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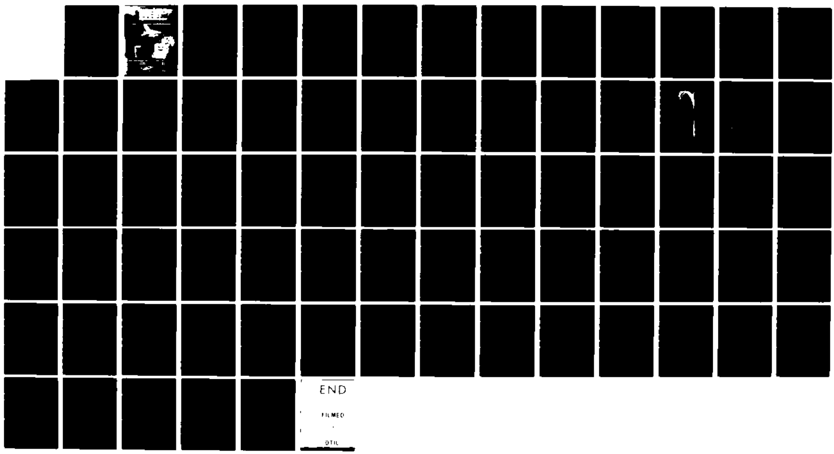

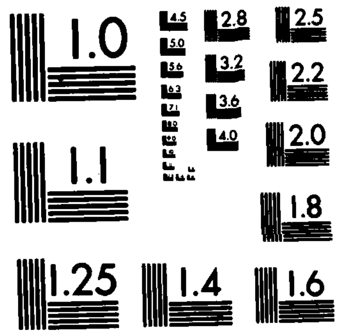
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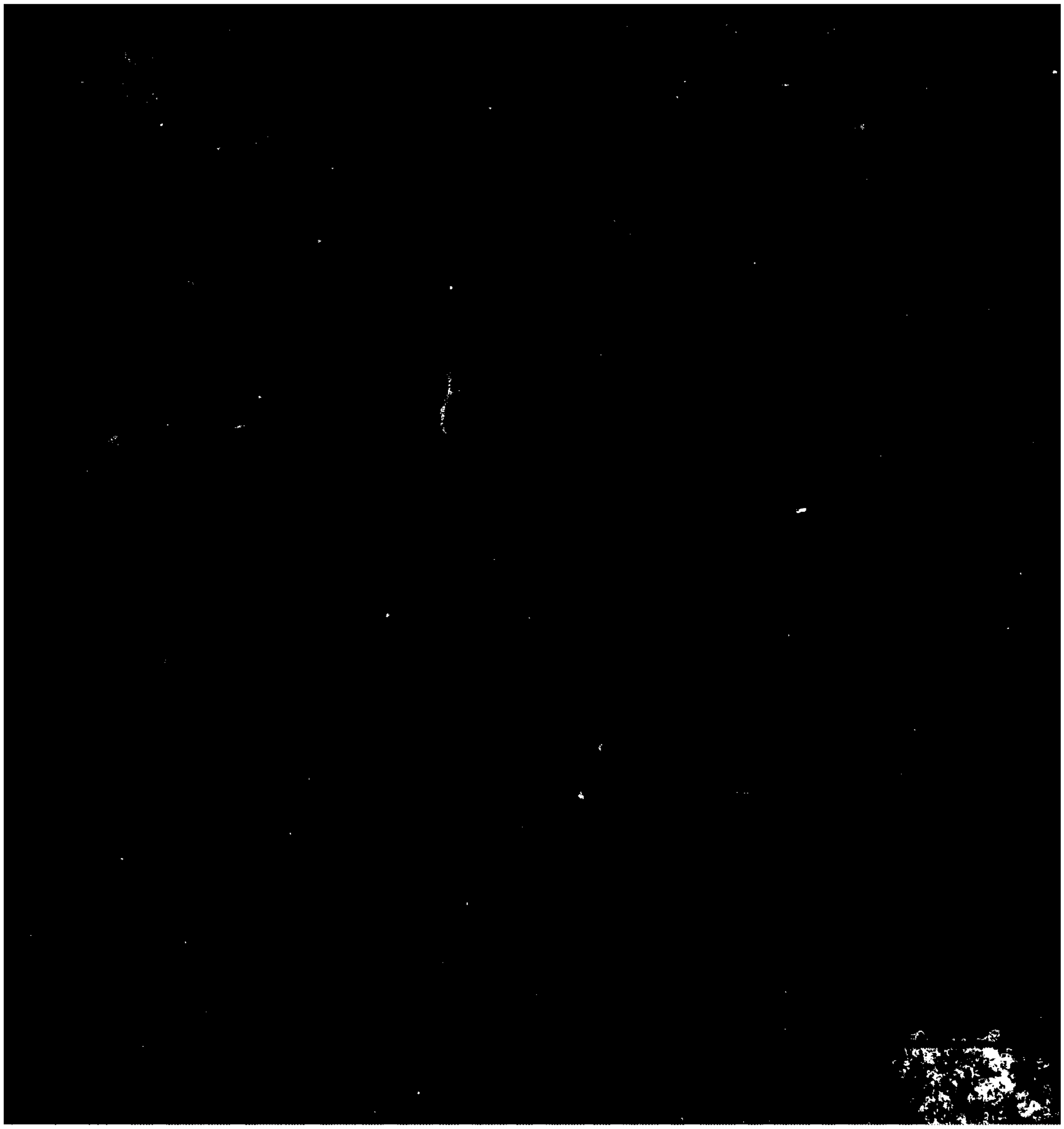

