levels, much greater differences can arise since maximum sound levels do not account for duration of exposure as discussed earlier.

MEASURES OF NOISE FOR MANY EVENTS

Noise exposure forecast (NEF) and actual noise exposure (ANE) are noise measures that account for the accumulation of noise from many events. As shown in Figure A, NEF and ANE use the EPNL exposure values for individual events combined with the operational factors of number of operations, mix of aircraft, flight paths and schedules. Thus, the NEF or ANE value at a ground position is a calculated estimate based on standard values of single event noise exposure levels resulting from aircraft operations.

The noise pollution level (L_{NP}), day-night average sound level (L_{dn}), and equivalent noise level (L_{eq}) scales are also measures of the integrated energy for many events over specified time intervals. The time intervals involved here are minutes, hours, day, night, and 24-hours depending on the location and purpose of the measurements. The L_{eq} measure is used in the present report for analysis of surface noises. Measurement data of surface noise and most ANE measurements are included in a later section of this report.

RELATIONSHIP OF NOISE EXPOSURE CRITERION LEVELS

Decisions on levels of acceptability require consideration of factors beyond the purely technical or scientific. These other factors include those in the political, social, ethical, and economic areas and are primarily administrative concerns. The following discussion is aimed primarily at describing the scientific technical relationship between NEF and ANE values and direct and indirect effects on health. These effects include hearing loss, speech communication, annoyance, and general health effects of noise.

There are two considerations in evaluating the potential effects of noise on hearing loss: the direct and indirect effects.

The direct effects are those created because the noise may be sufficiently intense to directly cause permanent hearing loss. The indirect effects are those that would prevent recovery of the hearing mechanism from an occupational, recreational or environmental noise exposure.

In its recent report to the Congress (Reference 4), the EPA concludes that there is at present insufficient evidence concerning indirect effects of noise on hearing loss to include such effects in noise impact analyses. That report indicates that noise exposure can be related to potential hearing loss, speech interference and annoyance. Further, Reference 4 concluded that, "Cumulative noise exposure levels as defined by such methodologies as day-night average sound level (L_{dn}), NEF, etc. are believed to be the best available means of identifying and evaluating the impact of noise around airports." Thus, L_{dn}, L_{NP}, L_{eq}, NEF and ANE are among the best available units for evaluating the effects of noise on hearing loss, speech communication and annoyance.

A further consideration in the choice of noise exposure is that NEF was originally developed from reported case histories of the effect of aircraft noise on people in their homes in airport communities (Reference 5). For this reason they bear a direct relationship to the overall impact of aircraft noise and its associated effects on people living near large airports and would include other possible effects of the noise, such as vibration, on habitability.

SUMMARY OF BASIC NOISE EXPOSURE METHODOLOGIES

Noise Exposure Forecast/Actual Noise Exposure

Noise Exposure values are determined from aircraft noise levels expressed in terms of the effective perceived noise level (EPNL) as defined in Reference 3. In calculating the noise exposure near an airport flight path resulting from the operation of a number of different aircraft types, it is convenient to group the different aircraft types into classes based upon considerations of aircraft noise and performance characteristics. Each class is then characterized by a set of takeoff and landing profiles and a set of noise-distance curves. Noise exposure values may then be determined from these curves. At any particular location the noise exposure is determined by the appropriate summation of the noise values from the individual aircraft classes.

Two noise exposure methodologies were used in this study. The NEF procedure uses a set of generalized noise-distance curves for each aircraft class. However, for the ANE procedure the generalized noise curves were redefined based upon the aircraft measurements taken in the SEA-TAC communities and described in Volume I of this report. Other than the difference in the sets of noise-distance curves, the two methodologies are identical.

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

$$NE\ (ij) = EPNL(ij) + 10 \log_{10}\left[\frac{N\ (day)(ij)}{K\ (day)} + \frac{N\ (night)\ (ij)}{K\ (night)}\right] - C$$

where

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

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

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

C = Arbitrary normalization constant which has been selected as 75.

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

$$10 \log_{10}\left[\frac{20}{K\ (day)}\right] = 0; \quad K(day) = 20$$

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

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$$10 = 10 \log_{10} \frac{K\ (day)}{K\ (night)} \times \frac{9}{15}$$

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

And, K (night) = 1.2

With the above choices for values of K and C, the NE equation becomes:

$$NE(ij) = EPNL(ij) + 10 \log_{10} \left[N(day)(ij) + 16.67\ N(night)(ij) \right] - 88$$

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

$$NE = 10 \log_{10} \sum_{i} \sum_{j} \text{antilog} \frac{NE(ij)}{10}$$

Aircraft Sound Description System

The Aircraft Sound Description System (ASDS) as described in Reference 6 provides a conceptual method for characterizing aircraft noise near airports. The technique finds the total time that the sound level exceeds 85 dBA as a means of depicting the noise exposure. The areas which are expected to be exposed to sound levels in excess of 85 dBA are defined by closed contours. There is a methodology for calculating noise exposure time values as well as a noise "Situation Index." The basis for this methodology is the 85 dBA noise contour for each aircraft type by weight and operation type (takeoff or landing).

The Aircraft Sound Description System produces exposure times for one or more zones which result from the overlapping of a set of aircraft noise contours. For example, when there are three ground tracks departing from a single runway, as many as six separate zones can be created by the overlap of the contours of a single aircraft. This is illustrated in the simplified example shown in Figure B. As shown in that figure, each ASDS zone is related to a total exposure time. In actual practice, the zones include both takeoff and landing exposure times. Each takeoff is assigned a 15 second exposure and each landing a 10 second exposure.

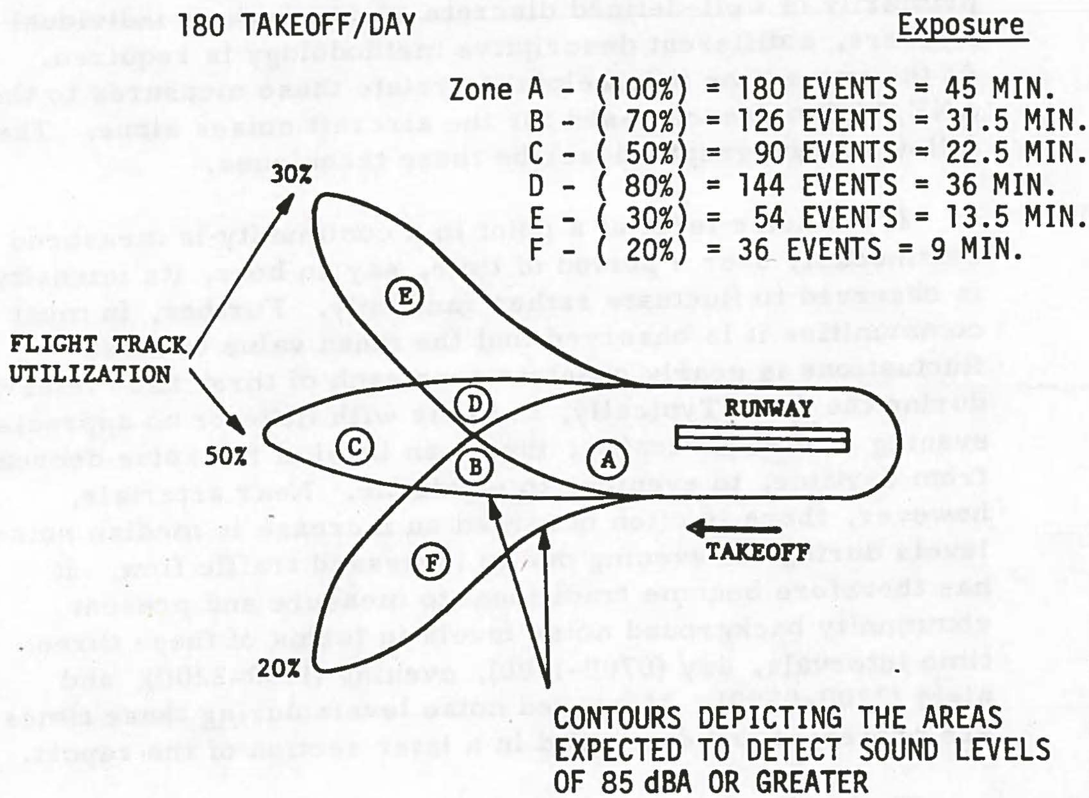

FIGURE 8 - Typical Aircraft Sound Description System contour set

In addition to the foregoing analysis, the numerical value of the "Situation Index" may also be developed. The Situation Index is a single number, expressed in acre-minutes, which represents the overall exposure in excess of 85 dBA for the area under analysis. It is a useful figure of merit for comparative purposes. In essence, the Situation Index equals the product of the total exposure time in minutes and the zone area in acres, For example, if the area of Zone A were 10 acres, the Situation Index would be:

$$SI = (45 \text{ min.}) \times (10 \text{ acres}) = 450 \text{ acre-minutes}$$

Percentile, Noise Pollution, and Equivalent Levels

During the noise measurement program, data was also obtained at fifteen sites in the airport community to include the effects of aircraft and of other noise sources in the vicinity. Because these background noises do not consist primarily of well-defined discrete events such as individual flyovers, a different descriptive methodology is required. At the same time it is helpful to relate these measures to the ANE/NEF measures used for the aircraft noises alone. The following paragraphs describe these techniques.

If the noise level at a point in a community is measured continuously over a period of time, say an hour, its intensity is observed to fluctuate rather randomly. Further, in most communities it is observed that the mean value of these fluctuations is nearly constant over each of three time intervals during the day. Typically, in areas with little or no appreciable evening rush-hour traffic, the mean level of the noise decreases from daytime, to evening, to nighttime. Near arterials, however, there is often observed an increase in median noise levels during the evening due to increased traffic flow. It has therefore become traditional to measure and present community background noise levels in terms of these three time intervals, day (0700-1900), evening (1900-2200), and night (2200-0700). Measured noise levels during these times are presented and discussed in a later section of the report.

The most useful methods for describing these fluctuating noise levels are based on measurements of the number of occurrences of the amplitudes of the fluctuations. These are then related to several standard percentile levels. For example, L_{50} is the sound level value whose amplitude is exceeded during 50 percent of the observation period; L_{10} is the level exceeded 10 percent of the time; L_1 is the level exceeded 1 percent of the time, and so forth for L_{90} and L_{99}. Note that in general, since L_{99} is exceeded 99 percent of the time, its value is lower than the higher percentile levels such as L_{90}, L_{50}, L_{10} and L_1. Likewise, the other percentiles are similarly ranked. Of course, there is no such definite relationship between measurement sites. The background noise levels presented herein are given in terms of these percentiles (median = 50th percentile). Also given are the mean (arithmetic average), standard deviation (S_{DEV}), noise pollution level (L_{NP}) and continuous noise equivalent level (CNEL).

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The standard deviation is simply determined by well known statistical techniques. Noise pollution level is then calculated from:

$$L_{NP} = L_{eq} + 2.56\ S$$

Thus, L_{NP} attempts to account for the median level of the noise as well as the fluctuations in the level. It has been found that this measure is also closely related to human reaction to noise. Noise pollution level is closely related to other measures of fluctuating noises including NEF, equivalent sound level (L_{eq}), day-night average sound level (L_{dn}) and CNEL. These relationships are described below.

Noise pollution level (L_{NP}) is related to L_{eq} by:

$$L_{eq} = L_{NP} - (L_{10} - L_{90})$$

Also, L_{eq} can be obtained from the percentile level values:

$$L_{eq} = L_{50} + \frac{(L_{10} - L_{90})^2}{60}$$

From the day, evening and night hourly values of L_{eq}, the CNEL can then be calculated as:

$$\mathrm{CNEL} = 10 \log_{10} \frac{1}{24} \left[\sum_{0700}^{1900} 10^{\frac{L_{eq}\,(\mathrm{day})}{10}} + 3 \sum_{1900}^{2200} 10^{\frac{L_{eq}\,(\mathrm{evening})}{10}} + 10 \sum_{2200}^{0700} 10^{\frac{L_{eq}(\mathrm{night})}{10}} \right]$$

The day-night average sound level (L_{dn}) can also be computed from the day and night hourly values of L_{eq} as:

$$L_{dn} = 10 \log_{10} \left[\sum_{0700}^{2200} 10^{\frac{L_{eq}(\mathrm{day})}{10}} + \sum_{2200}^{0700} 10^{\frac{L_{eq}(\mathrm{night})+10}{10}} \right]$$

The approximate relationship between these scales is:

$$\mathrm{CNEL} \approx L_{dn} \approx \mathrm{NEF} + 35\ (\pm 3\mathrm{dB})$$

Thus, a method for directly relating background noise and flyover noises is provided.

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NOISE EXPOSURE CALCULATIONS

In the calculation of the NEF and ANE values, information is required regarding the noise and performance characteristics of the aircraft operating at the airport. To simplify calculations it is convenient to group aircraft into classes based upon similar noise and performance characteristics. Seven different classes of aircraft were used in the SEA-TAC studies. These seven classes are defined in Table I, with examples of each class and include all of the aircraft types currently operating at SEA-TAC. Data are also needed on runway utilization figures for the airport and the fleet composition of the seven aircraft classes.

Data used in the Interim Study (Reference 7) were based on information readily available in the published literature. However, in the Final Study, these data were updated and several changes were made. These changes were with regard to aircraft noise and performance and the fleet composition. Since these changes significantly affect the noise exposure calculations, the data from both studies will be discussed.

Note in Table I, taken from the Interim Report, that for each aircraft class, there are a series of takeoff profiles corresponding to different stage lengths. In the Interim Study, stage lengths were taken to be the maximum trip distance as shown on the SEA-TAC master flight schedule. The longer trip distance performance curves are associated with lower takeoff profiles as shown in Figure C. Note that these are full power takeoffs. For a given aircraft the lower takeoff profiles will produce larger noise values on the ground than a higher takeoff profile. The takeoff profiles presented in Figure C show the aircraft altitude at a given distance from the brake release point.

For the Final Study, Table II shows that the takeoff performance for a given aircraft and stage length are associated with an operating weight of that particular aircraft. Information provided by the airlines showed that using the maximum trip distance as the stage length did not correspond to the actual case because some aircraft only fuel to the next major hub. Therefore, a more realistic breakdown of stage length and gross weight was used. A maximum of three different operating weights was used to represent the actual distribution

TABLE I - Aircraft classifications for noise exposure computations used in the interim study

AIRCRAFT TYPE	EXAMPLES	AIRCRAFT CLASS	TAKEOFF PROFILE Trip Length in N. Miles 0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500	4500+
Large 4-engine turbojet transports	Boeing 707-120, and 720 Douglas DC-8-10,-20,-30,-40 Convair 880	1	B	B	B	C	D	E	E
Large 4-engine turbofan transports (standard and stretched)	Boeing 707-320 B, C Douglas DC-8-50,-8F,-60 series	2	B	B	B	B	C	D	E
Three-engine turbofan transports	Boeing 727-100,-200	3	B	C	C	D	D		
Two-engine turbofan transports	Boeing 737 Douglas DC-9 BAC 111	4	B	B	B	B			
Large "new generation" 4-engine turbofan transports	Boeing 747	5	B	B	B	B	C	D	E
Large "new generation" 3-engine turbofan transports	Douglas DC-10 Lockheed 1011	6	B	C	C	D	D		
Two-engine piston and turboprop aircraft (over 12,500 lbs. max. gross wt.)	Convair 340, 440, series Douglas DC-3 Fairchild F-27 series Grumman Gulfstream I	7	← PA →						

TABLE II - Aircraft classifications for noise exposure calculations used in the final study

AIRCRAFT TYPE	EXAMPLES	AIRCRAFT CLASS	TAKEOFF WEIGHTS (IN 1000 LBS. ASSUMED FOR VARIOUS STAGE LENGTHS (IN N.M.) 500	500 to 1500	>1500 (b)	2000 to 3000	over 4000
Large 4-engine turbojet transports (a)	Boeing 707-120, and 720 Douglas DC-8-10,-20,-30,-40 Convair 880	1	190	200	230	--	--
Large 4-engine turbofan transports (standard and stretched)	Boeing 707-320 B, C Douglas DC-8-50,-8F,-60 series	2	200	215	245	--	--
Three-engine turbofan transports (c)	Boeing 727-100,-200	3	125	140	155	--	--
Two-engine turbofan transports	Boeing 737 Douglas DC-9 BAC 111	4	83	95	--	--	--
Large "new generation" 4-engine turbofan transports	Boeing 747	5	--	--	500 (d)	535	660
Large "new generation" 3-engine turbofan transports	Douglas DC-10 Lockheed 1011	6	300	325	345	--	--
Two-engine piston and turboprop aircraft (over 12,500 lbs. max. gross wt.)	Convair 340,440, series Douglas DC-3 Fairchild F-27 series Grumman Gulfstream I	7	PA				

(a) Four engine jet gross weights are based on the same percentage of maximum takeoff weight as the four engine fans (707-320B).
(b) Gross weight for ranges greater than 1500 miles are based on a weighted average (except B-747)
(c) Weights for the three engine class are averages for the 727-100's and 727-200's.
(d) 1500-2000 N.M.

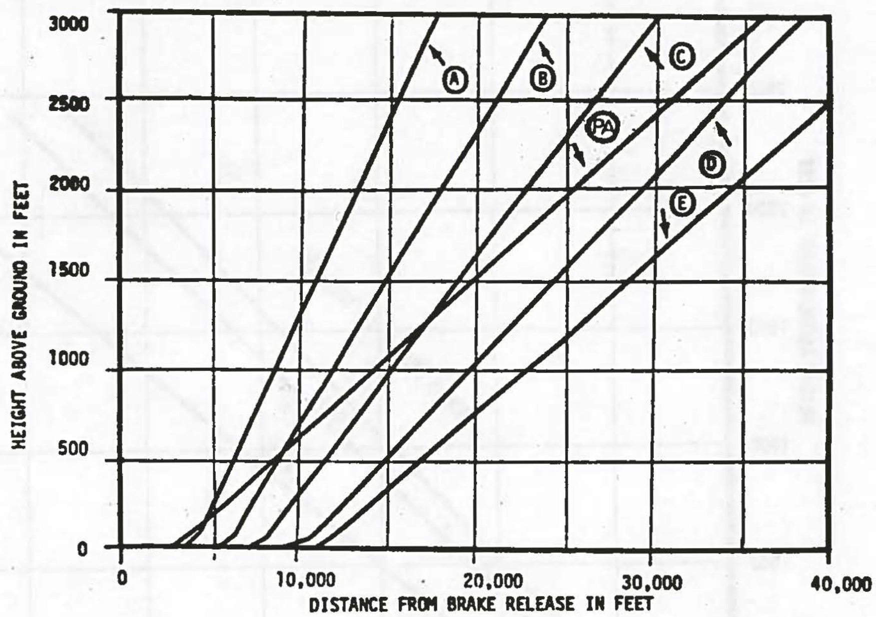

FIGURE C - Generalized takeoff profiles used in the interim study

of gross weights for a given aircraft class operating at the airport. The takeoff profiles for the six classes is presented in Figures Dl through D6 for full power takeoffs.

The NEF calculations for the Interim Study were based on the noise-distance curves shown in Figures El through E5. For each aircraft class there are noise versus distance curves for both approach and takeoff. These are the same basic noise curves as are given in References 8 and 9, for current aircraft. Estimated noise-distance curves for aircraft classes 2, 3, and 4 with nacelles equipped with sound absorbing materials (SAM) are also shown. These estimated curves, labeled "Q", were developed from data given in References 10 and 11 and reflect lower noise levels at altitudes under 5000 feet due to the SAM reducing high frequency noises. At greater distances, the extra attenuation of the atmosphere has already produced a significant reduction of the high frequency noises and the SAM effect is not observable.

An updated set of noise-distance curves was used in the final Study for all the aircraft classes except classes 1 and 7. The basic noise curves are shown in Figures Fl through F5. The retrofit noise curves for classes 2, 3, and 4 are shown in Figures F6 through F8. Notice that in these figures there are more than two noise-distance curves for each aircraft class. These figures represent noise-thrust-

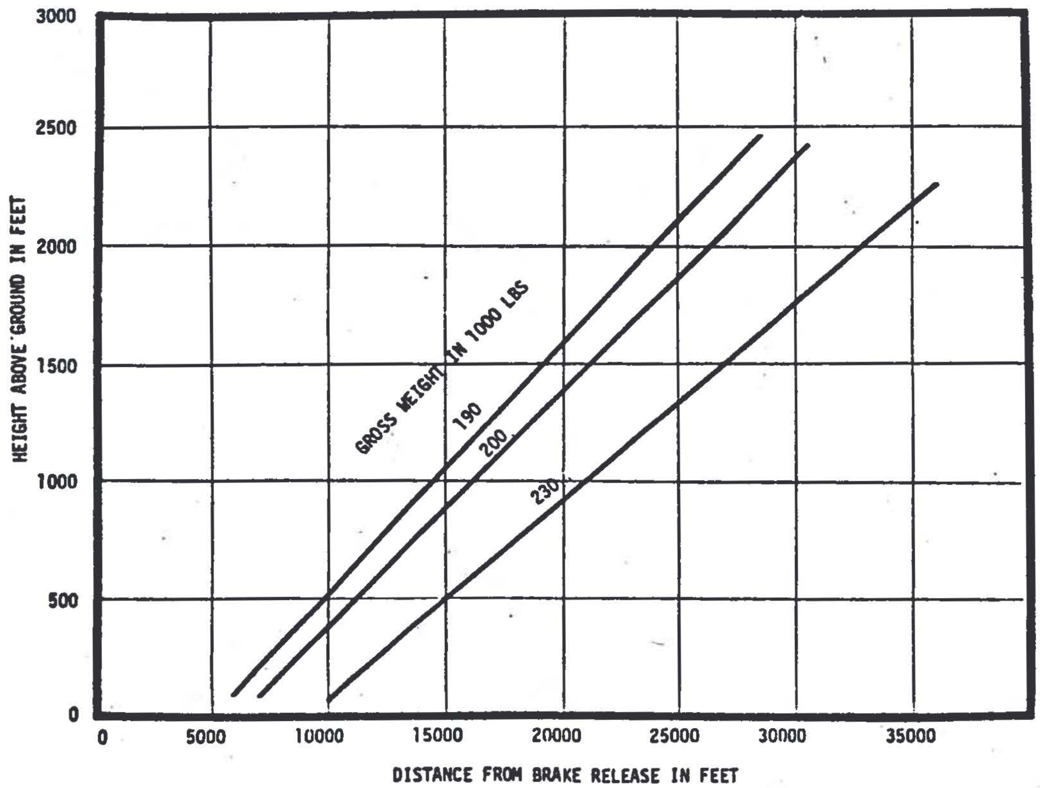

FIGURE D-1 - Takeoff profiles for Class 1 used in the final study

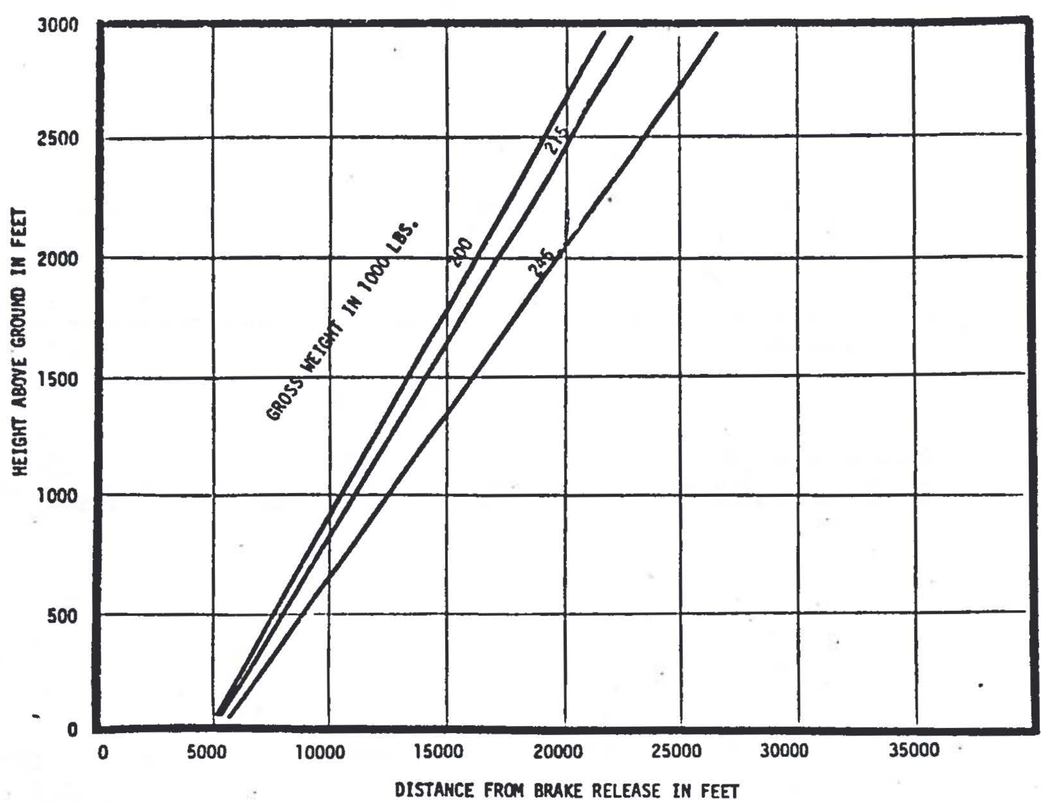

FIGURE D-2 - Takeoff profiles for Class 2 used in the final study

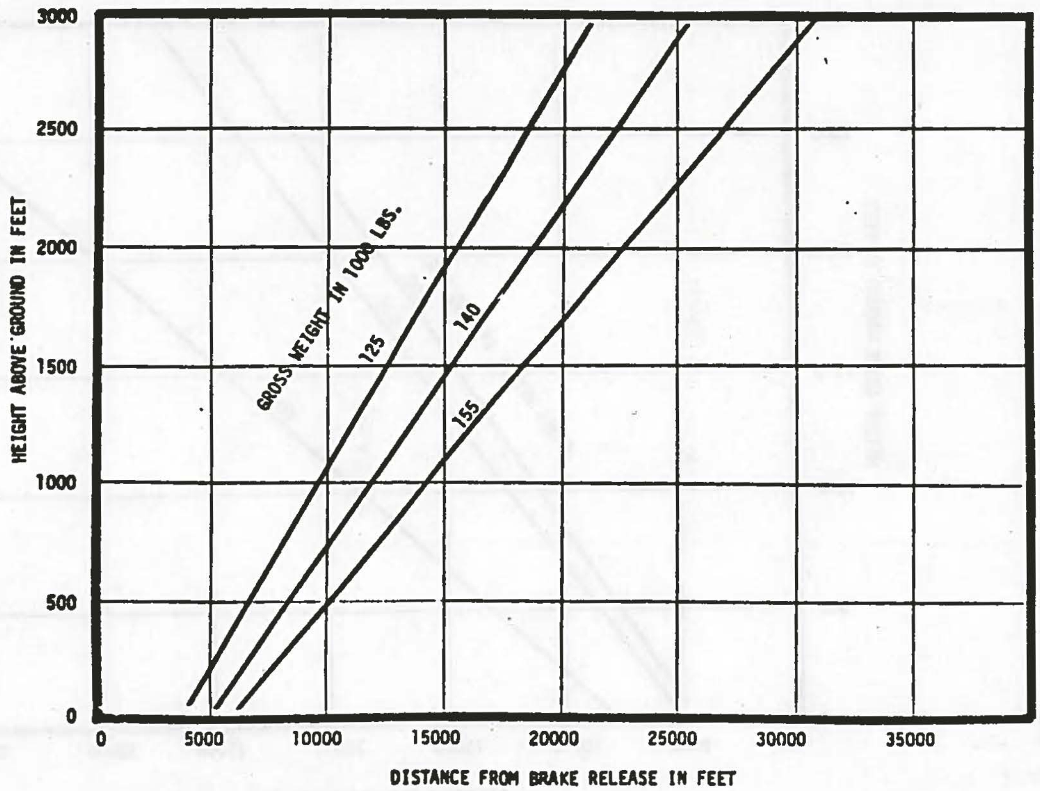

FIGURE D-3 - Takeoff profiles for Class 3 used in the final study

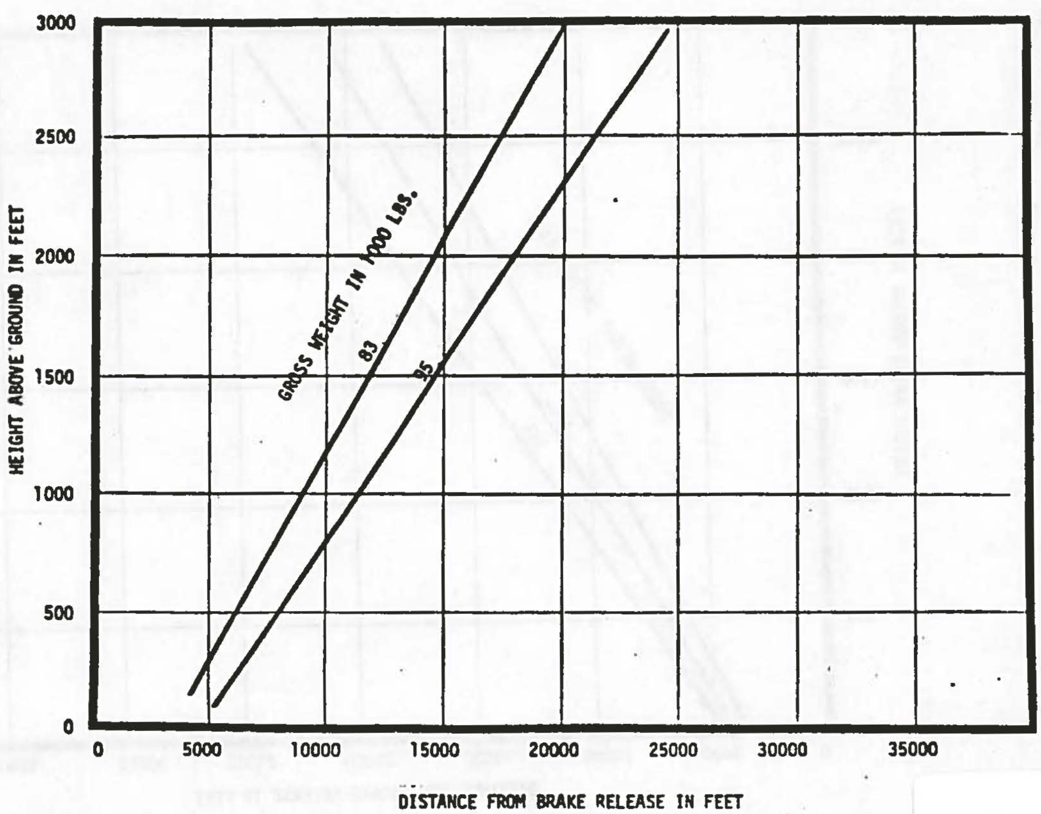

FIGURE D-4 - Takeoff profiles for Class 4 used in the final study

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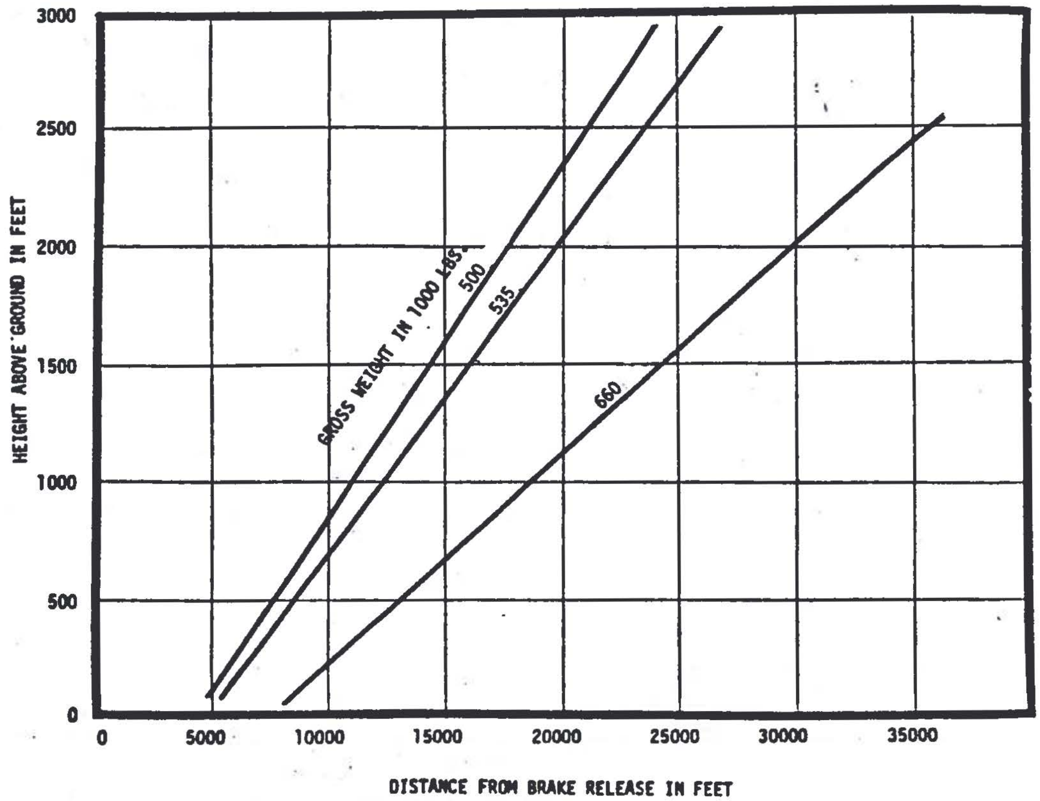

FIGURE D-5 - Takeoff profiles for Class 5 used in the final study

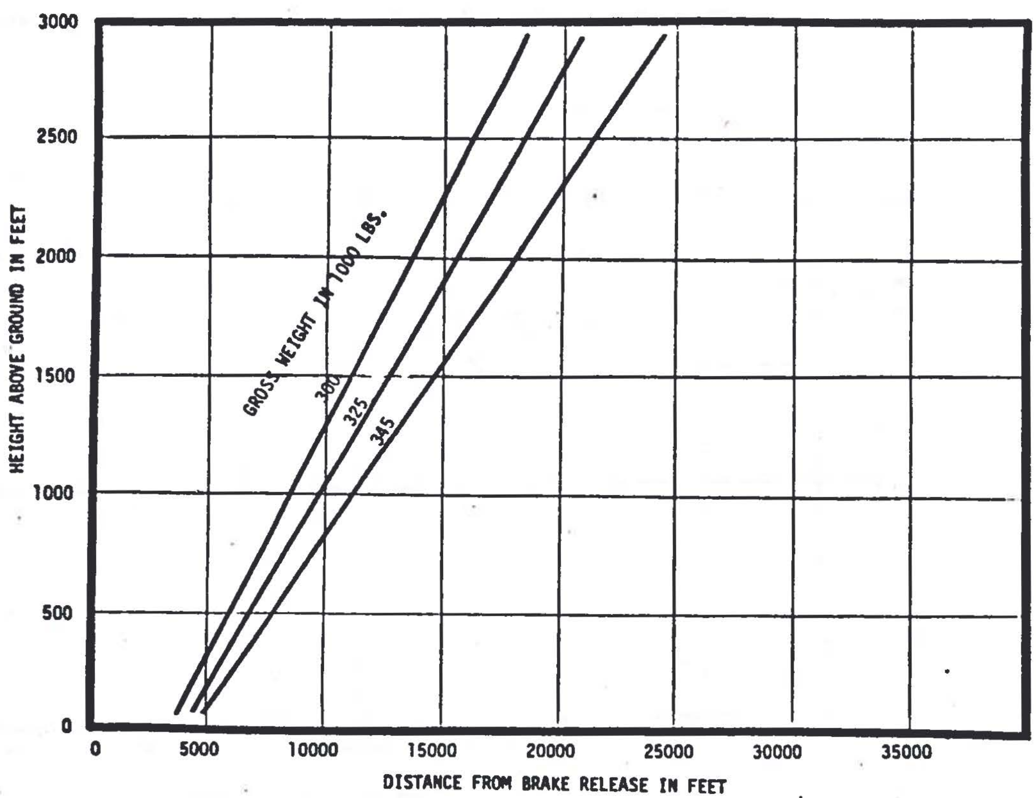

FIGURE D-6 - Takeoff profiles for Class 6 used in the final study

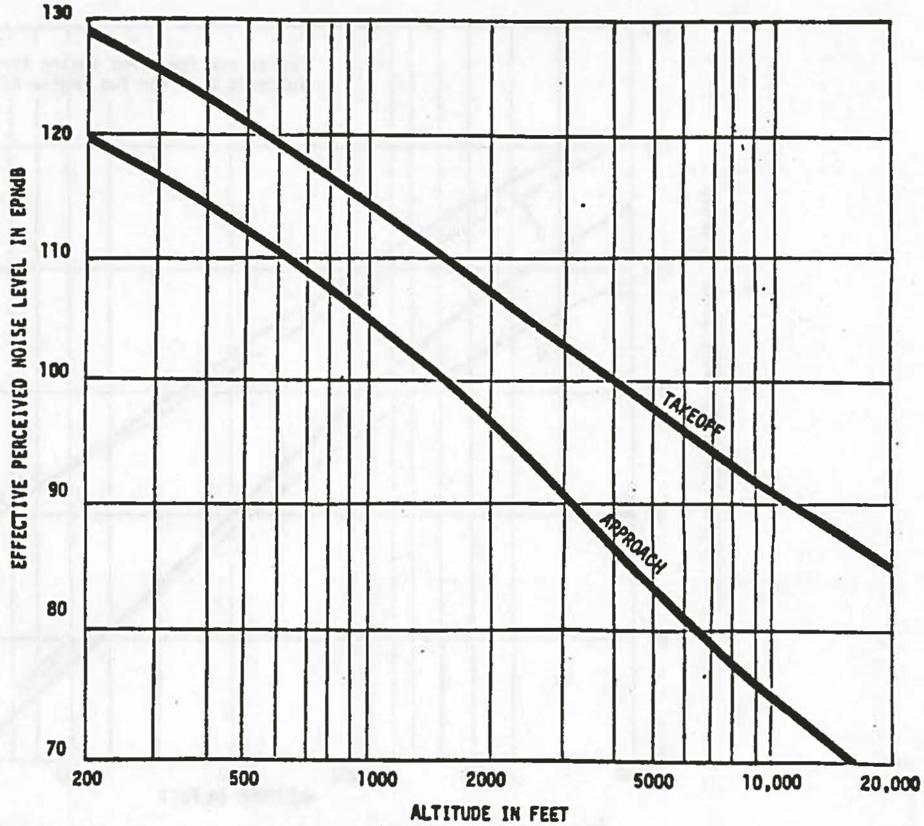

FIGURE E-1. - Variation in effective perceived noise levels with altitude
Four engine Turbojet transport aircraft - Class 1

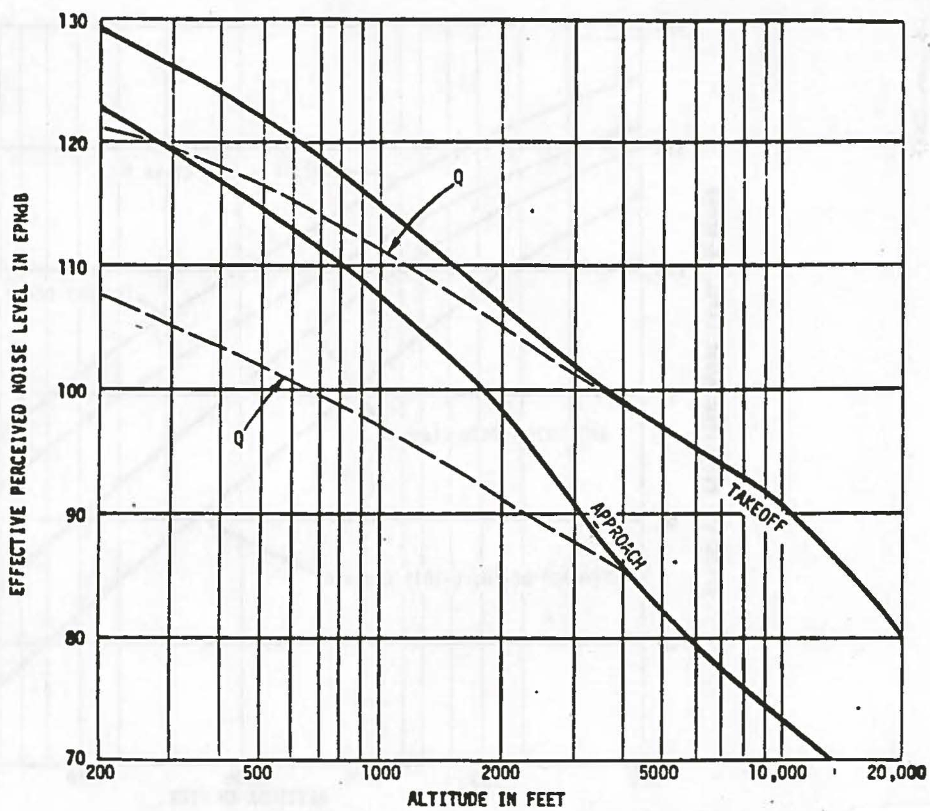

FIGURE E-2. - Variation in effective perceived noise levels with altitude
Four-engine turbofan transport aircraft LBPF - Class 2

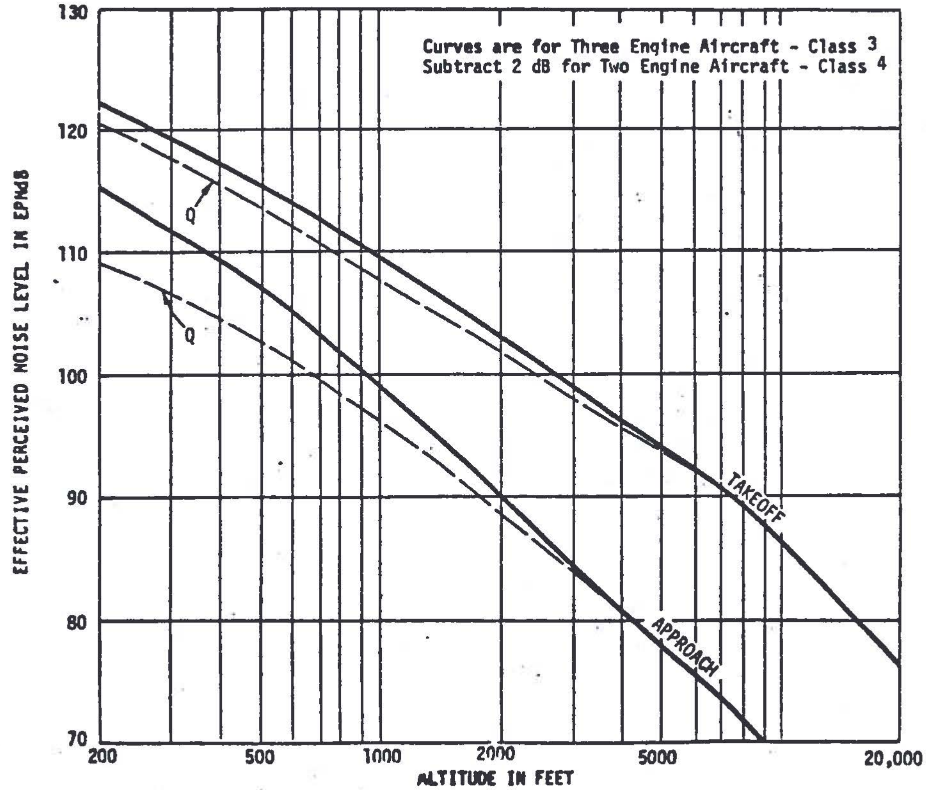

FIGURE E-3. Variation in effective perceived noise levels with altitude
Two and three-engine turbofan transport aircraft - LBPF

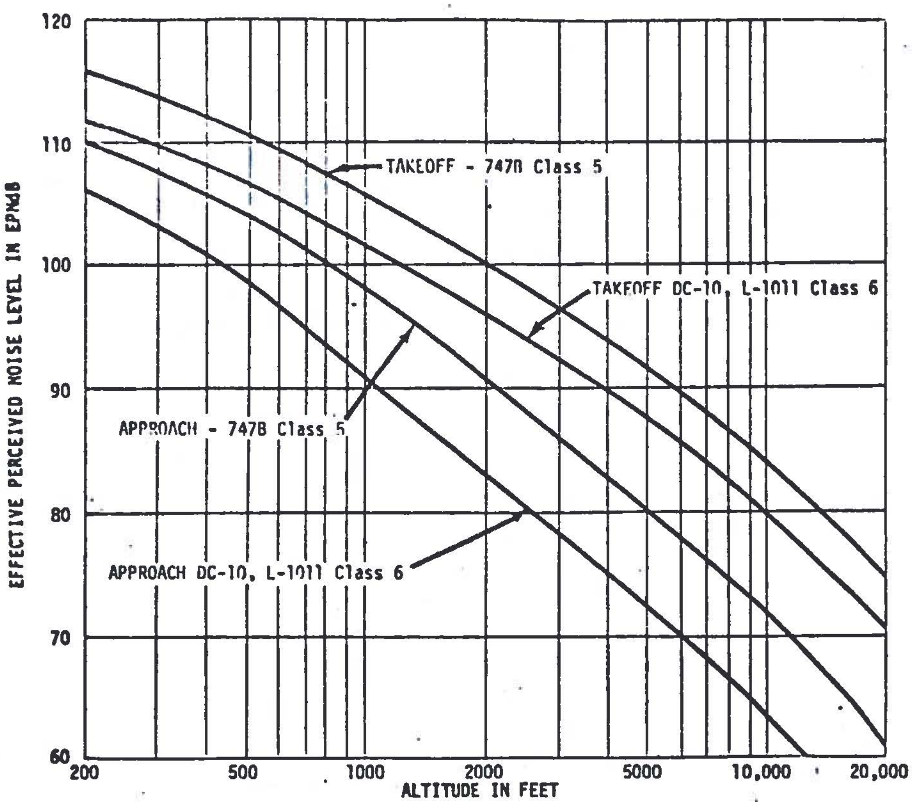

FIGURE E-4. - Variation in effective perceived noise levels with altitude
Three and four-engine high bypass ratio turbofan transport aircraft

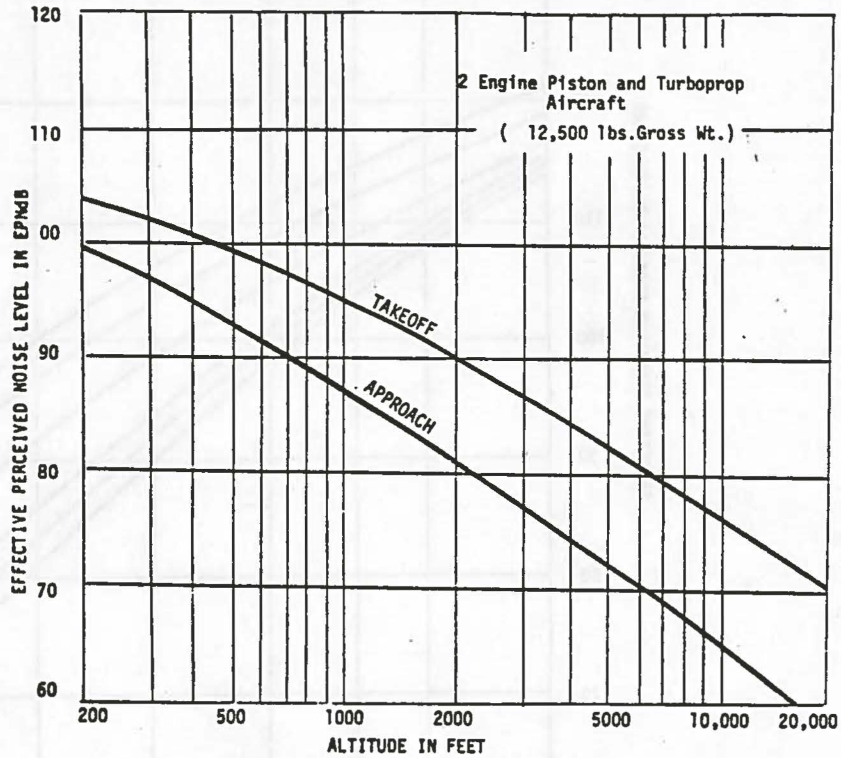

FIGURE E-5. - Variation in effective perceived noise levels with altitude
Two engine piston and turboprop aircraft - Class 7