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16. Abstract

The Federal Aviation Administration's Integrated Noise Model (INM) is a series of computer programs designed to estimate environmental noise level in the vicinity of an airport. As part of MITRE's efforts to validate INM outputs for the FAA, comparisons were made between the Sound Exposure Levels (SEL) of actual aircraft flyovers at Seattle-Tacoma International Airport and SELs which were computed by the INM for identical conditions. Data for this analysis were obtained from the FAA ARTS-III radar to determine the actual slant range and velocity of observed aircraft, and from noise monitors located beyond each runway end to determine actual SEL values associated with observed aircraft. The report presents the results of the comparison of INM and observed SEL values for seven transport-category aircraft.

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FAA Integrated Noise Model Validation: Analysis of Air Carrier Flyovers at Seattle-Tacoma Airport

George W. Flathers, II

September 1982

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EXECUTIVE SUMMARY

The Federal Aviation Administration's Integrated Noise Model (INM) is a series of computer programs designed to estimate the noise environment in the vicinity of an airport. The INM user provides data on the airport and runway layout, and the number and types of aircraft and the ground tracks they fly over. The INM then computes noise levels in terms of a noise metric of the user's choice. As part of MITRE's efforts to check the validity of the results of INM computations for the FAA's Office of Environment and Energy, an analysis was performed to compare single event noise levels measured during actual aircraft overflights with noise levels estimated by the INM for identical circumstances. The observed data, which included aircraft position information recorded by ARTS-III radar and single event noise levels recorded by an automatic noise monitoring system, were collected at the Seattle-Tacoma International Airport (SEA-TAC).

In an earlier INM validation study (Reference 2), comparions were made between observed aircraft single event noise levels and those calculated by the then-current Version 2 INM. The major findings of this study were that INM-calculated single event noise levels did not agree very well with observed noise levels, and that, in order to produce better agreement, the INM thrust-distance-noise relationships should be revised. Since that time, a refined version (Version 3) of the INM has been prepared, and the data base used by it has been completely restructured and improved. The revised data base is referred to as the Number 8 data base. In December 1981, the altitude and velocity profiles contained in the Number 8 data base were compared with profiles observed at the Seattle-Tacoma International Airport (Reference 4). Results of this comparison revealed that the INM profiles of the newer Number 8 data base agreed significantly better with observed profiles than did profiles from older versions. However, a few revisions to the INM profiles were suggested for narrow-body aircraft to enhance agreement, and these revisions were later incorporated into the data base. After the analysis of INM altitude and velocity profiles was completed, a study was initiated to examine the accuracy of INM noise estimates.