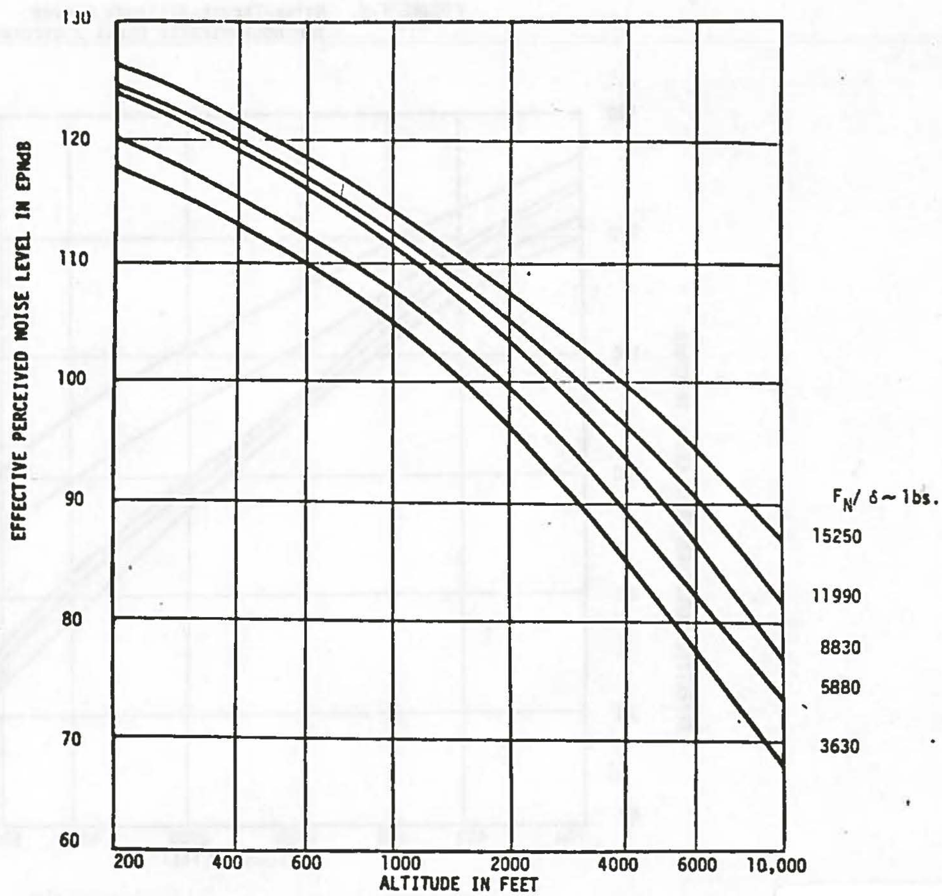

FIGURE F-1. - Noise-Thrust-Altitude curves
for non-retrofit Class 2 aircraft

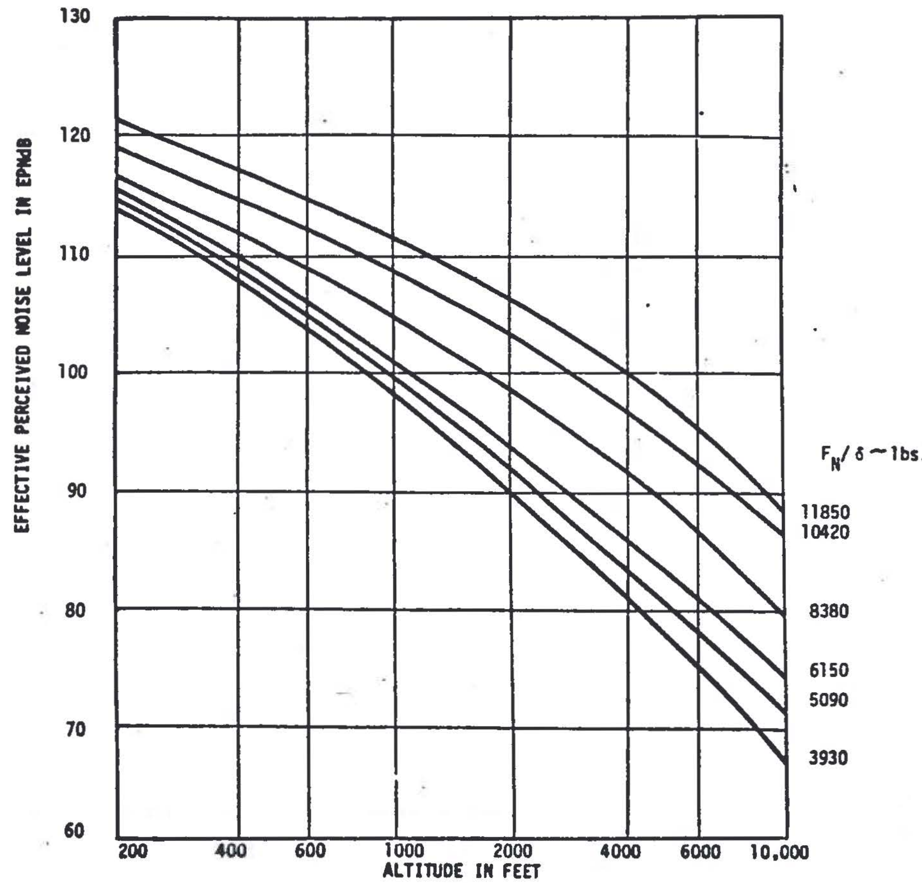

FIGURE F-2. Noise-Thrust-Altitude curves for non-retrofit Class 3 aircraft

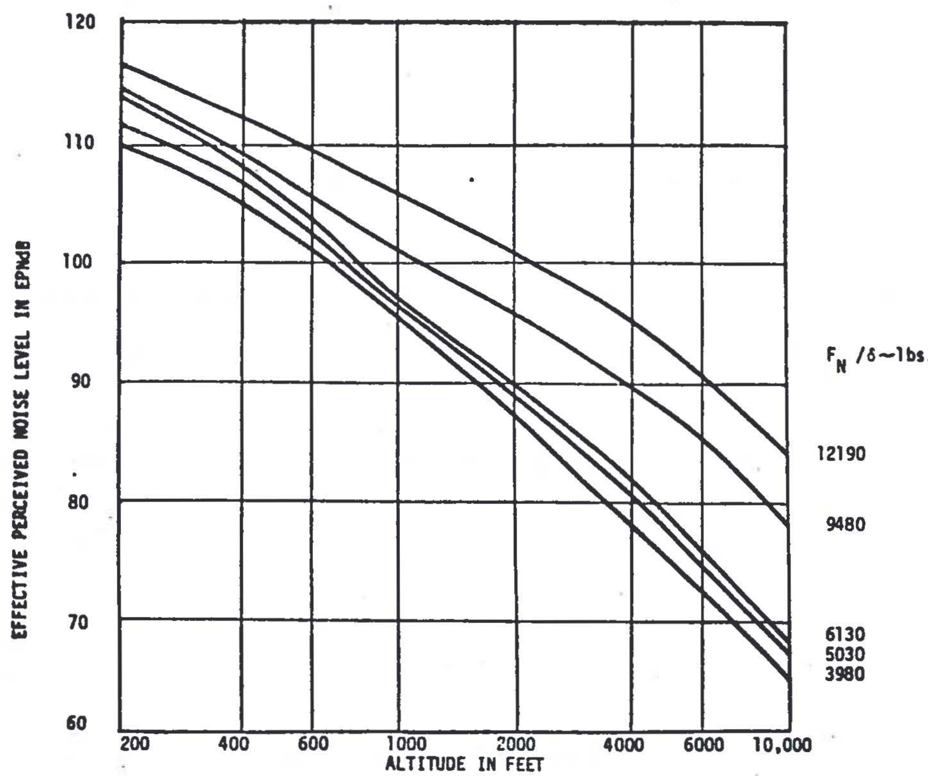

FIGURE F-3. Noise Thrust-Altitude curves for non-retrofit Class 4 aircraft

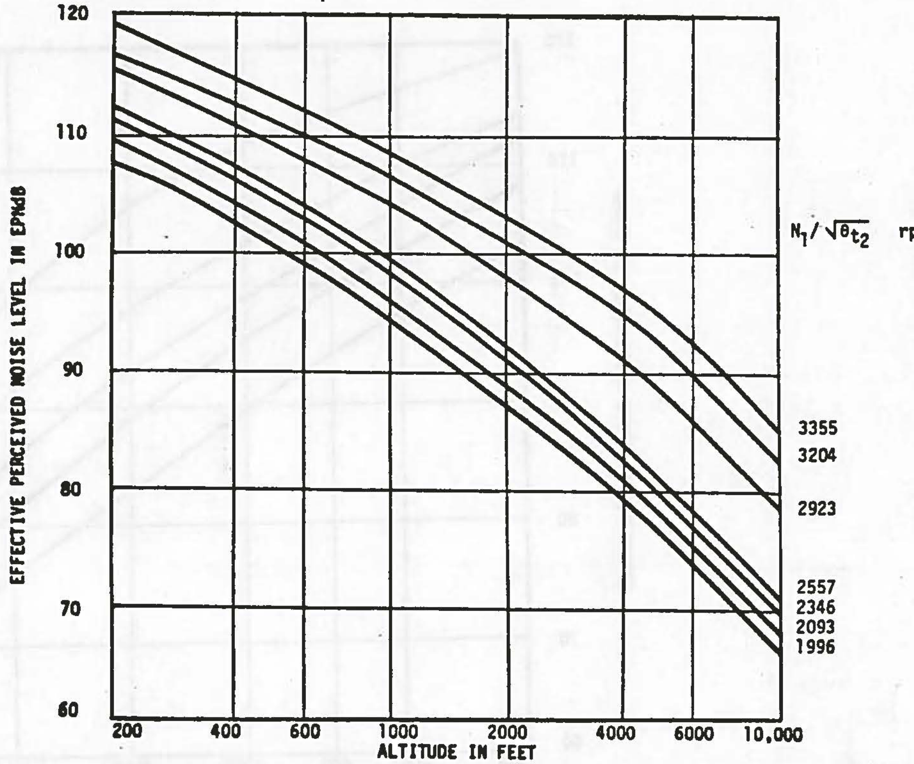

FIGURE F-4. Noise-Thrust-Altitude curves for Class 5 aircraft

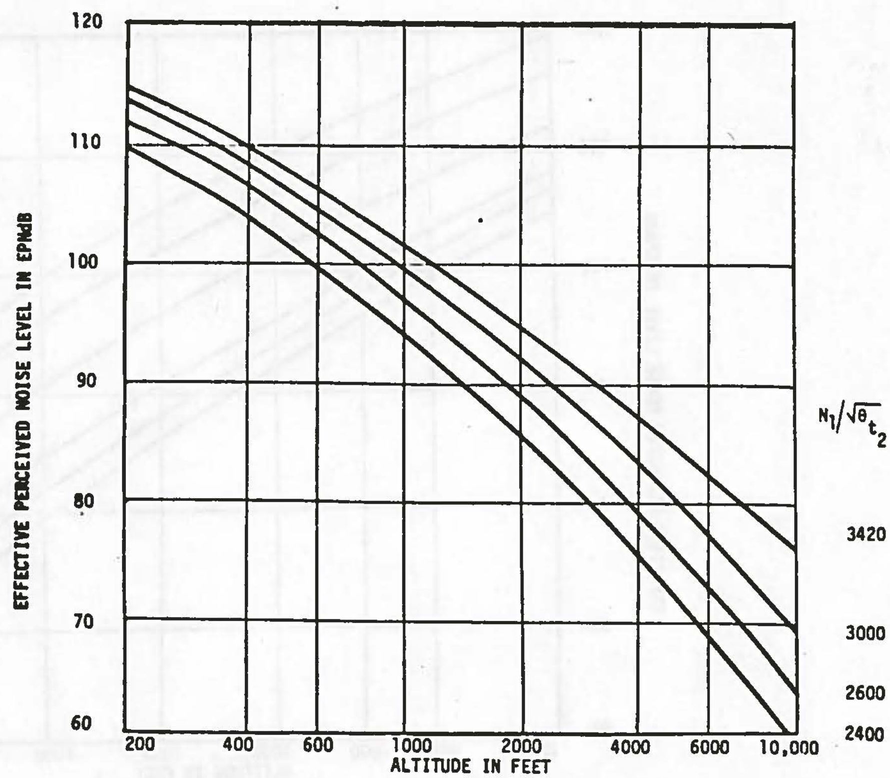

FIGURE F-5. Noise-Thrust-Altitude curves
for Class 6 aircraft

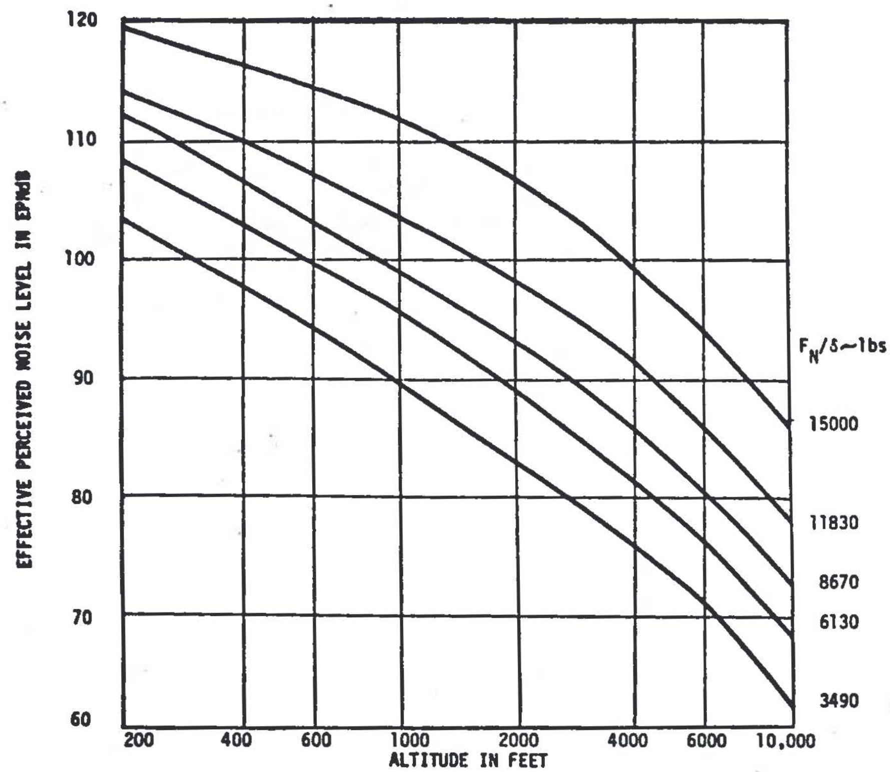

FIGURE F-6. - Noise-Thrust-Altitude Curves for retrofit Class 2 aircraft

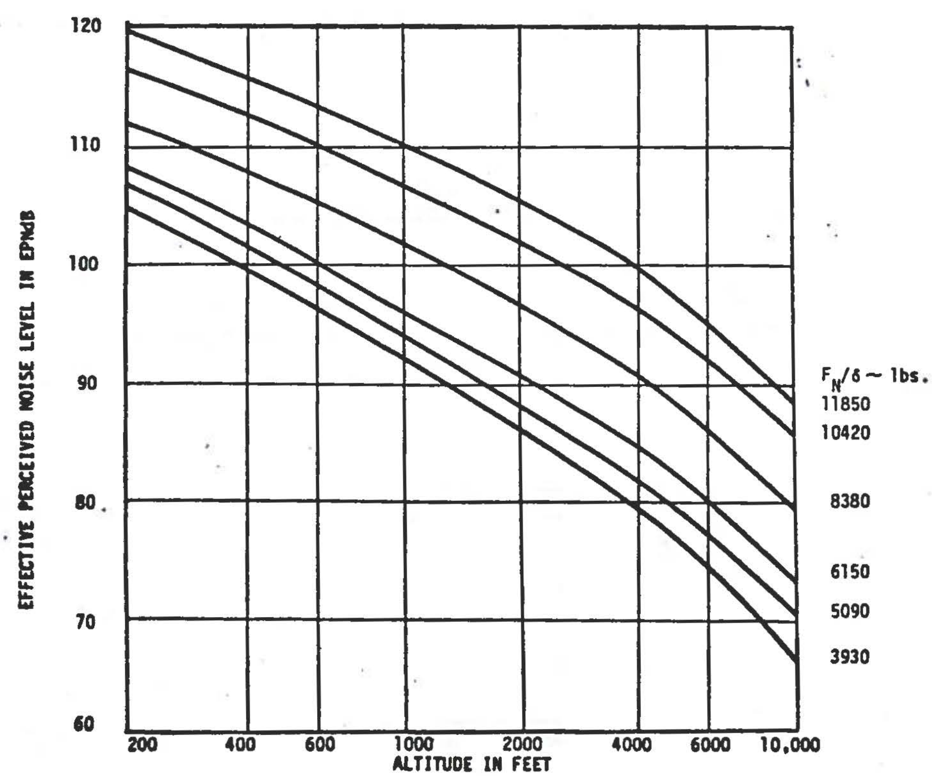

FIGURE F-7. - Noise-Thrust-Altitude curves for retrofit Class 3 aircraft

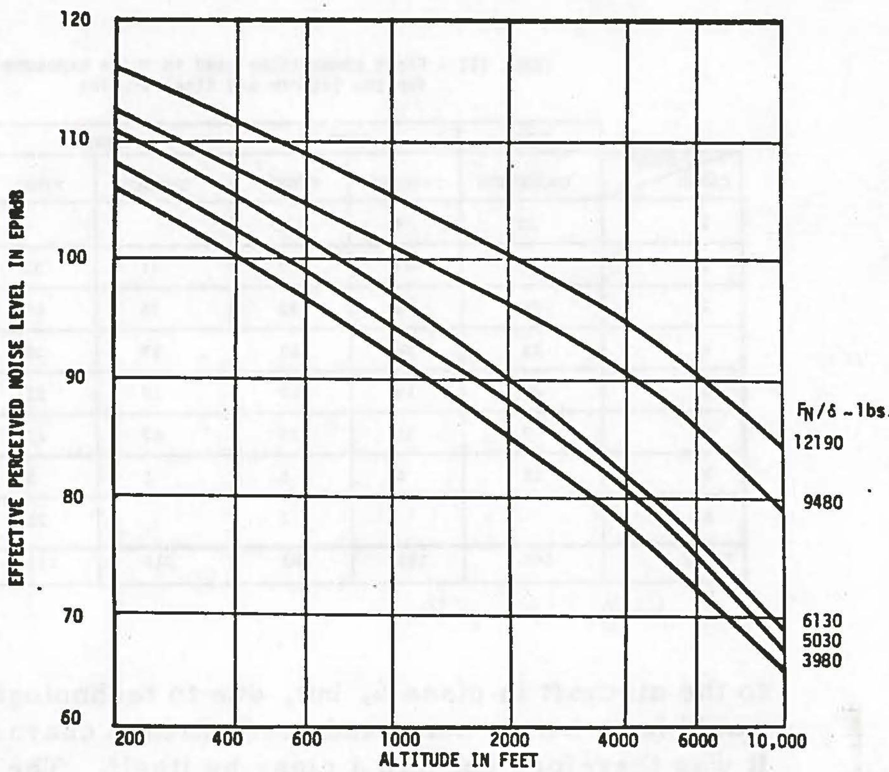

FIGURE F-8. - Noise-Thrust-Altitude curves for retrofit Class 4 aircraft

altitude (NTA) curves. For a given corrected net thrust, the noise as a function of altitude is plotted. In these figures the thrust settings represent the entire operating range of power settings for each particular aircraft. With this set of noise curves, noise values on the ground resulting from take-offs including a cutback procedure can readily be determined when the aircraft performance and thrust schedules are known.

In addition to the aircraft noise and performance changes, the projected fleet composition for the study years 1978, 1983, and 1993 was revised. A comparison of the fleet compositions for the Interim and Final Studies is presented in Table III. The revised fleet forecast was based on information supplied by the airlines operating at SEA-TAC. On the revised fleet forecast several important changes should be noted. Classes 2 and 4 are being phased out faster than originally forecast and the growth of classes 5 and 6 is not as rapid as originally projected. Also, note that an eighth class has been added in the revised fleet forecast.

The eighth class is a future aircraft type denoted the NSA-180. It was assumed that this aircraft would be similar

TABLE III - Fleet composition used in noise exposure calculations for the interim and final studies

STUDY / CLASS	1973	1978		1983		1993	
	UNCHANGED	INTERIM	FINAL	INTERIM	FINAL	INTERIM	FINAL
1	20	5	3				
2	47	47	47	41	33	7	
3	56	74	72	75	81	65	70
4	14	16	17	15	16	11	
5	10	13	10	17	11	38	13
6	7	32	27	67	47	154	106
7	11	6	5	1	5		
8			2		21		75
Total	165	193	183	216	214	275	264

Daily Departures

to the aircraft in class 6, but, due to technological advances, would have better noise and performance characteristics. It was therefore put into a class by itself. The noise data for the NSA-180 was assumed to be 5 dB lower than the DC10 up to altitudes of 1000feet, 3 dB lower at an altitude of 2000 feet, and the same at altitudes of 4000 feet and greater. Performance data for the NSA-180 was assumed to be the same as the class 6 performance data at a lesser stage length. Two operating weights were used for this aircraft, 345, 000 and 325, 000 pounds, which correspond to the class 6 performance data at 325, 000 and 300, 000 pounds respectively.

In addition to the noise and performance data for individual aircraft classes and the fleet composition, the NEF calculations require a description of the ground track traces of flight paths and their utilization. Paths used in the two studies are shown in Figure G. These were determined from radar observations and through discussions with FAA control tower personnel.

To develop flight path utilization numbers, the SEA-TAC master flight schedule, and the flight paths of Figure G were used along with the current FAA noise abatement takeoff and landing regulations (Reference 12). Thus, knowing the stage length, takeoff performance, and noise abatement procedures, the most probable path for each aircraft on the master schedule was determined.

In this way, the number of departures on each flight path was calculated. These results are presented in Table IV for the Interim Study and Table V for the Final Study. The difference in these two tables results from the updated takeoff performance data. These tables were then adjusted for changes in the forecast fleet mixes for the study years 1978, 1983, and 1993 by the changes shown in Table III.

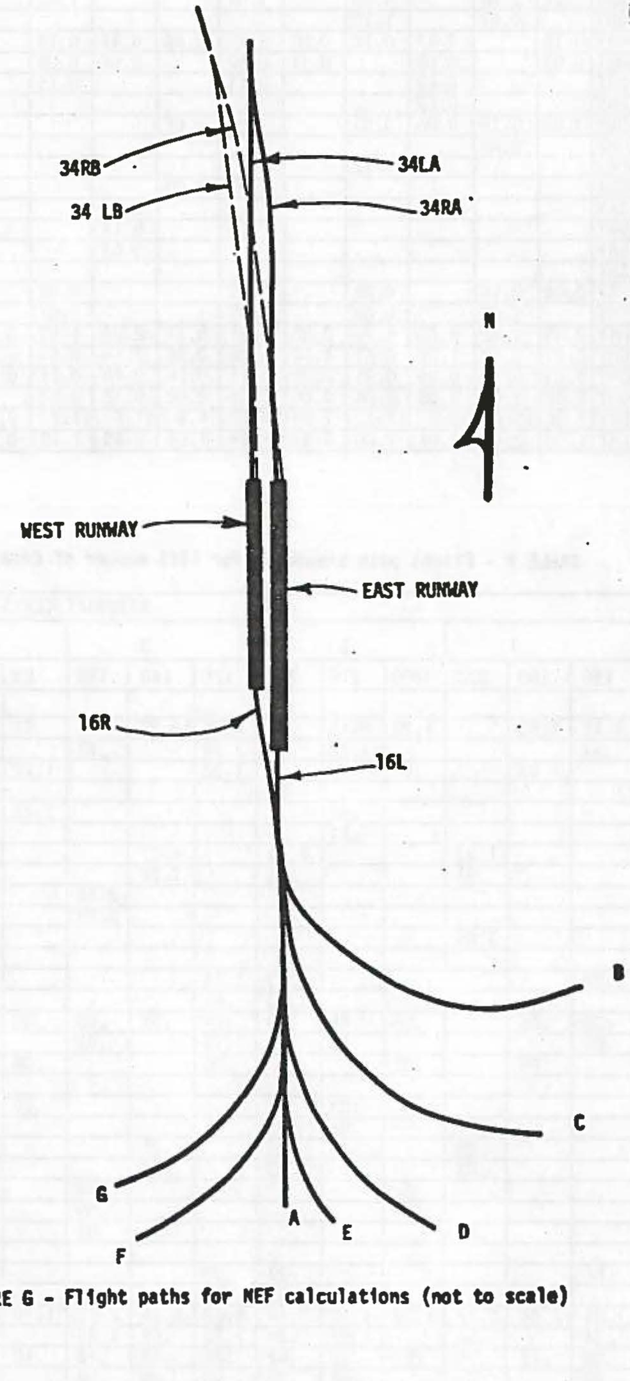

FIGURE G - Flight paths for NEF calculations (not to scale)

TABLE IV - Flight path breakdown for 1973 number of departures used in the interim study

	AIRCRAFT CLASS																
	1	1	2	2	2	3	3	3	4	5	5	5	5	6	6	6	7
T/O PROFILE	B	C	B	C	E	B	C	D	B	B	C	D	E	B	C	D	PA
FLIGHT PATH																	
16LA-DAY	2.43		8.95	3.30	1.02	2.02	7.79	6.53	2.84	0.46	0.61		0.61	0.61	1.22		1.22
NIGHT	0.61		1.67		2.02	0.51		1.30	0.74	0.46	0.61		0.61				0.61
16LB-DAY			1.67			2.02			2.84								2.43
NIGHT			0.56			0.51											
16LC-DAY			1.14	0.55			1.30			0.92							
NIGHT																	
16LD-DAY				2.20								0.61					
NIGHT							0.65										
16LE-DAY								7.16								1.82	
NIGHT								2.60								0.61	
16LF-DAY								0.65									
NIGHT																	
16LG-DAY	1.22	3.04		4.40		1.01			1.42		0.61						2.43
NIGHT		0.61		1.10							0.61						
16RA-DAY	0.13		0.47	0.17	0.05	0.11	0.40	0.34	0.15		0.03		0.03	0.03	0.06		0.06
NIGHT	0.03		0.09		0.11	0.02		0.06	0.04		0.03		0.03				0.03
16RB-DAY			0.09			0.11			0.15								0.13
NIGHT			0.03														
16RC-DAY	0.03	0.16	0.06	0.03			0.06										
NIGHT		0.03															
16RD-DAY				0.12								0.03					
NIGHT							0.03										
16RE-DAY								0.37								0.10	
NIGHT								0.14								0.03	
16RF-DAY								0.03									
NIGHT																	
16RG-DAY	0.06	0.16		0.24		0.05			0.08		0.03						0.13
NIGHT		0.03		0.05		0.01			0.02		0.03						
34LB-DAY	2.39	3.42	6.60	5.70	0.58	2.81	5.11	8.05	4.99	0.77	0.68	0.34	0.34	0.34	0.68	1.03	3.42
NIGHT	0.34	0.68	1.26	0.61	1.14	0.24	0.36	2.19	0.50	0.26	0.68		0.34			0.34	0.34
34RB-DAY	0.13	0.18	0.35	0.31	0.03	0.15	0.28	0.44	0.21	0.04	0.04	0.02	0.02	0.02	0.04	0.05	0.18
NIGHT	0.02	0.04	0.06	0.04	0.06	0.02	0.02	0.12	0.02		0.04		0.02			0.02	0.02
TOTAL-DAY	7.00	10.0	19.3	17.2	1.68	8.22	14.9	21.5	11.7	2.25	2.00	1.00	1.00	1.00	2.00	3.00	10.0
NIGHT	1.00	2.00	3.67	1.80	3.32	1.86	1.06	8.49	1.18	0.75	2.00		1.00			1.00	1.00

TABLE V - Flight path breakdown for 1973 number of departures used in the final study

	AIRCRAFT CLASS																	
GROSS WT.	1			2			3			4		5			6			7
1000 LBS.	190	200	230	200	215	245	125	140	155	83	95	500	535	660	300	325	345	PA
FLIGHT PATH																		
16LA-DAY	1.22	1.83		1.22	9.15	.61	4.88	10.37	.61	.61	4.27	.61			.61	.61		1.93
NIGHT	.61				1.22		2.44		.61									.61
16LB-DAY		1.83		.61			1.22			1.22								1.83
NIGHT																		
16LC-DAY					.61					1.22						1.83		
NIGHT					.61													
16LD-DAY			1.83			6.71		4.27			1.22	.61	.61				.61	
NIGHT			.61			.61		1.22				.61					.61	
16LE-DAY									3.66									
NIGHT									1.83									
16LF-DAY			3.05											.61				
NIGHT														.61				
16LG-DAY	1.22					5.49	1.83						1.83					2.44
NIGHT						1.83	.61						.61					
16RA-DAY	.06	.09		.06	.45	.03	.24	.51	.03	.03	.21	.03			.03	.03		.09
NIGHT	.03				.06		.12		.03									.03
16RB-DAY		.09		.03			.06			.06								.09
NIGHT																		
16RC-DAY					.03					.06						.09		
NIGHT					.03													
16RD-DAY			.09			.33		.21			.06	.03	.03				.03	
NIGHT			.03			.03		.06				.03					.03	
16RE-DAY									.18									
NIGHT									.09									
16RF-DAY			.15						.03					.03				
NIGHT														.03				
16RG-DAY	.06					.27	.09						.09					.12
NIGHT						.09	.03						.03					
34LB-DAY	1.36	2.04	2.72	1.02	5.44	7.14	4.42	6.16	2.72	1.70	3.06	.68	1.36	.34	.34	1.36	.34	3.40
NIGHT	.34		.34		1.02	1.36	1.70	.68	1.36			.34	.34	.34			.34	.34
34RB-DAY	.08	.12	.16	.05	.32	.42	.26	.48	.16	.10	.18	.04	.08	.02	.02	.08	.02	.20
NIGHT	.02		.02		.06	.08	.10	.04	.08			.02	.02	.02			.02	.02
TOTAL-DAY	4.0	6.0	8.0	3.0	16.0	21.0	13.0	24.0	8.0	5.0	9.0	2.0	4.0	1.0	1.0	4.0	1.0	10.0
NIGHT	1.0		1.0		3.C	4.0	5.0	7.0	4.0			1.0	1.0	1.0			1.0	1.0

100,04

4.96

5 6 9 3 19 25

Approach profiles used in the two studies are shown in Figure H. Approach altitudes are given for distance from runway threshold, where the aircraft altitude is 50 feet. Standard approaches from the north are conducted on a glide slope of 3 degrees while those from the south are on a 2.75 degree glide slope. Also shown in Figure H is the assumed $6^o/3^o$ two-segment approach with the transition about 3 miles from touchdown. The two-segment approach was chosen as one of the possible baseline options beginning in the study year 1983. This and other options are discussed in the section FLIGHT OPERATIONAL ALTERNATIVES.

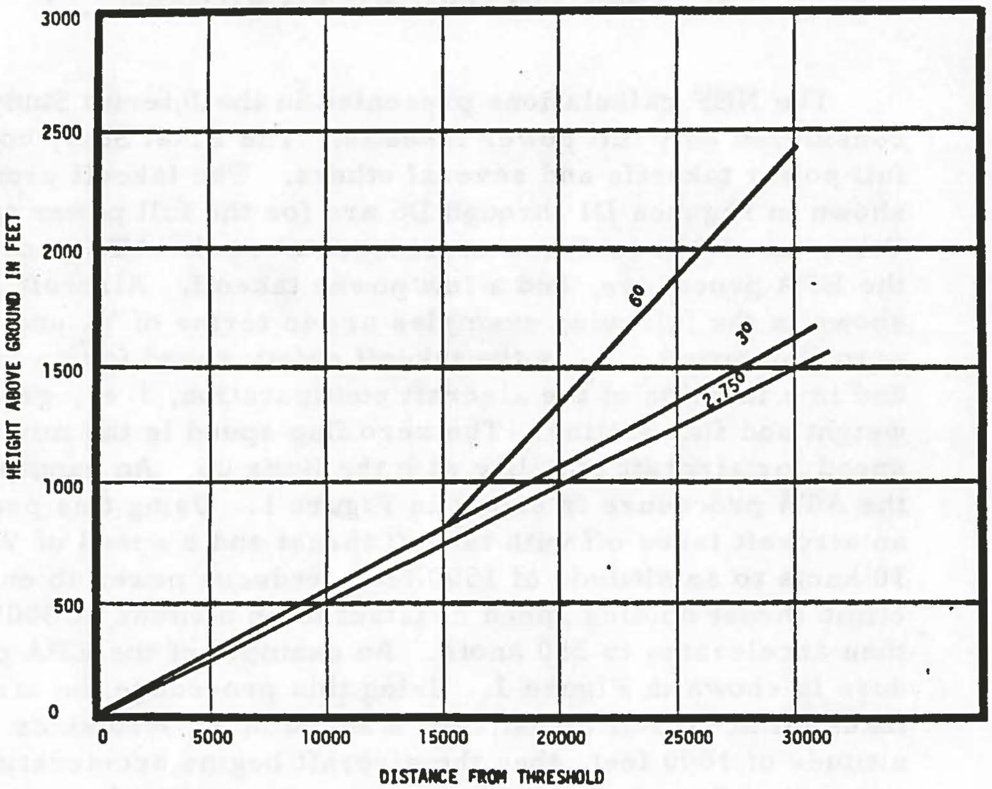

FIGURE H - Approach profiles used in the interim and final studies

The approach profiles remained unchanged between the two studies as did the approach flight path utilization. Table VI shows the approach flight path utilization figures for 1973. Again, these figures were adjusted in the future study years to reflect changes in the fleet mix composition.

TABLE VI - Flight path breakdown for 1973 number of approaches

	AIRCRAFT CLASS						
FLIGHT PATH	1	2	3	4	5	6	7
16LA-DAY	3.08	4.02	10.90	2.72	0.68	0.34	0.32
NIGHT		2.48	0.88	0.22	0.34	0.34	0.35
16LE-DAY	1.37	3.09	5.90	1.47	1.03	0.50	1.71
NIGHT	0.34	1.55	0.59	0.15			
16LF-DAY	1.37	4.33	0.89	0.22	0.68	1.37	1.37
NIGHT	0.68	0.62			1.03		
16RA-DAY	0.16	0.21	0.58	0.14	0.04	0.02	0.02
NIGHT		0.13	0.04	0.01	0.02	0.02	0.02
16RE-DAY	0.07	0.16	0.31	0.08	0.05		0.09
NIGHT	0.02	0.08	0.03	0.01			
16RF-DAY	0.07	0.23	0.04	0.01	0.04	0.07	0.07
NIGHT	0.04	0.04			0.05		
34LA-DAY	10.34	20.34	31.43	7.86	3.26	3.54	6.08
NIGHT	1.82	8.22	2.61	0.66	2.43	0.61	0.61
34RA-DAY	0.54	1.07	1.65	0.41	0.22	0.16	0.34
NIGHT	0.10	0.43	0.14	0.03	0.13	0.03	0.02
TOTAL-DAY	17.0	33.45	51.70	12.92	6.00	6.00	10.00
NIGHT	3.00	13.55	4.30	1.08	4.00	1.00	1.00

The NEF calculations presented in the Interim Study considered only full power takeoffs. The Final Study considered full power takeoffs and several others. The takeoff profiles shown in Figures D1 through D6 are for the full power takeoffs. Other takeoff procedures considered were the ATA procedure, the EPA procedure, and a low power takeoff. Aircraft speeds shown in the following examples are in terms of V_2 and the zero flap speed. V_2 is the takeoff safety speed for an aircraft and is a function of the aircraft configuration, i.e., gross weight and flap setting. The zero flap speed is the minimum speed for aircraft stability with the flaps up. An example of the ATA procedure is shown in Figure I. Using this procedure an aircraft takes off with takeoff thrust and a speed of V_2 + 10 knots to an altitude of 1500 feet, reduces power to enroute climb thrust holding speed constant to an altitude of 3000 feet, then accelerates to 250 knots. An example of the EPA procedure is shown in Figure J. Using this procedure the aircraft takes off at takeoff thrust, and a speed of V_2 + 10 knots to an altitude of 1000 feet, then the aircraft begins accelerating, retracting flaps and reducing power, at an altitude around 1500 feet the zero flap speed and required quiet thrust setting are reached; the aircraft then climbs to an altitude of 3000 feet maintaining the zero flap speed and quiet thrust setting with a rate of climb of 1000 feet per minute, at 3000 feet the enroute climb thrust is applied and the aircraft accelerates to 250 knots. The low power takeoff procedure is essentially the same as a full power takeoff except the aircraft uses only about 90 percent of its takeoff thrust. This takeoff procedure results in less noise on the ground at a given altitude when compared to a full power takeoff. However, the takeoff climb

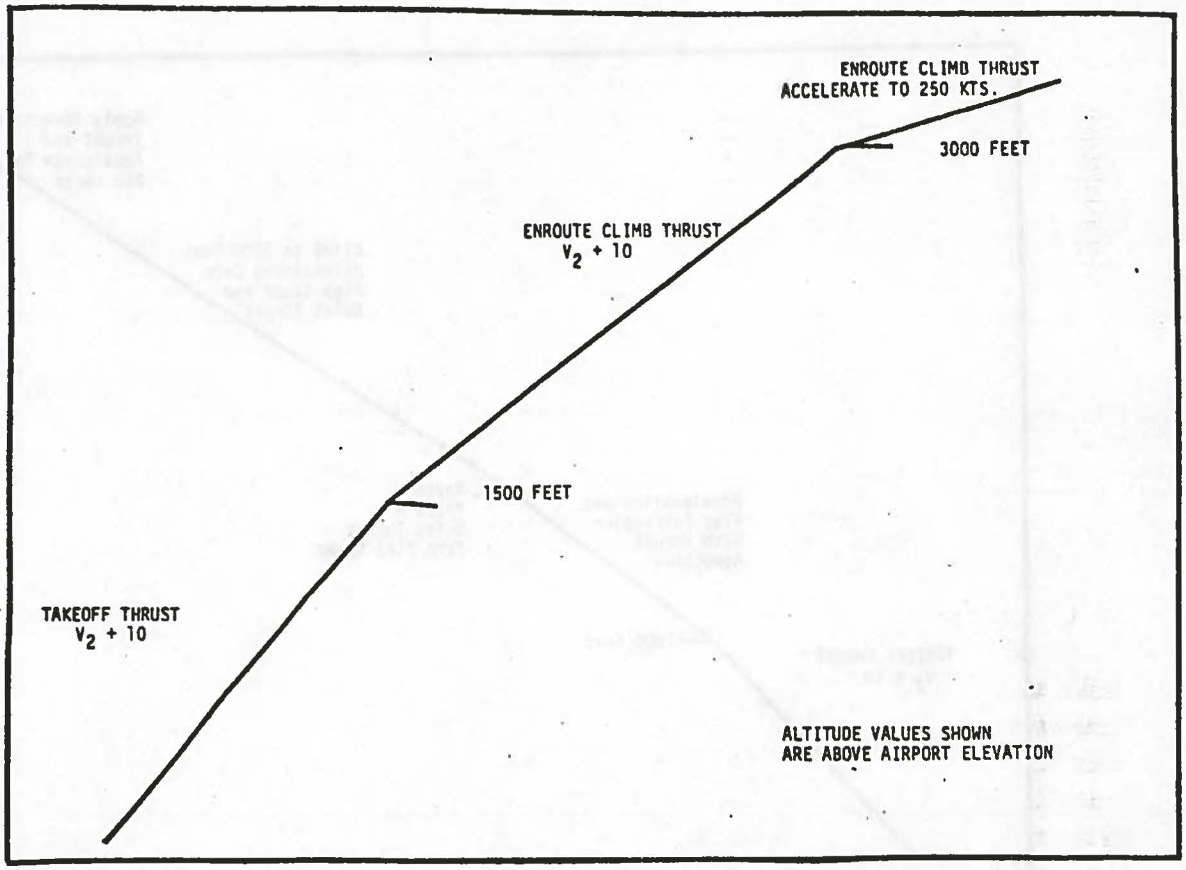

FIGURE I - Example of the ATA takeoff profile used in the final study

profile is lower than a full power takeoff for a given aircraft at the same gross weight. These procedures will be discussed in the section FLIGHT OPERATIONAL ALTERNATIVES.

One other point needs to be made regarding differences in the NEF calculations between the Interim and Final Studies. This is in regard to the retrofit assumptions made for the two studies. In both studies the retrofit assumptions were based on retrofit with quiet nacelles using sound absorption materials. Refanning was not considered in these studies. For both studies it was assumed that classes 2, 3, and 4 would be 100 percent retrofit in the study years 1983 and 1993. However, there is a difference in the 1978 retrofit assumptions. In both studies it was assumed that classes 2, 3 and 4 would be 50 percent retrofit by 1978. In the Interim Study it was assumed that 50 percent of the daytime flights and 50 percent of

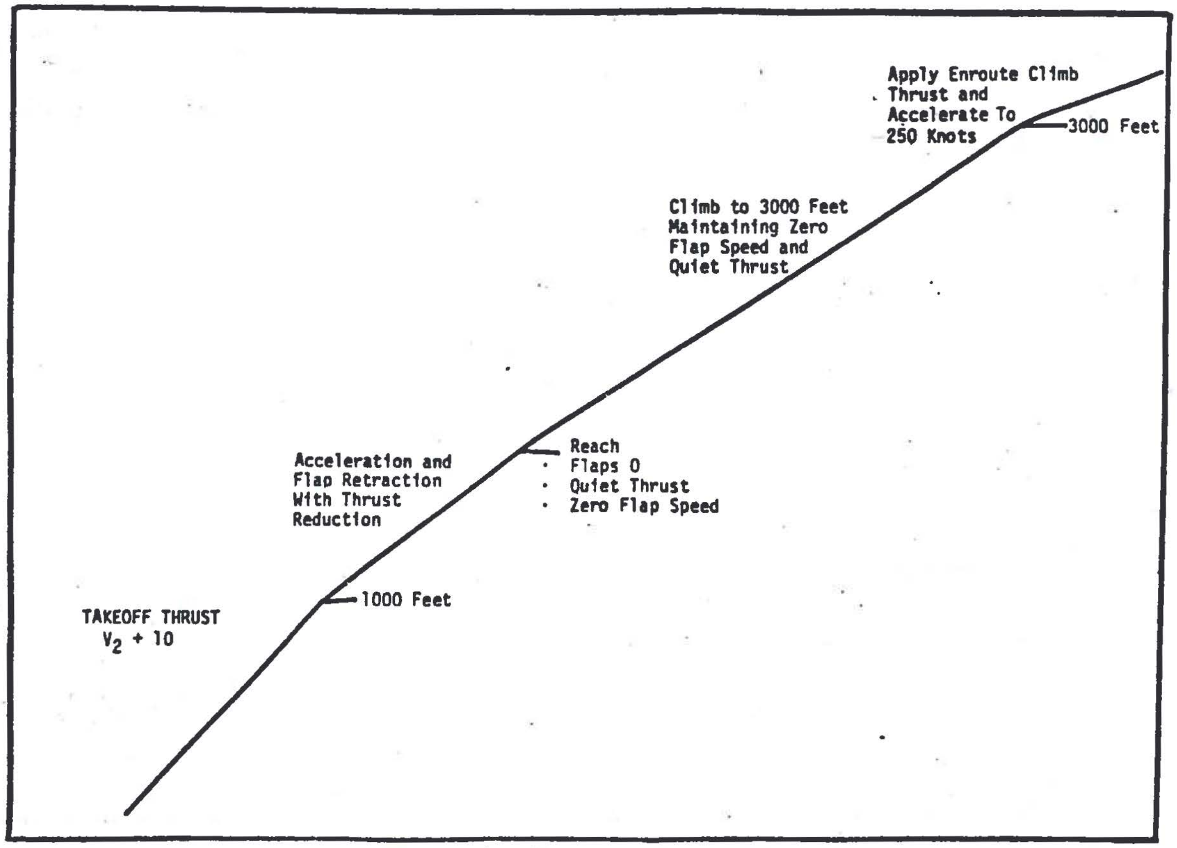

FIGURE J - Example of EPA takeoff profile used in the final study

the nighttime flights were retrofit. However, information supplied by the airlines showed that there would be no non-retrofit nighttime flights for aircraft of these classes. Therefore, in the Final Study for 1978, all nighttime flights from these classes are retrofit and there are more non-retrofit than retrofit aircraft from these classes during the daytime period.

As previously mentioned, the NEF and ANE calculations are identical except for the difference in noise-distance curves for the various aircraft classes. The ANE noise-distance curves were developed using the data from those measuring stations located directly under the major SEA-TAC flight paths. Best fit lines were obtained, using the measured data for each aircraft class. For altitudes outside the range of those measured, the curves were assumed to have the same rates of fall-off as those shown in figures F1 through F8.

EFFECTS OF WEATHER AND AIRCRAFT LOCATION

The propagation of sound, and hence its intensity at a given receiver location, can be strongly influenced by changes in both weather and distance. Thus, the calculated NEF values may be substantially different from measured ANE values as a result of both of these factors.

Procedures for accounting for the differences due to weather have been developed (Reference 13). As part of the present program, a study was made of Seattle weather for the years 1971-72 to determine a standard set of temperature and humidity values. These were found to be 50° Fahrenheit and 74% Relative Humidity. Average monthly values of temperature and humidity over the two year period are shown in Figures K1 through K4. All measured noise levels are corrected to these standard conditions to minimize this possible source of variation.