The specific objectives of this study were to determine the level of agreement or disagreement between INM-calculated single event noise levels and noise levels observed in actual operations, and, if necessary, to determine enhancements to the INM which would improve agreement. Single event INM noise levels are largely influenced by both the thrust-distance-noise curves and the thrust levels assumed for the conduct of standard arrivals and departures, as contained in the Number 8 data base. Therefore, these items were carefully examined to determine if modifications to them might improve INM performance.

Methodology

The general approach employed in this study is a refinement and an extension of that used in earlier INM validation studies (References 1 and 2). Actual aircraft noise levels and radar position data were recorded for many thousand aircraft overflights at SEA-TAC, which is serviced by a variety of transport-category aircraft. Aircraft position and range with respect to noise measuring equipment were accurately determined by the use of ARTS-III radar data in the same manner as earlier studies conducted at Dulles and Washington National Airports. This is in sharp contrast to other studies where aircraft position was only estimated using various approximation methods based on numerous assumptions. The INM was used to calculate a noise level for the same conditions surrounding each observed overflight. The differences between the INM noise levels and the observed noise levels were then computed and statistically analyzed for various types of aircraft. For the purpose of this study, the Sound Exposure Level metric (SEL) was chosen as the basic metric on which comparisons were made.

Observed noise data were collected over the period from April to October of 1981. Within this period, data were collected on 82 days for an average duration of 12 hours per day. The aircraft-generated noise events recorded during the entire collection effort numbered over 58,000. The quantity of data is larger than that collected in earlier aircraft noise studies and permitted a detailed comparison of INM and observed noise levels for the following seven aircraft types: B727, B737, DC9, A300, DC10, L1011 and B747.

For each noise event generated by any of the seven aircraft types, an INM SEL estimate was calculated. Before the calculation was made, however, special procedures were employed to make certain the values of variables involved in INM SEL calculations closely matched the conditions surrounding the observed noise event. The special procedures were designed to select the appropriate set of INM thrust-distance-noise curves (also called SEL curves), INM flight profile, and INM thrust level.

The INM flight profiles and thrust levels for departures are patterned after the FAA-recommended noise abatement departure profile as described in Reference 5. This profile features a large cutback in thrust, applicable to most narrow-body aircraft, after they have achieved a certain altitude and speed. Compliance with the FAA-recommended profile is voluntary, however, and it was suspected, a priori, that many airlines do not employ the deep thrust cutback. To examine this more closely, special analyses were performed in which the INM thrust assumptions were modified to reflect more likely actual operating practices.

Conclusions and Recommendations

The results of the INM and observed noise level comparisons are presented in Table 1. The numbers in this table are the mean SEL differences, in A-weighted decibels, obtained for each aircraft type at the INM assumed thrust levels. It was assumed that all aircraft were flown in strict compliance with the FAA-recommended departure procedure. For each observed noise event, the SEL difference was obtained by subtracting the observed SEL from the INM SEL. Therefore, a positive mean SEL difference in Table 1 indicates the INM was, on average, overestimating observed noise while a negative mean SEL difference indicates the INM, on average, underestimated observed noise levels. For the purposes of this study, an absolute mean SEL difference of 3dB or less was considered as evidence of acceptable agreement between INM and observed noise levels. This criteria for agreement was reached by trading off between establishing a sufficiently narrow margin for agreement and having a wide enough margin to account for variations associated with observed noise measurements.

Major results, conclusions, and recommendations are presented below for the four general aircraft classes given in Table 1.