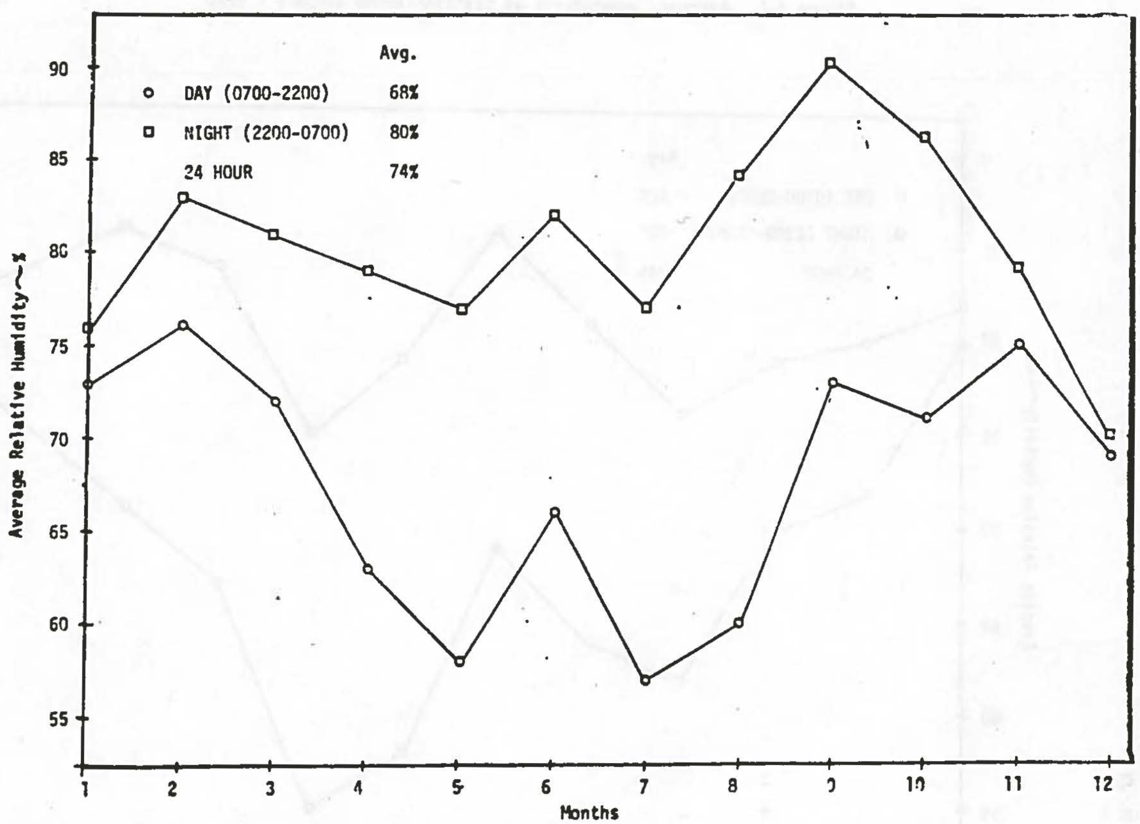

Figure K-1. Average Relative Humidity at Seattle-Tacoma Airport - 1972

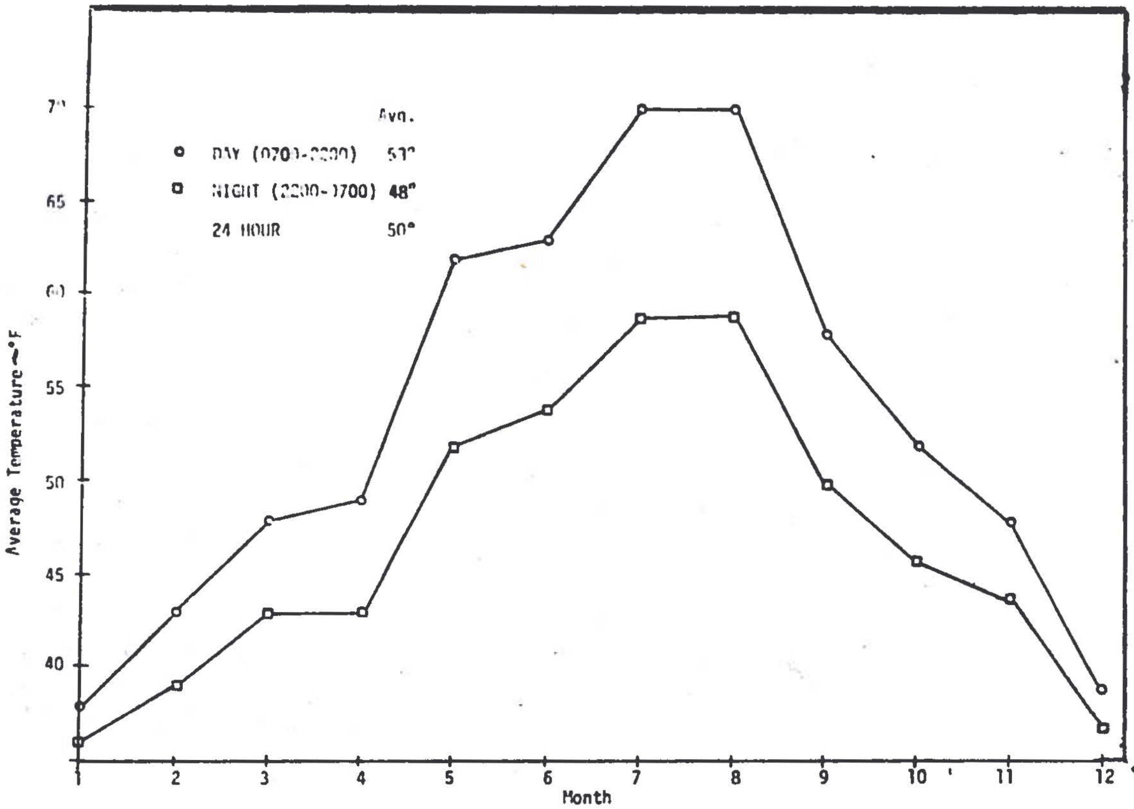

Figure K-2. Average Temperatures at Seattle-Tacoma Airport - 1972

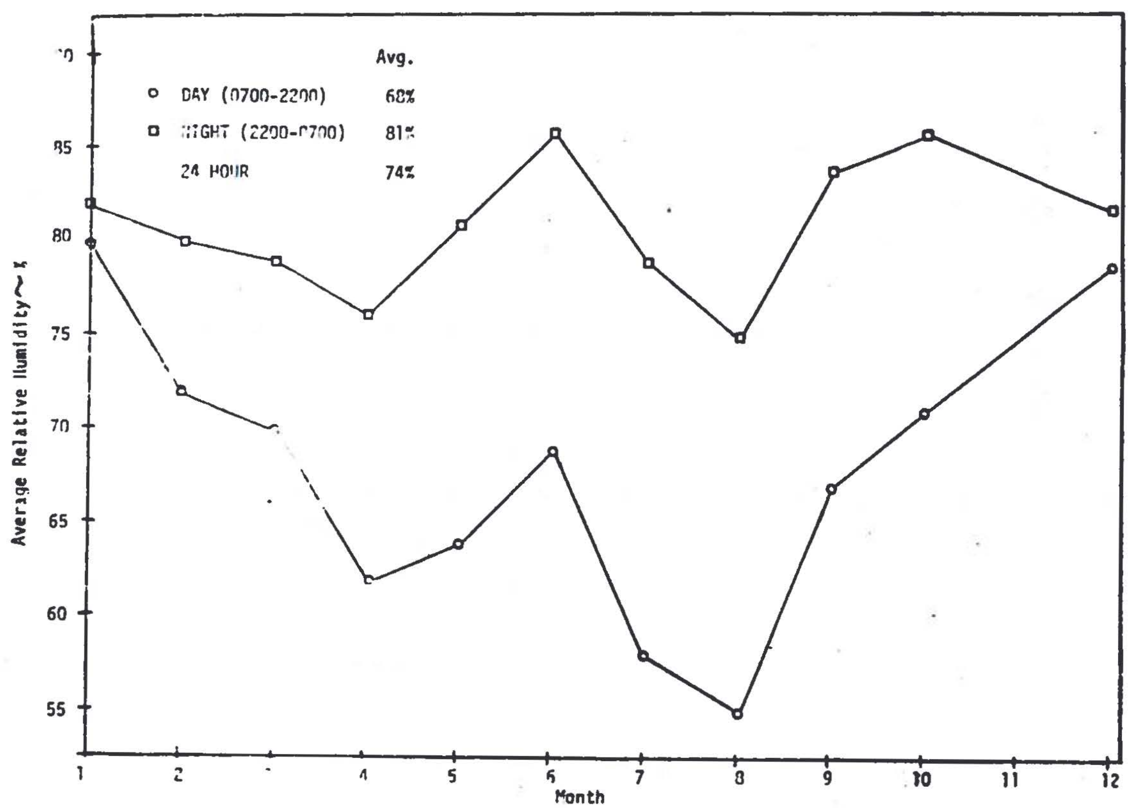

Figure K-3. Average Relative Humidity at Seattle-Tacoma Airport - 1971

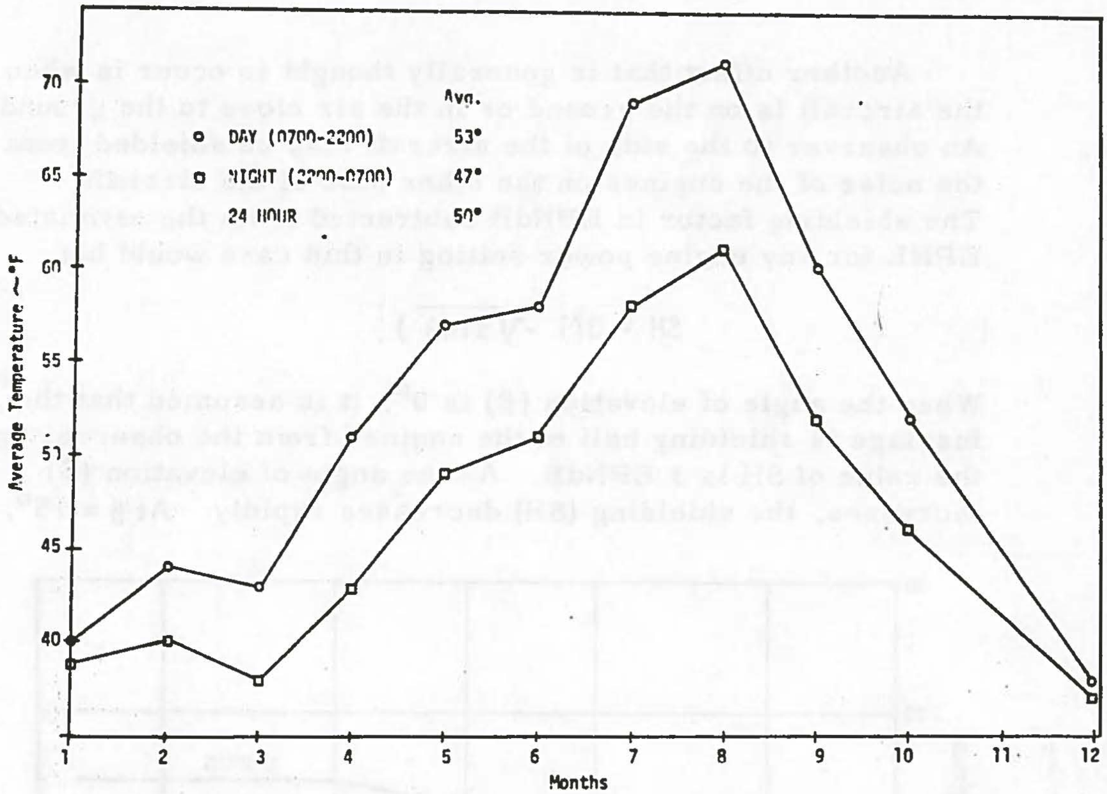

Figure K-4. Average Temperatures at Seattle-Tacoma Airport - 1971

From observations of the TRACON radar in the SEA-TAC control tower, it was concluded that, for the main flight paths shown in Figure G, there were virtually no deviations within the study area. However, since it is necessary to have fairly precise distance data available to correct measured data for weather, photo-ranging of most aircraft flyovers have been made.

In the calculation of noise exposure values, two other attenuation factors are considered. These are due to the ground and to aircraft shielding.

When the aircraft is on or near the ground, additional attenuation of aircraft noise propagating to other points on the ground is produced by noise refraction resulting from wind and temperature gradients and other effects. The ground-to-ground attenuation, Δ_0, used when the airplane is on the ground, is given by the curves in Figure L for the takeoff and the landing power settings. When the aircraft is close to the ground at an angle of elevation of β with respect to the observer, the ground-to-ground attenuation in EPNdB is:

$$\Delta = \Delta_0 e^{-\sqrt{\tan 3\beta}}$$

Another effect that is generally thought to occur is when the aircraft is on the ground or in the air close to the ground. An observer to the side of the aircraft may be shielded from the noise of the engines on the other side of the aircraft. The shielding factor in EPNdB subtracted from the estimated EPNL for any engine power setting in this case would be:

$$SH = 3(1 - \sqrt{\sin\beta})$$

When the angle of elevation (β) is 0°, it is assumed that the fuselage is shielding half of the engines from the observer and the value of SH is 3 EPNdB. As the angle of elevation (β) increases, the shielding (SH) decreases rapidly. At $\beta = 15^{\circ}$,

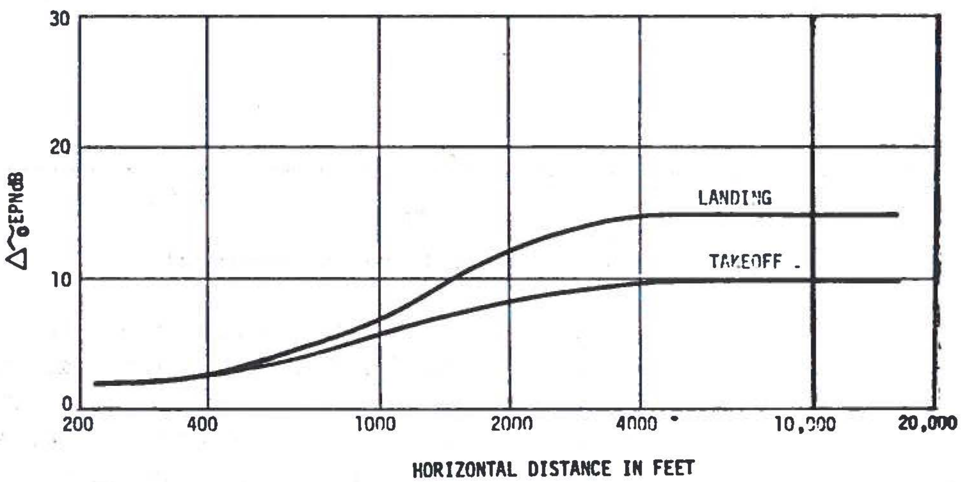

FIGURE L - Approximate addition attenuation for ground-to-ground aircraft noise propagation

SH = 1.5 EPNdB; and at $\beta = 45^{\circ}$, SH = 0.5 EPNdB. Calculations presented in the Interim Report (Reference 7) used this engine shielding correction. However, sideline noise measurements completed since that time and described in a later section indicate that this correction is unnecessary and has been deleted from the present calculations.

MAINTENANCE RUNUPS

Engine maintenance runup is a source of possible noise that is not directly accounted for in the NEF methodology. Current practice at SEA-TAC is to prohibit most engine runups between 2300 - 0600 hours. Further, when being run up, the aircraft are headed into the wind and sited at the airport north boundary for a northerly wind and at the south end for a southerly wind, thus minimizing noise propagation.

There is, or course, a legitimate reason for performing maintenance runups on aircraft at the airport; flight safety regulations require ground running of engines after periodic and repair maintenance. At the same time, ground running of engines can be a significant source of annoyance from the noise produced. Presently, SEA-TAC noise abatement regulations limit ground runups between the hours of 2300 and 0600. As of this writing only runups of less than two minutes duration or less than 50 percent of maximum takeoff power are permitted during those hours. (Further restrictions are currently being considered.) The purpose of this section of the report is to review ground runup noises and to recommend possible alternative procedures or abatement methods.

Sources of noise within turbojet or turbofan engines include the jet stream, the internal combustion process, and the rotating machinery parts of the compressor and turbine. The noise producing efficiency of each of these is different as is the relationship of each to engine power level. Thus, roughly speaking, at very low powers the order of predominance of these three types of sources is: 1) combustion, 2) rotating machinery, and 3) jet exhaust. Conversely, at high powers, the order of predominance is reversed. This is a main reason why exhaust noise is predominant at takeoff and compressor noise is much more noticeable during approach. Note, however, that all three sources produce increased noise with increased thrust level. But, at thrust levels above about 50 percent of the maximum takeoff value, the predominant source of noise is jet exhaust.

Although some machinery noise is radiated aft, the greater part is radiated forward of the engine. Jet exhaust noise is, however, radiated predominantly aft of the engine. Figure M, taken from Reference 14, shows a typical noise radiating pattern for a single turbojet/turbofan jet exhaust along a flat ground plane.

Note that the levels shown on the curves are in units of perceived noise decibels (PNdB) and can be converted to units of A-weighted decibels by the formula shown on the figure. In order to convert to units of effective perceived noise decibels, it is necessary to account primarily for the duration of the runup. The value to be used for that correction has been the subject of considerable discussion among research workers and as yet no universal agreement has been reached. According to one line of reasoning, exposure should increase in direct proportion to noise duration. A second line of reasoning proposes a proportionality based on the square root of the duration. A third line proposes a direct proportionality up to a maximum correction of $\pm$ 5 dB. This latter method is now being seriously considered by FAA as a modification to the present FAR Part 36 method based on a continuous direct proportion. For purposes of the present analysis, the direct proportion with $\pm$ 5 dB maximum has been selected. This is also in agreement with the correction used for ground runups in the Tri-Services Aircraft Noise calculation procedure. For the ground runup cases the conversion factors are: dBA $\approx$ PNdB - 13 and EPNdB $\approx$ PNdB+ 5.

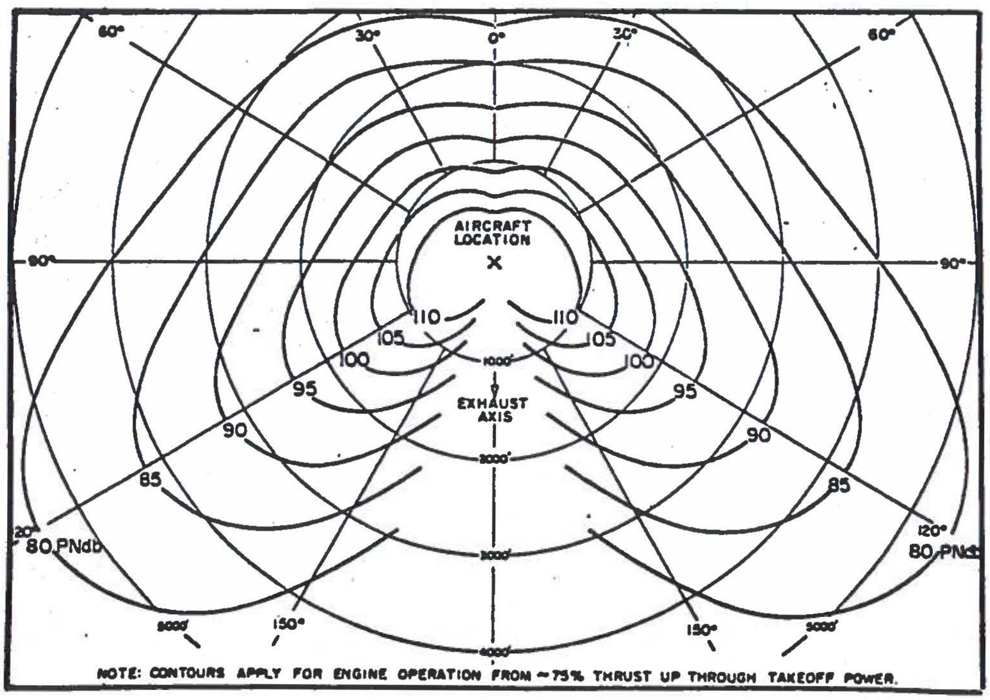

FIGURE M - Perceived noise level contours - one engine runups civil and military jet aircraft with turbofan engines

dBA=PNdB - 13

The conversion to L_{dn} is a little more complex, again because of the duration factor. Certain simplifications can be made, however, based on the assumption that the total duration of all the runups is less than one hour. This seems like a reasonable assumption in this case. Since the L_{dn} methodology includes a weighting penalty for nighttime noise levels, we must consider whether the runups occur in the day or night period.

Data from our files indicates that the daytime average background noise level is about 5 dB higher than during the nighttime period. Using these level differences and the one hour runup assumption, the following relationships are approximately correct.

If the runups occur during the daytime period:

$$L_{dn} = L_b + 10 \log_{10} \left[42 + 10^{\Delta/10} \right] - 14$$

If the runups occur during the nighttime period:

$$L_{dn} = L_b + 10 \log_{10} \left[40 + 10^{\frac{\Delta+5}{10}} \right] - 14$$

Where:

L_{dn} = day-night average level.
L_b = background level during day period.
Δ = incremental value of the runup above the existing background level.

(All values are A-weighted.)

In the early morning hours (nighttime period) at the west side of the airport, the existing background level (L_b) is about 45 dBA. Twelfth Avenue is approximately 3000 feet from the last taxiway where the runups are performed. Referring to Figure M, it is seen that maximum levels at that distance would be about 77 dBA. If the runups occurred during the nighttime hours, the day-night average sound level would be about 73 dB. Converted to NEF, that value would be approximately 38. This value is comparable to those predicted for takeoffs along the west side of the airport. Assuming that the daytime background level is 5 dB higher, i. e. L_b = 50 dBA, and the runups occurred during the daytime period, the L_{dn} value would be 63 dB. Converted to NEF, the value would be approximately 28. An NEF of 28 would be a tolerable level for the residents at this location.

Other interpretations of these effects are contained in Reference 14 and 15. In those documents, perceived noise level (PNL) values are adjusted for runup duration and time of day (night). The total adjustment can range from +5 to +15 decibels for runups lasting two minutes or more. Again, the effect of even rather brief runups can be quite serious if performed in the wrong place at the wrong time.

The general conclusion to be drawn from these analyses is to prohibit all runups during normal sleeping times. Further, if possible, aircraft should be placed at runup locations furthest removed from residential areas and oriented to obtain maximum advantage of the directivity characteristics of turbojet and turbofan aircraft. Present practice appears to achieve maximum benefit of the directivity feature but it may be possible to locate runups close to the airport center to alleviate exposure to those communities directly North and South of the East taxiway. Locations approximately 1000 feet from the present sites could be expected to produce significant noise relief.

THRUST REVERSER AND SIDELINE NOISE

Current airline thrust reverser practice is to limit engine RPM to about 65 percent of maximum as an engine saving technique. Even at 70 percent of max RPM, the sound power level of the engine is expected to be reduced by 20 decibels. The effect of the reverser mechanism is to produce a change in directivity of the noise emanated by the turbulent exhaust. This latter effect is of no appreciable concern since the source of sound, the aircraft, is in motion and the directivity pattern is swept along down the airport; i.e., it is not stationary even without reverser action.

Measured noise levels along the airport East and West boundaries are shown in Table VII-1 through VII-6. In that table hourly percentile, L_{eq}, and L_{NP} (NPL) levels are presented for a 24-hour interval. Figure N is a graphical presentation of the levels at one of those locations. Comparing that plot with Figure O shows that there is probably some, but not a perfect, correlation with aircraft operations.

It would appear from the noise pattern shown previously in Figure M that as much as a 5 decibel reduction in takeoff noise levels along Tenth and Twelfth Avenues could be achieved by restricting takeoffs to the East runway (16L - 34R). Measurements made with a hand-held sound level meter at sites along Twelfth Avenue tended to confirm this prediction. TableVIII shows the range of these measurements and the predicted ranges for takeoff and thrust reverser operations. The lower values tend to correspond to operations on the East runway. Thus, although reverser noise is higher on the West runway, it is not as high as takeoff noises on either East or West. Again, this suggests the idea of using the East runway exclusively for takeoffs.

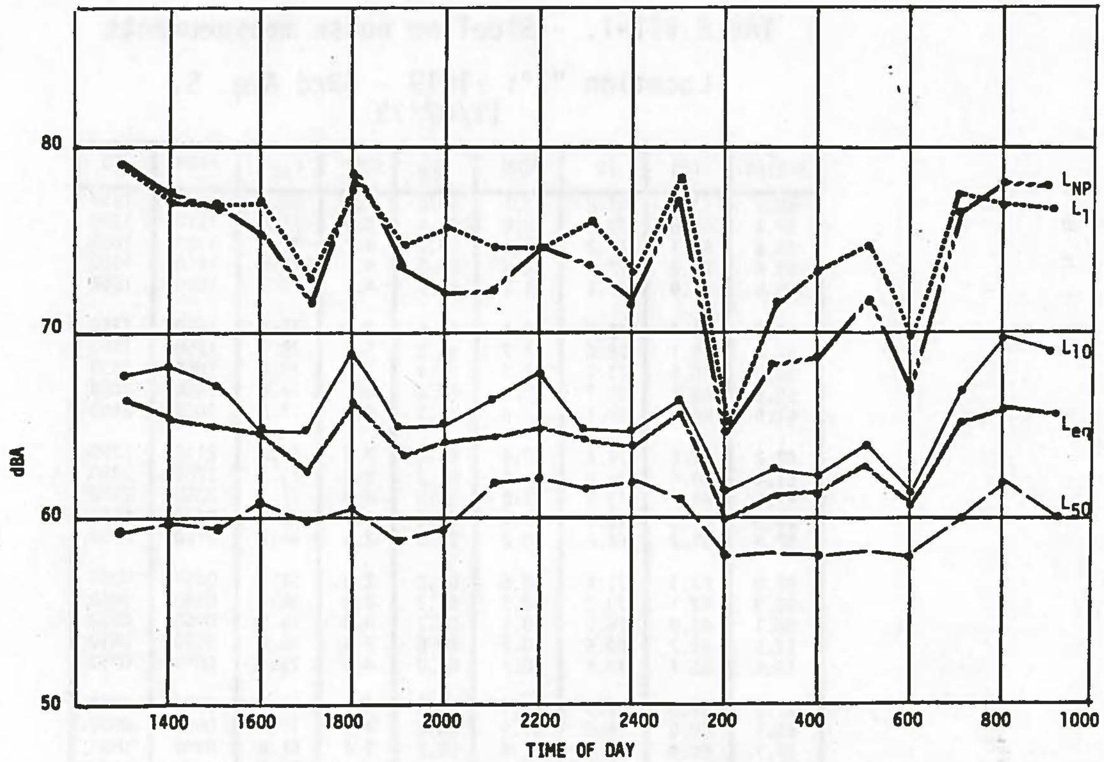

FIGURE N - Statistical levels measured at one sideline position

LOCATION - 16919 - 33rd Ave. S. (A)

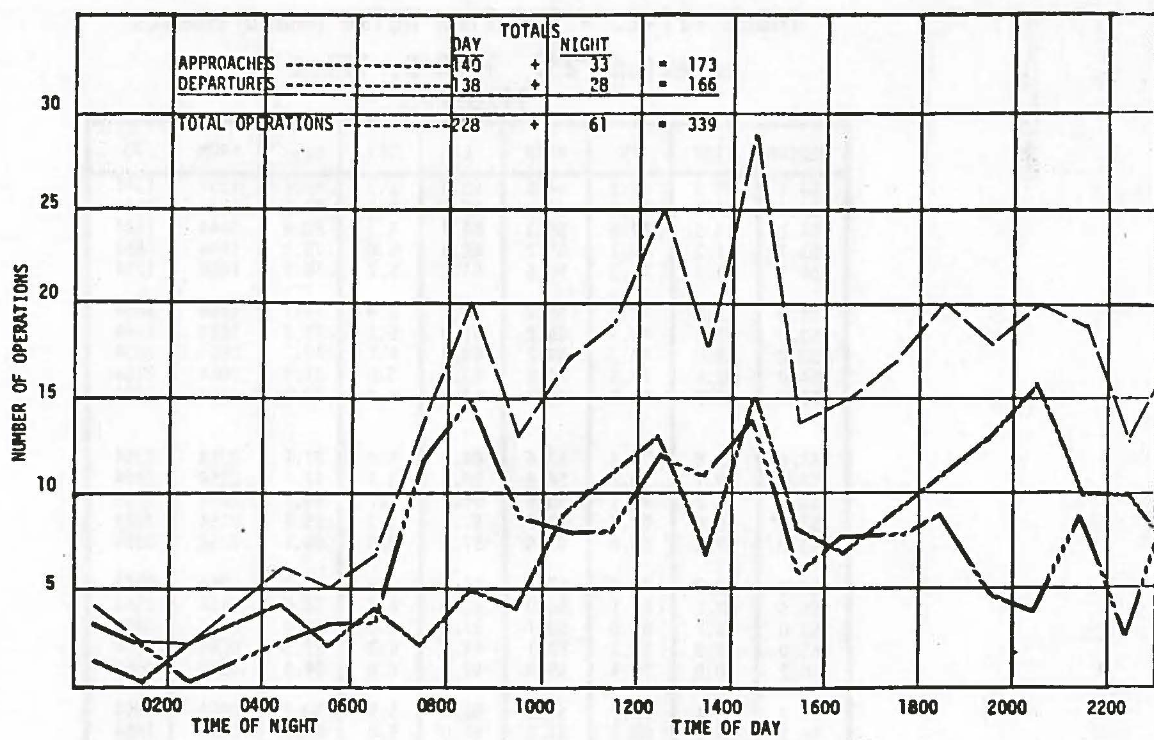

FIGURE O - Number of operations per hour at Seattle-Tacoma Airport on May 24, 1973
(Scheduled Commercial)

TABLE VII-1. - Sideline noise measurements

Location "1": 1619 - 33rd Ave. S.
11/07/73

MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	FROM	TO
58.7	63.5	64.8	59.1	59.8	2.3	65.8	1240	1250
59.4	67.8	79.1	60.8	66.4	4.9	79.0	1250	1350
59.8	68.1	77.2	61.1	65.3	4.7	77.4	1350	1450
59.6	67.4	77.0	60.9	65.0	4.6	76.8	1450	1550
60.8	64.9	77.1	61.1	64.7	4.1	75.1	1550	1650
59.9	64.7	72.7	60.4	62.5	3.5	71.4	1650	1750
60.6	69.1	78.0	61.7	66.2	5.0	78.9	1750	1850
58.9	64.9	74.7	60.0	73.4	4.0	73.5	1850	1950
59.5	65.1	75.7	60.5	64.0	4.1	74.6	1950	2050
61.9	66.3	74.5	62.0	64.3	3.6	73.5	2050	2150
62.2	67.8	74.6	62.4	64.8	3.9	74.7	2150	2250
61.4	64.8	76.0	61.4	64.3	3.6	73.6	2250	2350
61.9	64.7	73.8	61.8	63.8	3.0	71.5	2350	2450
60.9	66.3	78.3	61.4	65.6	4.4	76.9	2450	0150
57.9	61.2	64.8	58.2	59.6	2.0	64.7	0150	0250
58.0	62.5	71.4	58.6	61.2	2.8	68.3	0250	0350
57.9	62.1	73.2	58.5	61.3	2.9	68.7	0350	0450
58.1	63.8	74.5	59.1	62.7	3.6	71.9	0450	0550
57.8	60.7	69.5	58.2	60.6	2.4	66.8	0550	0650
59.6	66.7	77.5	60.7	65.0	4.5	76.6	0650	0750
61.7	69.3	77.0	62.4	65.9	4.8	78.1	0750	0850
60.1	69.0	76.6	61.5	65.4	4.9	77.9	0850	0950
57.7	59.9	64.4	57.9	58.2	1.4	61.8	0950	0953

TABLE VII-2. - Sideline noise measurements

Location "2": 1025 S. 171st St.
11/07/73

MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	FROM	TO
54.2	59.3	63.9	54.8	55.9	2.9	63.4	1337	1341
54.8	67.5	78.2	57.1	65.1	6.4	81.6	1341	1444
54.1	65.9	77.9	56.3	64.7	6.2	80.6	1444	1544
53.7	61.2	75.7	55.2	62.5	5.0	75.2	1544	1654
54.9	64.7	77.3	56.6	64.2	5.7	78.9	1654	1754
54.9	65.0	77.4	56.7	64.1	5.9	79.1	1754	1854
53.6	62.4	74.9	55.2	61.9	5.2	75.3	1854	1954
53.2	59.0	73.2	54.2	60.2	4.1	70.7	1954	2054
54.0	62.6	79.6	55.8	67.0	5.8	81.9	2054	2154
53.9	60.3	74.0	55.3	61.0	4.7	73.0	2154	2254
57.0	63.5	77.6	57.6	64.2	5.0	77.1	2254	2354
53.8	59.1	70.3	54.6	58.4	3.5	67.4	2354	2454
52.9	56.7	73.1	53.6	59.3	3.7	68.7	2454	0154
53.0	58.0	68.3	53.7	57.2	3.3	65.7	0154	0254
53.0	57.5	65.6	53.6	57.0	2.8	64.1	0254	0354
56.8	62.8	74.6	57.2	61.9	4.5	73.3	0354	0454
55.5	61.2	75.1	56.2	62.0	4.7	74.0	0454	0554
53.0	57.7	69.6	53.7	57.8	3.2	66.0	0554	0654
55.0	67.3	78.5	57.1	65.3	6.3	81.5	0654	0754
58.2	70.8	79.4	59.8	67.3	6.8	84.8	0754	0854
57.3	66.4	78.7	58.3	65.5	5.9	80.7	0854	0954
56.9	64.5	80.2	57.8	67.0	5.8	81.9	0954	1054
54.5	62.4	76.3	56.0	63.1	5.3	76.6	1054	1154
57.4	68.3	78.7	58.6	65.8	6.2	81.6	1154	1254
59.5	69.8	83.3	61.2	69.7	6.3	85.8	1254	1354
59.3	73.7	83.6	61.9	70.6	7.3	89.2	1354	1438

TABLE VII-3. - Sideline noise measurements

Location "3": 15417 - 10th Ave. S.
11/07/73

MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	FROM	TO
54.5	64.5	72.0	56.4	60.7	5.2	74.1	1034	1106
53.3	60.4	67.9	54.4	57.3	3.7	66.8	1106	1206
53.8	60.9	68.4	55.0	57.7	3.9	67.6	1206	1306
54.2	62.4	69.8	55.6	59.5	4.4	70.8	1306	1406
53.9	60.4	68.3	55.0	58.0	3.8	67.8	1406	1506
53.4	59.4	68.2	54.3	57.4	3.5	66.5	1506	1606
53.3	59.6	68.5	54.3	57.1	3.6	66.4	1606	1706
53.9	61.1	68.1	55.1	57.8	3.9	67.7	1706	1806
53.9	59.2	66.5	54.6	56.5	3.2	64.7	1806	1906
52.9	61.2	69.5	54.0	58.0	4.0	68.3	1906	2006
53.4	59.0	66.4	54.2	56.3	3.2	64.4	2006	2106
54.6	62.9	72.0	56.0	60.5	4.6	72.4	2106	2206
53.4	62.4	76.6	55.1	62.7	5.2	76.2	2206	2306
54.5	67.3	79.9	57.2	67.3	6.9	85.1	2306	2406
54.2	65.7	78.2	56.4	64.7	6.2	80.6	2406	0106
52.6	54.6	76.2	53.0	64.4	3.3	72.8	0106	0206
52.5	54.6	59.0	52.6	53.1	1.2	56.1	0206	0306
53.3	61.7	78.4	54.8	64.5	5.3	78.0	0306	0406
53.4	61.8	77.9	54.9	63.8	5.2	77.0	0406	0506
53.2	59.5	73.8	54.5	60.3	4.6	72.1	0506	0606
56.4	64.1	79.0	57.3	65.4	5.6	79.8	0606	0706
58.2	68.8	77.9	59.6	65.4	5.9	80.6	0706	0806
55.9	65.2	74.2	57.1	62.6	5.5	76.6	0806	0906

TABLE VII-4. - Sideline noise measurements

Location "4": 19054 - 32nd Ave. S.
11/07/73

MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	FROM	TO
54.1	59.7	68.5	55.1	57.5	3.7	67.0	1226	1259
55.4	61.5	69.0	56.0	58.6	4.0	68.9	1259	1400
55.2	62.6	69.1	56.1	58.9	4.2	69.7	1400	1500
56.0	63.3	68.7	56.6	59.1	4.3	70.1	1500	1600
57.6	62.2	68.9	57.8	59.4	3.1	67.4	1600	1700
56.6	60.3	68.9	56.7	58.7	3.6	67.9	1700	1800
57.4	63.1	69.0	57.7	59.5	3.6	68.8	1800	1900
54.8	60.3	66.2	55.6	57.8	3.7	67.3	1900	2000
53.2	57.9	64.3	53.7	55.0	2.6	61.6	2000	2100
54.1	59.6	68.3	54.9	57.2	3.6	66.4	2100	2200
52.9	56.3	67.1	53.4	55.3	2.6	62.0	2200	2300
53.4	59.0	68.6	54.3	56.9	3.5	65.9	2300	2400
52.8	55.9	63.8	53.2	54.4	2.2	60.0	2400	0100
53.2	58.3	66.4	53.9	55.6	2.9	63.0	0100	0100*
52.7	54.9	62.1	53.0	53.7	1.8	58.4	0100	0200
52.6	54.6	58.2	52.7	53.1	1.1	56.0	0200	0300
53.3	58.7	64.9	54.0	55.7	3.0	63.3	0300	0400
52.7	54.8	65.7	53.0	54.6	2.3	60.4	0400	0500
52.6	54.8	59.9	52.8	53.5	1.5	57.3	0500	0600
52.7	54.9	62.6	53.0	54.0	1.9	58.8	0600	0700
54.6	61.4	68.8	55.6	58.2	4.0	68.6	0700	0800
57.0	62.2	69.2	57.2	59.3	3.7	68.8	0800	0900
56.8	61.5	68.8	56.9	58.8	3.6	68.0	0900	1000
57.5	60.9	68.8	57.6	59.1	3.0	66.7	1000	1100
57.6	59.9	67.9	57.7	58.7	2.3	64.7	1100	1200
58.8	64.5	69.5	59.6	61.1	3.2	69.2	1200	1234

TABLE VII-5. Sideline noise measurements

Location "5": 19027 - 37th Ave. S.
11/07/73

MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	FROM	TO
58.6	66.0	73.6	59.7	62.6	4.1	73.1	1402	1502
57.6	64.0	72.7	58.1	61.1	4.1	71.7	1502	1602
57.4	61.7	71.6	57.7	60.2	3.5	69.2	1602	1702
54.9	62.6	71.3	56.1	59.7	4.5	71.3	1702	1802
53.8	62.2	71.3	55.2	59.5	4.6	71.3	1802	1902
53.2	59.3	70.5	54.3	58.2	3.9	68.3	1902	2002
52.9	57.5	69.9	53.7	57.4	3.5	66.3	2002	2102
53.0	58.7	71.1	54.0	58.2	3.9	68.3	2102	2202
52.8	55.0	67.9	53.3	55.8	2.9	62.9	2202	2302
52.6	54.7	64.5	52.9	54.6	2.0	59.7	2302	2402
52.7	54.9	69.7	53.4	57.1	3.3	65.7	2402	0102
52.7	54.9	70.5	53.4	57.3	3.3	65.8	0102	0202
52.6	54.6	61.3	52.7	54.3	1.7	58.6	0202	0302
52.6	54.6	62.5	52.7	54.1	1.6	58.3	0302	0402
52.5	54.6	55.8	52.6	52.7	0.7	54.4	0402	0502
52.6	54.7	68.1	53.0	55.5	2.5	62.0	0502	0602
53.7	59.1	67.5	54.5	56.7	3.3	65.1	0602	0702
56.4	64.6	70.8	57.1	60.6	4.8	72.8	0702	0802
55.8	64.3	70.9	56.7	60.4	4.8	72.7	0802	0902
53.7	60.0	69.7	54.9	58.5	4.2	69.3	0902	1002
54.0	63.8	69.8	55.7	59.6	4.8	71.9	1002	1102
54.6	59.8	68.8	55.4	57.9	3.7	67.4	1102	1202
55.9	62.1	69.8	56.4	59.5	4.2	70.3	1202	1302
57.3	63.9	69.8	57.7	60.4	4.2	71.1	1302	1402
57.5	63.2	69.8	57.9	60.2	3.7	69.6	1402	1502
57.4	64.3	69.7	57.8	60.4	4.1	71.0	1502	1602
56.7	59.9	68.3	56.6	58.3	3.3	66.8	1602	1635

TABLE VII-6. Sideline noise measurements

Location "6": 236 S. 171st St.
11/07/73

MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	FROM	TO
67.5	69.9	74.4	67.5	68.1	2.1	73.5	1702	1715
57.5	67.1	72.4	57.9	60.6	3.6	70.0		
57.5	61.9	72.4	57.8	60.6	3.6	69.8	1715	1802
58.2	65.8	73.3	59.2	62.3	4.3	73.3	1802	1902
57.1	64.5	73.3	57.6	61.4	4.6	73.2	1902	2002
53.4	59.0	70.5	54.3	58.0	3.6	67.4	2002	2102
54.3	63.3	71.9	55.9	60.1	4.8	72.4	2102	2203
53.9	62.3	73.5	55.4	60.7	4.9	73.3	2203	2303
53.1	59.2	71.8	54.2	58.8	4.0	69.1	2303	2403
54.7	62.4	71.5	55.9	59.8	4.5	71.2	2403	0103
52.9	58.2	73.0	54.0	59.3	4.3	70.3	0103	0203
52.6	54.6	59.0	52.7	53.0	1.1	55.8	0203	0303
52.9	57.1	66.9	53.5	55.7	2.7	62.7	0303	0403
52.8	55.4	67.4	53.4	55.7	2.8	62.9	0403	0503
53.7	59.3	69.9	54.7	58.2	3.8	67.9	0503	0603
57.3	63.0	71.9	57.6	60.7	4.0	70.9	0603	0703
58.6	68.7	74.5	60.2	64.2	5.1	77.2	0703	0803
57.9	68.5	74.7	59.1	64.2	5.8	79.0	0803	0903
55.2	62.8	73.4	56.3	60.9	4.8	73.2	0903	1003
54.7	62.1	73.7	56.0	61.0	4.9	73.5	1003	1103
55.7	59.9	72.0	56.1	59.6	4.0	69.9	1103	1203
56.6	64.0	73.6	57.2	61.4	4.8	73.7	1203	1303
57.1	63.9	73.9	57.6	61.8	4.6	73.6	1303	1403
57.8	65.9	74.4	58.7	62.9	4.6	74.7	1403	1503
57.8	65.5	73.7	58.6	62.1	4.2	73.0	1503	1603
57.9	63.0	73.0	58.6	61.3	3.3	69.8	1603	1703
57.9	63.2	72.1	58.6	60.9	3.2	69.2	1703	1733

TABLE VIII - Full power takeoff - runup and reverser noise levels (dBA)

(Various locations along 12th Avenue)			
GENERAL LOCATION	RANGE MEASURED	RANGE ESTIMATED (FULL POWER)	RANGE ESTIMATED (THRUST REVERSER)
I	75-85	75-80	55-60
II	75-85	82-87	62-67
III	50-85	80-85	60-65
IV	70-85	75-80	55-50

As mentioned previously, the sideline measurements were also used as a comparison with predicted sideline values. Table IX shows that comparison.

The measured values in Table IX were derived from the hourly L_{eq} levels shown in Table VII-1 to VII-6 by computing the CNEL and subtracting 35 to obtain an equivalent ANE value for comparison. The calculated ANE values were prepared for the Interim Study. The average difference between the measured and calculated values is 4dB. For this reason the engine shielding correction was eliminated from the calculations for the Final Study. The deletion of this correction combined with the updated data used in the noise exposure calculations for the Final Study, as mentioned earlier, reduced the average difference to .5dB.

TABLE IX - Comparison of measured and calculated sideline noise levels

SITE	MAP CELL	MEASURED (CNEL-35)	CALCULATED ANE
1	S21	35	22
2	M21	33	29
3	M17	35	34
4	R26	27	32
5	T26	28	27
6	K21	31	21

Although the range of differences was much greater, several factors contribute to the differences. As mentioned earlier in this report, the conversion from CNEL to ANE can have a ± 3dB error. Also, the ANE values account for noises solely from aircraft while the L_{eq} values account for noises from all sources. Finally, the ANE values are computed at the center of the map cell and the measurements were not necessarily at the center. For the map cells shown in Table IX, the ANE values could vary ±4dB within the cell.

BACKGROUND NOISE SURVEY

The residents of the SEA-TAC study area are exposed to other noise as well as to aircraft noise, and a realistic evaluation of noise impact should consider the total noise environment.

The other major noise source in the area (besides aircraft noise) is surface vehicular traffic, although there may be a few areas where industrial noise predominates. Measurement locations, therefore, were based primarily on considerations of proximity to a freeway, highway, or other street.

Fifteen measurement locations were chosen (measurement locations selected for the aircraft noise recordings were not suitable for the background noise survey), representing the two extremes of surface traffic noise exposure, and a variety of exposure conditions in between. The following location selection criteria were utilized:

a. 2 locations near a highway or freeway
b. 2 locations far from a highway or freeway
c. 2 locations near an arterial
d. 2 locations far from an arterial
e. 5 typical neighborhood locations
f. 2 rural locations

Three recordings of one hour each were made at each location, representing day (7 A. M. to 7 P. M.), evening (7 P. M. to 10 P. M.) and night (10 P. M. to 7 A. M.). These recordings were reduced to obtain the following hourly A-weighted levels: L_1, L_{10}, L_{50}, L_{90}, L_{99}, standard deviations, Noise Pollution Level and energy average (or Hourly Noise Level). Table X gives the locations of the fifteen sites used in these recordings.

Results from that survey are presented in Table XI. In addition to the above-mentioned measures, the table also presents CNEL values with and without aircraft flyover noises. As mentioned previously, the continuous noise equivalent level (CNEL) can be correlated with noise exposure forecast vales by the approximate expression:

$$CNEL \approx NEF + 35 \quad (\pm 3 \text{ dB})$$

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There is a wide variation of levels throughout the community. The equivalent NEF range observed is 43.3 to 12.9 without aircraft included, with a mean value of about 28 and a standard deviation of 8.4 dB. With aircraft included, somewhat higher values are observed. The maximum observed equivalent NEF is 43.4 with a minimum of 16.5, a mean of 33, and a standard deviation of 7.3 dB. It must be noted that these values are based on a single one-hour sample and as such are not representative of the actual values that would be observed over the entire time intervals involved. However, they do give an indication of the probable range of values that can be observed in the area. It is clear that at many locations the existing noise levels due to surface vehicles and other non-aircraft noise are easily equivalent to aircraft noise values.

POSITION	LOCATION
A	N.E. corner of S. Donovan St. and 8th Ave. S. 100' from W. Marginal Way S.
B	S. 139th and 51st Ave. S. 240' east of I-5
C	S.E. corner of S. 138th St. and 3rd Ave. S. 500' west of SR 509
D	S. 249th St. and 34th Ave. S. 500' west of 1st Ave. S. (SR 509)
E	West side of 1st Ave. S., 500' north of S.W. 197th St., 500' west of 1st Ave. S.
F	N.E. corner of S. 121st Pl. and Military Road South, 150' east of Military Road South
G	South side of S. 216th St. and 21st Ave. S. 80' from S. 216th St.
H	S. 216th and Frager Road 500' south of S. 212th St.
J	South side of S. Donovan St., 100' west of 12th Ave. S., 500' from W. Marginal Way S.
K	West side of 16th Ave. S. and S. 126th St. 600' north of S. 128th St.
L	S.W. corner of 8th Ave. S.W. and S.W. 128th 40' from S.W. 128th St.
M	North side of S. 175th St., halfway between 32nd Ave. and 33rd Ave. S., 1300' east of Highway 99
N	S.W. corner of S.W. 162nd St. and 9th Ave. S. 750' south of S.W. 160th St.
P	Saltwater State Park, lower parking lot 50' from Puget Sound
Q	End of 6th Pl. S.W. and S.W. 171st (dead-end road), 3500' west of SR 509

TABLE XI - Surface noise levels (dBA)

3/29/74

POS.	D/E/N	99%	90%	MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	** CNEL	EQUIV. NEF	* CNEL	EQUIV. NEF
A	D*	46.8	52.2	61.9	70.3	79.0	62.1	67.5	6.4	84.0				
	D	46.6	53.6	61.1	68.9	75.9	61.2	65.3	5.9	80.3				
	E*	40.2	42.1	50.3	64.2	75.8	52.1	62.3	8.5	84.1	66.4	31	67.7	33
	E	40.2	41.9	49.5	62.2	72.8	51.0	59.8	7.6	79.2				
	N*	42.8	46.2	52.2	62.1	69.1	53.2	58.1	5.9	73.2				
	N	42.8	46.1	52.0	61.8	69.1	53.0	57.9	5.8	72.9				
B	D*	65.3	70.3	75.8	80.0	84.6	75.5	77.1	3.9	87.2				
	D	65.1	70.2	75.5	79.9	84.6	75.2	77.0	4.0	87.3				
	E*	56.3	63.5	70.8	75.7	80.4	70.2	72.5	4.8	84.9	78.3	43	78.4	43
	E	56.3	63.5	70.8	75.7	80.4	70.2	72.5	4.8	84.9				
	N*	44.3	51.4	61.2	71.9	83.3	61.6	69.9	8.0	90.4				
	N	44.3	51.4	61.2	71.9	83.3	61.6	69.9	8.0	90.4				
C	D*	45.6	50.3	55.6	63.3	75.5	56.2	62.7	5.5	76.8				
	D	45.5	50.0	55.1	59.9	67.2	55.1	57.6	4.2	68.4				
	E*	47.9	51.4	57.0	63.4	69.8	57.2	60.0	4.3	71.1	60.2	25	63.1	28
	E	47.6	51.2	56.4	60.6	65.0	56.3	57.9	3.5	67.0				
	N*	40.7	45.4	49.8	56.8	62.2	50.4	53.0	4.3	64.1				
	N	40.6	45.2	49.0	54.5	60.0	49.5	51.5	3.8	61.3				
D	D*	55.1	57.8	63.1	69.3	77.9	63.5	66.9	4.4	78.1				
	D	55.1	57.6	62.9	68.6	73.6	63.0	64.8	3.8	74.4				
	E*	50.8	55.8	62.1	68.8	74.5	62.2	65.0	4.8	77.4	68.9	34	71.0	36
	E	50.7	55.5	61.6	67.8	73.2	61.5	63.9	4.5	75.4				
	N*	47.8	52.4	58.7	66.8	75.6	59.3	63.8	5.4	77.5				
	N	47.6	52.2	58.3	65.0	70.4	58.7	61.5	4.7	73.7				

POS.	D/E/N	99%	90%	MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	** CNEL	EQUIV. NEF	* CNEL	EQUIV. NEF
E	D*	43.7	50.7	63.9	71.9	77.1	62.5	67.8	7.8	87.7				
	D	42.9	49.6	62.2	71.8	77.4	61.5	67.5	8.1	88.2				
	E*	50.7	55.9	66.2	74.1	79.2	65.6	69.8	6.7	86.9	75.1	40	75.3	40
	E	50.6	55.7	65.7	73.9	79.1	65.3	69.6	6.7	86.6				
	N*	46.0	52.1	63.6	73.4	78.7	63.2	68.6	7.8	88.6				
	N	45.9	51.9	62.9	73.2	78.7	62.7	68.4	7.8	88.4				
F	D*	42.1	46.3	52.9	68.5	77.3	55.1	64.7	8.3	85.9				
	D	41.6	46.0	52.2	67.2	74.9	54.2	63.2	7.8	83.2				
	E*	36.9	42.3	49.2	67.9	78.7	52.2	65.3	9.5	89.6	70.0	35	71.8	37
	E	37.0	42.0	48.5	62.4	75.7	50.5	61.9	8.0	82.3				
	N*	35.3	38.1	51.4	68.4	77.3	52.6	65.2	10.7	92.7				
	N	35.3	38.0	50.4	67.6	75.4	51.9	63.5	10.4	90.2				
G	D*	35.6	40.7	52.4	63.9	85.9	52.8	70.9	9.5	95.1				
	D	35.1	40.5	52.0	61.6	69.1	51.5	57.7	7.7	77.4				
	E*	50.1	50.7	53.7	64.2	82.2	55.9	67.9	6.4	84.3	60.4	25	69.6	35
	E	50.1	50.7	53.4	59.7	68.3	54.4	57.4	3.6	66.6				
	N*	35.6	40.1	43.1	49.5	66.0	44.2	52.1	5.1	65.2				
	N	35.6	40.1	43.1	49.5	66.0	44.2	52.1	5.1	65.2				
H	D*	36.9	41.3	48.6	61.0	72.8	50.0	59.3	7.6	78.8				
	D	36.4	40.9	47.0	56.0	72.4	48.1	57.8	6.6	74.8				
	E*	39.3	41.2	47.1	59.1	69.8	48.7	57.3	6.9	75.1	58.2	23	59.3	24
	E	38.8	41.1	46.2	55.0	68.8	47.4	55.8	6.0	71.1				
	N*	35.1	36.0	39.9	48.7	59.5	41.4	47.6	5.2	60.8				
	N	35.1	36.0	39.9	48.7	59.5	41.4	47.6	5.2	60.8				

TABLE XI - Surface noise levels (dBA) (continued)

POS	D/E/N	99%	90%	MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	** CNEL	EQUIV. NEF	* CNEL	EQUIV. NEF
J	D*	45.3	47.6	54.0	71.8	83.7	57.1	70.1	9.1	93.4	62.8	28	77.1	42
	D	45.2	47.0	52.6	60.4	69.8	53.3	59.8	5.2	73.2				
	E*	40.2	42.3	48.2	64.7	78.8	51.0	64.9	8.8	87.4				
	E	40.2	42.1	47.6	57.0	68.2	48.6	55.5	5.8	70.3				
	N*	45.1	46.0	49.9	57.4	86.2	51.7	70.8	7.3	89.5				
	N	45.1	45.9	49.6	54.7	66.6	50.5	55.4	4.0	65.7				
K	D*	40.3	42.8	48.5	60.3	84.0	50.7	71.8	8.2	92.9	62.7	28	74.1	39
	D	40.2	41.9	47.3	54.1	68.2	47.9	55.7	5.0	68.6				
	E*	40.2	42.2	48.0	60.2	78.5	49.9	64.5	7.8	84.5				
	E	40.2	41.9	47.3	54.5	67.1	48.0	55.3	5.1	68.4				
	N*	35.4	39.1	45.5	63.7	81.5	48.8	66.5	10.1	92.5				
	N	35.3	37.7	43.2	52.9	69.5	44.6	56.1	6.5	72.7				
L	D*	39.7	44.2	56.4	67.7	76.6	56.2	64.4	8.6	86.4	67.8	33	68.2	33
	D	39.7	44.2	56.2	67.3	75.6	56.0	63.9	8.5	85.6				
	E*	45.7	50.8	59.5	68.6	75.3	59.6	64.7	6.6	81.7				
	E	45.6	50.5	58.5	67.6	74.4	58.7	63.6	6.4	79.9				
	N*	41.6	47.0	55.8	63.8	70.5	55.7	60.4	6.2	76.4				
	N	41.3	46.5	54.5	63.6	71.3	54.8	60.2	6.4	76.5				
M	D*	53.7	56.2	61.7	69.3	77.4	62.3	66.2	4.9	78.9	63.1	28	66.0	31
	D	52.9	55.9	60.4	65.4	72.4	60.7	63.1	3.8	72.7				
	E*	50.2	51.7	58.0	69.5	79.0	59.4	66.6	6.6	83.5				
	E	50.2	51.6	57.4	66.4	74.6	58.3	63.2	5.5	77.2				
	N*	40.2	41.9	46.7	49.7	54.5	46.5	47.6	2.8	54.8				
	N	40.2	41.9	46.7	49.7	54.5	46.5	47.6	2.8	54.8				

POS.	D/E/N	99%	90%	MEDIAN	10%	1%	MEAN	L_{EQ}	SDEV	L_{NP}	** CNEL	EQUIV. NEF	* CNEL	EQUIV. NEF
N	D*	40.2	42.3	48.8	61.9	70.6	50.6	58.3	7.2	76.7	52.4	17	58.9	24
	D	40.1	41.7	47.2	54.5	65.7	47.9	53.4	5.1	66.6				
	E*	35.1	36.6	42.4	55.6	65.3	44.1	52.9	7.1	70.9				
	E	35.1	36.3	41.1	45.9	53.2	41.2	43.3	3.6	52.7				
	N*	30.3	32.9	39.3	46.9	63.9	40.1	49.8	6.2	65.7				
	N	30.2	32.2	38.6	44.3	52.7	38.7	41.8	4.6	53.5				
P	D*	25.0	31.9	45.3	60.4	73.4	45.6	59.6	10.5	86.5	52.6	18	69.1	34
	D	23.7	30.3	42.3	49.6	58.8	41.3	47.6	7.6	67.1				
	E*	35.1	35.6	37.8	40.8	44.6	38.1	38.5	1.6	42.7				
	E	35.1	35.6	37.8	40.8	44.6	38.1	38.5	1.6	42.7				
	N*	40.1	41.4	46.6	59.4	77.7	48.4	63.1	7.8	83.0				
	N	40.1	41.0	45.2	49.2	51.5	45.2	46.0	2.6	52.7				
Q	D*	32.2	36.0	41.4	52.0	63.0	42.7	50.2	6.3	66.3	47.9	13	51.5	17
	D	32.2	35.9	40.6	48.3	55.9	41.3	45.1	4.7	57.3				
	E*	30.3	32.5	37.8	50.0	59.8	39.4	47.6	6.6	64.4				
	E	30.2	32.1	37.2	43.0	54.8	37.6	42.5	4.4	53.7				
	N*	30.2	31.9	38.1	44.5	53.8	38.4	42.5	4.9	55.0				
	N	30.2	31.7	37.8	44.0	48.9	37.9	40.2	4.3	51.2				

* With SEA-TAC aircraft included (if any).

** CNEL values for non-aircraft day only.

$$CNEL = 10 \log_{10} \frac{1}{24} \left[\sum_{0700}^{1900} 10^{\frac{L_{eq}(day)}{10}} + 3 \sum_{1900}^{2200} 10^{\frac{L_{eq}(evening)}{10}} + 10 \sum_{2200}^{0700} 10^{\frac{L_{eq}(night)}{10}} \right]$$

COSTS OF INSULATING RESIDENCES

A study was performed on the costs and benefits of providing insulation in residences as a means of reducing aircraft noise. The study was based on a review of the technical literature on this subject. The study indicates that the primary need is for forced air ventilation that would allow sealing all windows. Once that is accomplished, various stages of additional insulation can be provided commensurate with the intensity of exterior noise levels. It appears tnat these techniques are useful in the range of NEF 30 to 45. Insulation costs would typically range from 15 to 30 percent of the fair market value for each home. A detailed discussion of this subject is included in Appendix A.

NOISE CONTROL ALTERNATIVES

A variety of possible noise control alternatives have been considered in the study. These have included both those operations that are under direct control of the airport.and those that are controlled by the Federal Aviation Administration and relating to operational flight controls.

Among the possibilities that have been considered as options for the airport have been:

1. Time restrictions on maintenance engine runups.

2. Optimum placement and orientation of runups.

3. Runup shelters.

4. Blast fences or berms.

Items 1. and 2. have been discussed in detail elsewhere in the report. Items 3. and 4. are alternate means for accomplishing runup abatement that can be achieved by 1. and 2. Blast fences or berms, to be effective, must intersect the line of site between the source and receiver. The primary noise source for a turbojet or turbofan engine at high power levels is the turbulent exhaust. Noise sources in that stream extend to distances of up to 50 engine diameters behind the exit plane. For this reason, the size of the noise source is on the order of 100 to 150 feet in length. Because sound waves tend to bend around obstacles, effective barriers must extend far beyond the source. These factors make blast fences or berms unsuitable for shielding against jet noise.

Fixed installations, such as runup shelters, would require a sizable investment to solve the runup noise problem. Portable muffling devices have been developed. However, each engine type requires its own suppression device. Also, the useful life of these suppression devices is relatively short. Again, night restrictions and optimum placement of runups can achieve the same result.

FLIGHT OPERATIONAL ALTERNATIVES

A variety of flight type noise abatement alternatives are also possible. It is almost certain that most of the current narrow-bodied commercial transports will be retrofitted with engine nacelles incorporating noise attenuating materials in the next few years. Refan was not considered in these studies. More aircraft with quiet engines will also be forthcoming and the current fleet will gradually be retired. The FAA and EPA are studying a variety of takeoff and approach noise abatement procedures. The two-segment approach seems to be an excellent noise abatement possibility. This and three different possible noise abatement takeoff procedures have been investigated in the present study. Table XII summarizes the various

TABLE XII - Operational Alternatives Used in NEF/ANE/ASDS Calculations

	FLEET MIX	
	Interim	Final
1973		
FULL POWER	A	A
ATA		B
1978:		
FULL POWER & RETROFIT	A	A
ATA		B
ATA & RETROFIT		A
ATA & RETROFIT & WEST APPROACHES		A
EPA & RETROFIT		A
LOW POWER & RETROFIT		A
1983 AND 1993:		
FULL POWER & RETROFIT & 2-SEGMENT	A	A
ATA		A
ATA & RETROFIT & 2-SEGMENT		B
ATA & RETROFIT & WEST APPROACHES		A
EPA & RETROFIT & 2-SEGMENT		A
LOW POWER & RETROFIT & 2-SEGMENT		A

A = NEF CALCULATIONS ONLY
B = NEF, ANE AND ASDS CALCULATIONS

Note: Retrofit here means quiet nacelles using sound absorbing materials.

abatement options that have been selected for the noise exposure calculations for the study years 1973, 1978, 1983 and 1993. Details concerning the number and types of each aircraft for each of the study years and data on the noise and performance features of each option are described under NOISE EXPOSURE CALCULATIONS.

One set of cases shown in Table XII needs further clarification. It is the set denoted with West approaches. For these cases it was assumed that the west runway was used exclusively for landings and the east runway was used exclusively for takeoffs.

In addition to the NEF/ANE calculations, some computations have also been completed using the aircraft sound description system (ASDS) technique. As shown in Table XII, these calculations were completed for the same cases as for the ANE procedure.

NOISE EXPOSURE FORECAST CONTOURS

A map of the official study area is shown in Figure P. The NEF contours for the Final Report were only calculated within the official study area. A set of contours was calculated for each of the 20 NEF cases listed in Table XII. The contour set corresponding to each of the cases listed in that Table have been plotted and are presented in Volume 3 of this report.

The total land areas enclosed by the contours are presented in Table XIII. These areas include only the land area within

TABLE XIII - Land area in square miles enclosed within NEF contours

			CONTOUR			
YEAR	CASE	CONDITION	30	35	40	45
1973	1	FULL POWER	25.17	14.11	7.05	3.08
	2	ATA	21.10	12.27	6.23	2.86
1978	3	FULL POWER & RETROFIT	20.81	10.48	4.25	1.68
	4	ATA	17.88	10.24	5.16	2.33
	5	ATA & RETROFIT	15.03	7.06	3.30	1.58
	6	EPA & RETROFIT	10.20	5.28	2.69	1.43
	7	LOW POWER & RETROFIT	16.49	7.68	3.08	1.23
	8	ATA & RETROFIT & WEST APPROACHES	14.80	6.77	3.04	1.43
1983	9	FULL POWER & RETROFIT & 2-SEGMENT	19.89	9.41	3.62	1.42
	10	ATA	17.02	9.43	4.59	2.04
	11	ATA & RETROFIT & 2-SEGMENT	13.42	5.87	2.74	1.30
	12	EPA & RETROFIT & 2-SEGMENT	8.43	4.41	2.36	1.23
	13	LOW POWER & RETROFIT & 2-SEGMENT	15.53	6.45	2.43	.95
	14	ATA & RETROFIT & WEST APPROACHES	13.70	5.79	2.63	1.23
1993	15	FULL POWER & RETROFIT & 2-SEGMENT	15.81	6.55	2.48	1.03
	16	ATA	12.57	5.64	2.51	1.14
	17	ATA & RETROFIT & S-SEGMENT	11.33	4.80	2.05	.95
	18	EPA & RETROFIT & 2-SEGMENT	7.50	3.77	1.94	.94
	19	LOW POWER & RETROFIT & 2-SEGMENT	12.39	4.97	1.97	.78
	20	ATA & RETROFIT & WEST APPROACHES	11.65	4.72	1.85	.89

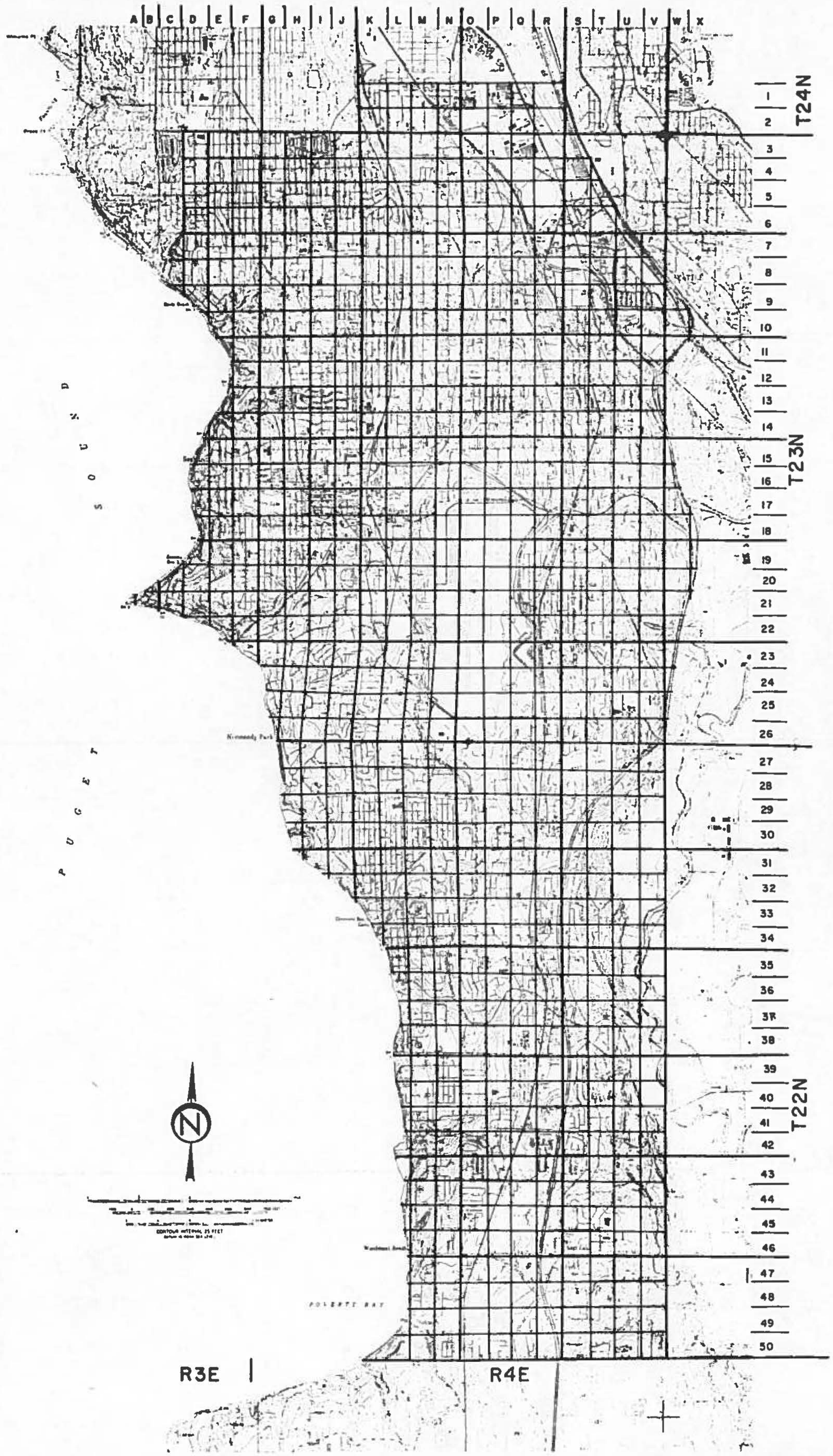

FIGURE P - Official study area map

the official study area, and the airport area - approximately three square miles - has not been subtracted from the areas shown.

Using the data in Table XIII, several things may be deduced. Examination of cases 2, 4, 10 and 16 show the effect the projected fleet changes will have on the area enclosed within a given contour. In these cases, the ATA takeoff procedure was assumed and the area changes over the study years are due solely to the phasing out of the older narrow bodied jets and replacing them with the new technology aircraft types. These cases show that although the number of operations increases 60% over the twenty year period (shown in Table III), the contour areas are reduced by an average of more than 40%. Also, comparing cases 3, 5, 6 and 7 (for 1978) or cases 9, 11, 12 and 13 (for 1983) or cases 15, 17, 18 and 19 (for 1993), the effect the different types of takeoff procedures have upon the contour areas is shown. For each of these three sets of cases, the fleet mix is held constant and the contour area differences are due to various takeoff procedures. Ranking the takeoff procedures in terms of the NEF 30 contour areas reveals that the EPA takeoff procedure would impact the least amount of area followed by the ATA procedure, the low power procedure and the full power takeoffs respectively.

For a better understanding of the relationship of the contour areas to the study area, the contour maps in Volume III should be consulted.

ACTUAL NOISE EXPOSURE CONTOURS

ANE contours have also been plotted for the study years 1973, 1978, 1983 and 1993 and are presented in Volume III. Table XIV shows the areas enclosed within the ANE contours. The assumptions made for the ANE calculations, using the fleet mixes shown in Table III, were that there would be no retrofit in 1978 and that there would be 100% retrofit and fully operational two-segment approaches in the study years 1983 and 1993.

In addition to the ANE contours, values at the center of each map cell in the official study area are shown in Tables XV through XVIII for the four respective study years. The tables are arranged so that the rows and columns have the same designations as the 1/16th section map cells in the official

TABLE XIV - Land area in square miles enclosed within ANE contours

	CONTOUR			
YEAR	30	35	40	45
1973	26.50	13.65	5.11	1.90
1978	22.70	11.08	4.14	1.55
1983	21.55	7.97	2.39	.84
1993	18.33	6.05	1.93	.70

study area shown in Figure P. The value shown within each cell represents the ANE at the center of the cell.

A reiteration of the sections of this report regarding the NEF and ANE methodologies and contour maps prefaces the Volume III report.

AIRCRAFT SOUND DESCRIPTION SYSTEM CONTOURS

Contours are presented in Volume III using the ASDS methodology. These contours represent the time the noise exposure level exceeds 85 dBA. ASDS contours were calculated using the same assumptions as were used in the ANE calculations.

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TABLE XV - Actual noise exposure values for each 1/16 section within the study area

1973 ---- ANE in dB

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1											32	34	36	37	39	35	31	27						
2											33	34	36	38	40	35	31	28	25					
3			17	19	20	22	23	25	28	31	32	34	36	38	40	36	31	28	25					
4			17	19	20	22	23	25	28	30	30	34	36	38	41	36	32	28	25	24				
5			17	19	20	21	23	25	27	30	32	34	36	39	42	36	32	29	26	24				
6			18	19	20	21	23	25	27	30	32	34	36	39	43	37	32	29	26	24	23			
7			18	19	20	21	23	24	26	29	32	34	36	39	43	37	33	29	27	25	23	22		
8			18	19	20	21	23	24	26	29	31	34	36	40	44	37	33	30	27	25	24	22		
9				19	20	21	23	24	26	28	31	34	36	40	45	37	33	30	27	25	24	23	21	
10				19	20	21	23	24	26	28	31	34	36	40	46	38	34	30	28	26	25	23	22	
11					20	22	23	24	26	28	31	34	37	40	47	38	34	31	28	27	25	24	23	
12					21	22	23	25	26	28	30	34	37	41	49	38	35	31	29	27	26	24		
13					21	22	23	25	27	28	31	34	37	41	50	39	35	32	30	28	26	25		
14					21	22	24	25	27	39	31	34	37	42	51	39	35	33	30	29	27	26		
15				20	21	22	24	26	37	29	31	34	38	42	53	40	36	34	31	29	28	26	25	
16				20	21	23	24	26	27	29	31	34	38	43	54	43	38	35	32	30	28	26	25	
17				20	21	23	24	26	27	29	31	34	38	44	56	50	40	36	33	30	28	26	25	23
18				15	17	18	20	21	23	25	27	30	34	42	55	48	36	31	28	26	23	22	20	19
19			14	15	16	18	19	21	23	25	27	30	34	42	56	48	36	31	28	25	23	21	20	18
20			14	15	16	17	19	21	22	24	26	29	33	41	57	48	35	30	27	25	23	21	20	18
21	1	12	13	15	16	17	19	20	22	24	26	29	32	40	57	48	35	30	27	25	23	21	20	
22			14	15	16	18	19	21	22	24	27	29	33	40	58	49	37	32	28	26	24	22	20	
23						18	20	21	23	25	27	30	34	41	47	49	38	32	29	27	24	22	21	
24							20	22	23	25	28	30	34	41	57	49	38	33	30	27	25	23	21	
25							23	25	26	28	31	33	37	45	55	48	40	35	32	29	27	25	24	
26							23	25	26	28	31	33	36	41	48	47	40	35	32	29	27	25		
27								25	26	28	30	33	36	40	47	46	40	35	32	30	27	26		
28								25	26	28	30	32	36	40	46	45	40	35	32	30	27	26		
29								24	26	28	30	32	36	39	45	45	39	35	32	30	27	25		
30								24	26	27	29	32	36	39	44	44	40	36	32	30	27	25		
31									25	27	29	32	36	39	44	44	39	36	32	29	27	25		
32										27	29	32	36	38	44	44	38	36	32	29	27	25		
33											29	32	36	38	43	43	38	36	32	29	27	25		
34											29	32	36	38	43	43	38	36	33	29	27	25		
35												33	35	38	42	42	38	35	33	30	27	25		
36												33	35	38	42	42	38	35	33	30	27	25		
37												32	35	37	41	41	37	35	32	29	27	25		
38												32	35	37	41	41	37	35	32	30	27	25		
39												32	35	37	40	40	37	35	32	30	27	25		
40												32	35	37	40	40	37	34	32	30	27	25		
41												32	34	36	39	40	37	34	32	30	27	25		
42												32	34	36	39	39	36	34	32	30	28	26		
43												32	34	36	39	39	36	34	33	30	28	26		
44												32	34	36	38	38	36	34	33	31	28	27		
45												32	34	36	38	38	36	34	33	31	29	27		
46												32	33	35	38	38	36	34	33	31	30	29		
47												31	33	35	37	37	36	34	32	31	30	30		
48												31	33	35	37	37	35	34	32	32	31	30		
49												32	33	35	36	36	35	34	33	32	31	31		
50												32	33	35	36	36	35	34	33	32	32	31		

Airport boundary outlined

TABLE XVI- Actual noise exposure values for each 1/16 section within the study area

1978 ---- ANE in dB

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1											31	33	35	36	38	34	30	26						
2											31	33	35	37	39	34	30	26	23					
3			16	17	18	20	22	24	27	29	31	33	35	37	39	35	30	27	24					
4			16	17	18	20	22	24	26	29	31	33	35	37	40	35	30	27	24	22				
5			16	17	18	20	21	23	26	29	31	33	35	38	41	35	31	27	24	22				
6			16	17	18	20	21	23	25	28	31	33	35	38	42	36	31	28	25	23	21			
7			16	17	18	20	21	23	25	28	31	33	35	39	43	36	31	28	25	23	21	20		
8			16	17	18	20	21	23	25	27	30	33	35	39	43	36	32	27	25	23	22	21		
9				17	18	20	21	23	24	27	30	33	35	39	44	36	32	28	26	24	22	21	20	
10				17	18	20	21	23	24	27	29	33	35	39	46	37	32	29	26	24	23	22	20	
11					19	20	21	23	24	27	29	33	35	39	47	37	33	29	27	25	24	22	21	
12					19	20	22	23	25	27	29	33	36	40	48	37	33	30	27	26	24	23		
13					19	20	22	23	25	27	29	33	36	40	49	38	33	30	28	26	25	23		
14					19	21	22	24	25	27	29	32	36	40	51	38	34	31	29	27	25	24		
15					19	21	22	24	26	27	30	33	36	41	52	39	35	32	30	28	26	24		
16				18	20	21	22	24	26	28	30	33	36	42	54	41	37	34	31	29	26	25	23	
17				18	20	21	22	24	26	28	30	33	36	43	55	48	39	35	31	29	27	25	23	
18				14	15	16	18	20	21	24	26	29	33	41	55	46	35	30	27	24	22	20	19	
19			12	13	15	16	18	20	21	23	26	29	33	40	55	46	34	30	26	24	22	20	18	17
20			12	13	14	16	17	19	21	23	25	28	32	40	56	46	34	29	26	24	21	20	18	16
21	10	11	12	13	14	16	17	19	20	22	25	27	31	38	56	46	34	29	26	24	21	20	18	
22			12	13	15	16	18	19	21	23	25	28	32	39	56	47	35	30	27	24	22	20	19	
23						16	18	20	21	23	26	29	32	39	56	48	36	31	28	25	23	21	19	
24							18	20	22	24	26	29	33	40	56	47	37	32	28	26	23	21	20	
25							22	23	25	27	29	32	36	43	54	47	39	34	30	28	26	24	22	
26							22	23	25	27	29	32	35	40	47	46	39	34	31	28	26	24		
27								23	252	27	29	31	35	39	46	45	39	34	31	28	26	24		
28								23	25	26	29	31	34	39	45	44	38	34	31	28	26	24		
29								23	24	26	28	31	34	38	44	44	38	34	37	28	26224			
30								23	24	26	28	31	35	38	43	43	38	34	31	28	26	24		
31									24	26	28	31	35	38	43	43	38	34	31	28	26	24		
32										26	28	31	35	37	43	43	37	35	31	28	25	24		
33											28	31	35	37	42	42	37	34	31	28	25	23		
34											28	31	34	37	42	42	37	34	31	28	25	23		
35												31	34	37	41	41	37	34	31	28	25	23		
36												31	34	36	41	41	36	34	31	28	26	24		
37												31	34	36	40	40	36	34	31	28	25	23		
38												31	34	36	40	40	36	34	31	28	25	23		
39												31	33	36	39	39	36	33	31	28	25	23		
40												31	33	35	39	39	36	33	31	28	26	23		
41												31	33	35	38	38	35	33	31	29	26	24		
42												31	33	35	38	38	35	33	31	29	26]	24		
43												31	33	35	38	38	35	33	31	29	27	25		
44												31	32	35	37	37	35	33	31	29	27]	25		
45												30	32	35	37	37	35	33	32	30	27	26		
46												30	32	34	37	37	35	33	32	30	28	27		
47												30	32	34	36	36	34	33	31	30	29	28		
48												30	32	34	36	36	34	32	31	30	29	29		
49												30	32	34	35	35	34	32	31	30	30	29		
50												31	32	34	35	35	34	32	31	30	30	30		

Airport boundary outlined

POS 208163

PORT 0012743

TABLE XVII - Actual noise exposure values for each 1/16 section within the study area

1983 ---- ANE in dB

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1											30	33	34	33	33	31	29	25						
2											31	32	34	34	34	21	29	26	23					
3			15	17	18	20	21	24	27	29	31	32	34	34	34	32	30	26	23					
4			15	17	18	20	21	23	26	29	30	32	34	35	35	32	30	27	24	22				
5			16	17	18	19	21	23	26	28	30	32	34	35	36	33	30	27	24	22				
6			16	17	18	19	21	23	25	28	30	32	34	36	37	33	30	27	24	22	21			
7			16	17	18	19	21	23	25	28	30	32	34	36	37	33	31	28	25	23	21	20		
8			16	17	18	19	21	22	24	27	30	32	34	36	38	34	31	28	25	23	22	20		
9				17	18	19	21	22	24	27	29	32	34	37	39	34	31	28	26	24	22	21	20	
10				17	18	19	21	22	24	26	29	32	34	37	40	34	32	28	26	24	23	21	20	
11					18	20	21	22	24	26	29	32	34	37	41	35	32	29	27	25	23	22	21	
12					19	20	21	23	24	27	29	32	35	38	42	35	32	29	27	25	24	23		
13					19	20	22	23	25	27	29	32	35	38	43	36	33	30	28	26	25	23		
14					19	20	22	23	25	27	29	32	35	39	44	37	33	31	29	27	25	24		
15				18	19	21	22	24	25	27	39	32	35	39	45	38	34	32	30	28	26	24	23	
16				18	19	21	22	24	25	27	30	32	36	40	47	40	36	33	31	29	26	25	23	
17				18	19	21	22	24	25	27	30	32	36	41	50	46	38	34	31	29	27	25	23	22
18				13	15	16	18	19	21	23	26	28	32	39	49	43	33	29	26	24	22	20	18	17
19			12	13	14	16	17	19	21	23	25	28	32	38	50	43	33	29	26	24	22	20	18	16
20			12	13	14	15	17	19	20	23	25	27	31	38	51	43	33	28	26	24	21	19	18	16
21		11	12	13	14	15	17	19	20	22	25	27	30	37	51	44	33	29	26	24	21	19	18	
22			12	13	14	16	17	19	21	23	25	27	31	37	51	45	34	30	27	24	22	20	18	
23						16	18	20	21	23	26	28	32	38	51	45	35	31	27	25	23	21	19	
24							18	20	22	24	26	29	32	38	51	44	36	31	28	26	23	21	19	
25							21	23	25	27	29	32	35	41	51	45	38	33	30	28	25	24	22	
26							21	23	25	27	29	31	34	39	47	43	38	33	30	28	26	24		
27								23	25	27	29	31	34	38	43	43	38	33	30	28	26	24		
28								23	24	26	29	31	34	38	42	42	37	33	30	28	26	24		
29								23	24	26	28	30	34	37	41	41	37	34	30	28	25	24		
30								22	24	26	28	30	34	37	41	41	37	34	30	28	25	23		
31									24	25	28	30	34	37	40	40	37	34	30	28	25	23		
32										25	28	30	34	36	40	40	36	34	30	28	25	23		
33											28	31	34	36	39	39	36	34	31	28	25	23		
34											28	31	34	36	39	39	36	34	31	28	25	23		
35												31	34	36	38	38	36	34	31	28	25	23		
36												31	33	35	38	38	35	33	31	28	25	23		
37												31	33	35	38	38	35	33	31	28	25	23		
38												31	33	35	37	37	35	33	31	28	25	23		
39												31	33	35	37	37	35	33	31	28	25	23		
40												31	33	35	36	36	35	33	31	28	25	23		
41												31	33	34	36	36	34	33	31	28	26	23		
42												31	32	34	36	36	34	33	31	29	26	24		
43												31	32	34	35	35	34	33	31	29	27	24		
44												30	32	34	35	35	34	33	31	29	27	25		
45												30	32	33	35	35	34	33	31	30	27	26		
46												30	32	33	34	34	34	32	31	29	28	27		
47												30	31	33	34	34	33	32	31	30	29	28		
48												30	31	33	34	34	33	32	31	30	29	28		
49												30	31	32	33	33	33	32	31	30	29	29		
50												30	31	32	33	33	32	31	31	30	29	29		

Airport boundary outlined

TABLE XVIII - Actual noise exposure values for each 1/16 section within the study area

1993 ----- ANE in dB

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1											29	31	33	32	32	30	28	25						
2											29	31	33	33	33	30	28	25	22					
3			15	16	17	19	21	23	26	28	29	31	33	33	33	31	29	25	22					
4			15	16	17	19	20	22	25	28	29	31	33	34	34	31	29	26	23	21				
5			15	16	17	19	20	22	25	27	29	31	33	34	35	32	29	26	23	21				
6			15	16	17	19	20	22	24	27	29	31	33	35	36	32	29	26	23	22	20			
7			15	16	17	19	20	22	24	27	29	31	33	35	37	32	29	27	24	22	20	19		
8			15	16	17	19	20	22	23	26	29	31	33	36	37	33	30	27	24	22	21	20		
9				16	17	19	20	22	23	26	28	31	33	36	38	33	30	27	25	23	21	20	19	
10				16	18	19	20	22	23	25	28	31	33	36	39	34	30	28	25	23	22	21	19	
11					18	19	20	22	23	25	28	31	33	36	40	34	31	28	26	24	23	21	20	
12					18	19	21	22	24	26	28	31	33	37	41	34	31	28	26	25	23	22		
13					18	19	21	22	24	26	28	31	33	37	42	35	32	29	27	25	24	23		
14					18	20	21	23	24	26	28	31	34	37	43	36	32	30	28	26	25	23		
15				17	19	20	21	23	25	26	28	31	34	38	45	37	33	31	29	27	25	24	22	
16				17	19	20	22	23	25	27	29	31	34	39	47	39	35	32	29	28	26	24	22	
17				17	19	20	22	23	25	27	29	31	34	40	49	45	37	33	30	28	26	24	23	21
18				13	14	16	17	19	20	22	25	27	31	38	49	43	32	28	25	23	21	19	18	16
19			11	13	14	15	17	18	20	22	24	27	30	37	49	43	32	28	25	23	21	19	17	16
20			11	12	13	15	16	18	20	22	24	26	30	37	50	42	32	27	25	23	20	19	17	15
21	9	10	11	12	13	15	16	18	20	21	24	26	29	36	51	43	32	28	25	23	21	19	17	
22			11	12	14	15	17	18	20	22	24	26	30	36	51	44	33	28	26	23	21	19	18	
23						16	17	19	21	22	25	27	30	36	51	44	34	29	26	24	22	20	18	
24							18	19	21	23	25	27	31	37	51	43	35	30	27	25	22	20	19	
25							21	22	24	26	28	30	34	40	51	43	36	32	29	27	25	23	21	
26							21	22	24	26	28	30	33	38	46	42	36	32	29	27	25	23		
27								22	24	26	28	30	33	37	42	42	36	32	29	27	25	23		
28								22	24	25	27	30	32	36	41	41	36	32	29	27	25	23		
29								22	23	25	27	29	32	36	40	40	36	32	29	27	25	23		
30								22	23	25	27	29	32	36	40	40	35	32	29	27	24	23		
31									23	25	27	29	32	35	39	39	35	32	29	27	24	23		
32										24	27	29	32	35	39	39	35	32	29	27	24	22		
33											27	29	32	35	38	38	35	32	29	27	24	22		
34											27	30	32	35	38	38	35	32	30	27	24	22		
35												30	32	34	38	38	34	32	30	27	24	22		
36												30	32	34	37	37	34	32	30	27	24	22		
37												30	32	34	37	37	34	32	30	27	24	22		
38												30	32	34	36	36	34	32	30	27	24	22		
39												30	32	34	36	36	34	32	30	27	24	22		
40												30	32	33	35	35	33	32	30	27	24	22		
41												30	31	33	35	35	33	31	30	27	25	22		
42												30	31	33	35	35	33	31	30	28	25	23		
43												30	31	33	34	34	33	32	30	28	26	24		
44												29	31	32	34	34	33	32	30	28	26	24		
45												29	31	32	33	34	33	32	30	29	26	25		
46												29	31	32	33	33	32	31	30	29	27	26		
47												29	30	32	33	33	32	31	30	29	28	27		
48												28	30	31	32	33	32	31	30	29	28	28		
49												28	30	31	32	32	31	30	30	29	28	28		
50												28	30	31	32	32	31	30	29	29	28	28		

Airport boundary outlined

POS 208165

PORT 0012745

CRITERIA AND APPLICATION OF RESULTS

Establishing firm noise criteria, that will lead to specific actions for an unique situation such as an individual airport, has many facets. It involves the wants of specific persons and special interests in the communities, generalized health and welfare criteria, technical feasibility of selected solutions, and trade-offs among costs. Considering these diverse and often conflicting aspects plus the fact that aircraft noise from the Seattle-Tacoma airport will decrease markedly during the next decade, it is recommended that the four ANE contours (1973, 1978, 1983, 1993) be utilized as the basis for a time-scheduled land use planning program in the following manner:

ANE $\geqq$ 45	Single family, multiple family or apartment complexes are to be eliminated through a land use planning program.
45 > ANE $\geqq$ 35	Apply noise improvement program possibilities of Reference 19. to all existing single and multiple family residences.
35 > ANE $\geqq$ 25	Apply items 5., 9., and 10 of Reference 19. or an adjusted version of these items to this part of the study area. The intent is that property owners should not be denied mortgage insurance due to airport noise and that new construction plans in this area should be carefully investigated relative to airport noise impact. The extent that mortgage insurance nonavailability for this area has occurred should be determined.
25 > ANE	Consider this area as not being in any manner impacted by SEA-TAC aircraft noise.

The above recommendations emphasize the residential living situation and to a considerable extent are based on levels from the EPA "Levels Document" (Reference 17.) plus those of Reference 16. The basis for selecting 45 > ANE $\geqq$ 35, as the criteria for applying the programs of Reference 19. is:

1. The EPA "Levels Document" (Reference 17.) makes no claim to offering mandatory standards but leaves the selection of noise criteria to the local communities. For example,

   Cover page - "This document has been approved for general availability. It does not constitute a standard, specification or regulation."

   Page 5 - "These levels are not to be construed as standards as they do not take into account cost or feasibility."

   Page 9 - "Neither Congress nor the Environmental Protection Agency has reached the conclusion that these identified levels should be adopted by states and localities. This is a decision which the Noise Control Act clearly leaves to the states and localities themselves."

2. EPA (Reference 17.) recommends that noise levels in living quarters should not exceed 45 L_{DN}. An L_{DN} of 45 dB is equal to an out-of-doors ANE of 10 dB. However, 20 dB is a reasonable noise attenuation result for home construction (Reference 18.) Thusly, it would require an ANE of 30 if the EPA recommended standard were to be met. There is another factor which requires consideration in establishing this inside level and that is the fact that EPA has subtracted 5 dB from all of their recommended levels as, "a margin of safety." It is proposed that this additional 5 dB not be utilized. This finally leads to the conslusion that an ANE less than 35 is acceptable for the indoors living situation.

3. A last consideration is based on the findings of the "SEA-TAC Community Attitude Study" (Reference 20.) Approximately 74% of the respondents in the middle level noise area (NEF is approximately 25 to 35) did not mention aircraft noise among "things disliked" about the area. This leads to the conclusion that a large number of people in this middle noise area do not have high concern relative to Sea-Tac aircraft noise effects.

POS 208167

PORT 0012747

CONCLUSIONS

1. An extensive measurement program has confirmed that the noise exposure forecast methodology, with slight modification, is a reasonably accurate noise prediction model.

2. The size of noise impact areas decreases over the time period covered by the study.

3. Fleet mix changes projected by the airlines will have a beneficial effect in terms of noise reduction.

4. Implementation of retrofit and flight operational alternatives could significantly reduce the noise impact areas beyond the reductions due solely to fleet mix changes.

5. Selection of optimum runup sites and positioning can produce significant noise relief.

6. At many locations in the study area, vehicular and non-aircraft generated noises are equivalent to or greater than aircraft noise.

RECOMMENDATIONS

1. Land use planning criteria should be developed for the ASDS methodology.

2. A study should be conducted to determine more precisely the variability of operational characteristics for the various classes of aircraft.

3. An airport noise monitoring system should be installed to measure the effects of operational changes. This is particularly essential to an equitable application of the programs designed to mitigate noise impact effects on the community.

4. A several years long community response evaluation program should be conducted to quantify the effectiveness of the programs which are aimed at mitigating noise impact effects on the community.

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APPENDIX A

ESTIMATING COSTS OF INSULATING RESIDENCES FROM AIRCRAFT NOISE

1. INTRODUCTION

The Port of Seattle has requested MAN, Inc. to investigate the feasibility of insulating houses near the airport from the noise of flyovers. Recent literature has been researched and average costs per square foot of occupied floor space have been computed.

The primary factor is the need for forced air ventilation which enables the windows to be closed year-round. Minimizing air leaks at doors is helpful but not generally quantifiable. Where more noise reduction is necessary, modifications of door, window, roof-ceiling, wall and floor systems may be necessary. The following is a discussion of methods and costs for insulating residential buildings in particular airport noise areas.

2. DISCUSSION

Studies of the costs of insulating houses near O'Hare, J. F. K. and L. A. International Airports to protect the inhabitants from aircraft noise are described in References 1 - 3.

The Los Angeles study, involving actual modifications of homes, showed actual cost increments similar to the other two studies that were based on estimated costs.

In the Los Angeles study, twenty homes in high noise areas around Los Angeles International Airport were acoustically modified to provide data on insulation techniques and associated costs. Stage 1 modifications consisted of provision of forced air ventilation systems and minor modifications to doors and windows, at a total average cost of $3,210 per unit, or $2.10 per square foot of floor area. Stage 2 changes consisted of minor modifications to exterior doors and windows (such as acoustical doors and double-glazed windows) and new ventilation systems, at a cost of $4,820 per unit or $3.15 per square foot of floor area. The final Stage 3 homes required complete modification, including roof-ceiling systems, floors, walls and all improvements included in the Stage 1 and 2 treatments. Costs for the Stage 3 program averaged $12,550 per home, or $8.20 per square foot of floor area. The average home contained 1,530 square feet of floor area. Assuming an average market value of $25,000, insulation costs for the Stage 2 modifications would be approximately 20 percent of the home value.

An approach to estimating the amount of additional noise reduction required can be based on ANE or NEF values. An exterior NEF of less than 30 is normally acceptable according to HUD Standards as stated in their circular 1390.2. In the range of NEF 30 to NEF 40, the HUD Standards require noise attenuation measures. Using the HUD Standards as a guideline would require a 5 dB attenuation increment between NEF 30 and 35 and a 10 dB increment between NEF 35 and 40. The results of the Los Angeles insulation study can be used to estimate both the types of modifications needed for these increments and the approximate costs. Note that the Los Angeles study was completed in 1969 and that about 30 percent additional costs should now be allowed to account for the effects of inflation.

In the Los Angeles study, the attenuation values are reported in terms of octave-band levels and speech interference levels. Neither of these is directly indicative of the overall improvement in terms of NEF because of the spectrum weightings employed. For this reason we have calculated resulting sound level-A values for a typical flyover noise and each stage of insulation. Then, using the open window condition as a reference, we have determined the incremental attenuation achieved by each stage and the equivalent cost per square foot of living space. These values are summarized in Table 1.

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TABLE 1. Incremental values of attenuation and costs based on the Los Angeles Study.

HOUSE CONDITION	ATTENUATION dBA	INCREMENTAL COST/SQ.FT. (Dollars)
Stage 3	30	8.20
Stage 2	26	3.15
Stage 1	22	2.10
Windows Closed	21	--
*Windows Open	15	--

*Expected reference attenuation

From Table 1 we can see that the HUD criteria can be met in the NEF 30-35 range with Stage 1 modifications and by Stage 2 in the NEF 35-40. If minimal outdoor activities are required, Stage 3 modifications appear feasible in the NEF 40-45 range.

As we mentioned above, the Stage 1 modifications were designed to allow residents to live with doors and windows closed by providing forced-air ventilation. Stage 1 modifications also involved repairing cracks and openings, replacing hollow core doors with seals, and improved window seals for all windows except those on the sheltered side of the house. Average cost for such modifications to the six homes of the study was $2.10 per square foot of floor area. (Modifications were performed in 1969 and current costs will be greater.)

Stage 2 modifications involved replacement of all exterior doors with acoustical doors and seals, providing double glazing on all but the shielded rooms, closure of mail ducts, installation of fireplace dampers, modification of kitchen and bathroom vent ducts by including a bend and acoustic lining. With the exception of rooms with beamed ceilings, which were provided with an external auxiliary roof section, Stage 2 modifications were accomplished without modifications to walls, floors or ceilings. Average cost for eleven homes receiving Stage 2 modifications was $3.15 per square foot for homes without beamed ceilings, and $4.20 per square foot for homes with beamed ceilings.

Stage 3 modifications were performed in three homes. In addition to Stage 2 modifications, these homes included tests of addition of sound traps inside foundation vents, fiberglass batts between floor joists, chemical foam insulation between ceiling joists, installation of a double ceiling of fiberglass batts and wood fiber sound-deadening board. Wall modifications involving addition of cemented layers of gypsum and wood fiber sound-deadening board inside exterior walls were tried but sound insulation results were marginal.

What are the expected results from a program to insulate houses against aircraft noise? Table 2, adapted from the Los Angeles study, provides an indication. In most of the categories investigated, there was considerable subjective improvement, even in some non-acoustical categories such as television flicker. Least improvement appears to have been achieved in reducing perception of house vibration or shaking. Generally, bigger improvements are noted in all categories except vibration for the Stage 2 and 3 houses. Evidently, house vibration is a more pronounced source of irritation in the higher noise level areas and less amenable to increased insulation. This would tend to indicate that in this respect, additional insulation is more effective at the Stage 1 level (NEF equals 30-35).

3. CONCLUSION

Improved acoustical insulation can be an effective means of improving liveability in areas between NEF 30 and NEF 45. Costs of such a program could be estimated from the data presented here in conjunction with demographic data on the number of residences within the NEF 30-45 areas as finally established.

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TABLE 2 - Comparison of before-soundproofing and after-soundproofing responses to questions on specific activities interfered with.
(Los Angeles Department of Airports 1970)

	Do the aircraft ever. . .	ALL HOUSES				STAGE 1 & 2 HOUSES ONLY			
		Before Modification		After Modification		Before Modification		After Modification	
		Yes%	No%	Yes%	No%	Yes%	No%	Yes%	No%
A	Startle you?	62	38	31	69	63	37	26	74
B	Keep you from going to sleep?	49	51	41	59	44	56	26	74
C	Wake you up?	67	33	46	54	74	26	41	59
D	Interfere with listening to TV/radio?	95	5	54	46	96	4	48	52
E	Make the TV picture flicker?	74	26	59	41	70	30	52	48
F	Make the house vibrate or shake?	92	8	77	23	100	0	85	15
G	Interfere with conversation?	97	3	49	51	100	0	44	56
H	Disturb your rest or relaxation?	77	23	33	67	74	26	22	78
I	Interfere with or disturb any other activity? IF YES, SPECIFY ONE ONLY	72	28	26	74	63	37	19	81
J	Bother, annoy or disturb you in any other way? IF YES, SPECIFY ONE ONLY	38	62	21	79	44	56	19	81
Note:	*Average for all questions, all houses:*	*72.3*	*27.7*	*40.5*	*59.5*	*73*	*27*	*38*	*62*

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