- For three engine narrow-body aircraft, INM noise estimates agreed exceptionally well with observed noise levels for aircraft which were assumed to be at takeoff, climb, and approach thrust. At cutback thrust, the INM underestimated observed noise levels by a considerable margin. This underestimation was explained by the fact that most airlines do not employ the deep thrust cutback assumed by the INM, but use the higher normal climb thrust. Additional analyses of observed noise levels and examinations of several airline flight operations manuals supported this explanation. The larger mean SEL difference of 4.46 dB noted for B727s with treated nacelle at takeoff thrust was attributed to uncertainty as to the timing of the first reduction of power from takeoff thrust to climb thrust. To confirm this possibility, an analysis in which the distance the aircraft had traveled from the brake release point (BRP) was

TABLE 1
RESULTS OF COMPARISON OF INM AND OBSERVED NOISE LEVELS

AIRCRAFT CLASS	AIRCRAFT TYPE/ENGINE (THRUST ASSUMED BY INM)	MEAN SEL DIFFERENCE, dB TAKEOFF THRUST	CUTBACK THRUST	CLIMB THRUST	APPROACH THRUST
THREE ENGINE NARROW-BODY	B727/UNTREATED NACELLE	2.13	-5.30	-1.07	1.62
	B727/TREATED NACELLE	4.46	-6.07	-1.37	-0.94
TWO ENGINE NARROW-BODY	B737/UNTREATED NACELLE	6.65	-1.54	NO DATA	-3.40
	B737/TREATED NACELLE	7.01	-6.28	0.06	-4.80
	DC9/UNTREATED NACELLE	6.83	-0.54	0.23	0.34
TWO AND THREE ENGINE WIDE-BODY	A300/CF6	-0.20		-0.64	-2.20
	DC10/CF6	0.88	NOT APPLICABLE	-0.38	-3.30
	DC10/JT9D	0.53		0.17	-3.06
	L1011/RB211	1.24		1.17	-1.93
FOUR ENGINE WIDE-BODY	B747/JT9D FIXED LIP	-2.49	NOT APPLICABLE	NO DATA	-5.45

COMPARISON AS A RESULT OF THE FOLLOWING RECOMMENDATIONS:

- No Deep Thrust Cutback
- Regroup B727, B737 and DC9 Departure Data
- Increase B747 Approach Thrust to Full Flaps

AIRCRAFT CLASS	AIRCRAFT TYPE/ENGINE (THRUST ASSUMED BY INM)	MEAN SEL DIFFERENCE, dB TAKEOFF THRUST	CUTBACK THRUST	CLIMB THRUST	APPROACH THRUST
THREE ENGINE NARROW-BODY	B727/UNTREATED NACELLE	0.09	NOT APPLICABLE	0.12	1.62
	B727/TREATED NACELLE	2.00		-0.17	-0.94
TWO ENGINE NARROW-BODY	B737/UNTREATED NACELLE	3.97	NOT APPLICABLE	4.24	-3.40
	B737/TREATED NACELLE	6.22		1.01	-4.80
	DC9/UNTREATED NACELLE	4.93		3.78	0.34
TWO AND THREE ENGINE WIDE-BODY	A300/CF6	-0.20		-0.64	-2.20
	DC10/CF6	0.88	NOT APPLICABLE	-0.38	-3.30
	DC10/JT9D	0.53		0.17	-3.06
	L1011/RB211	1.24		1.17	-1.93
FOUR ENGINE WIDE-BODY	B747/JT9D FIXED LIP	-2.49	NOT APPLICABLE	NO DATA	-3.45

considered. It revealed that, for those departure events in which the actual thrust level used was known with a greater amount of certainty, INM and observed noise levels for takeoff and climb thrust agreed very well.

Based on these results, it appears the INM SEL curves and the thrust levels assumed for takeoff, climb, and approach operations are accurate for three engine narrow-body aircraft. Also, there is convincing evidence that the INM-specified deep thrust cutback is rarely used in actual operations. Therefore, it is recommended that departure profiles of B727 aircraft be modified, by the elimination of the deep thrust cutback, to reflect more common operating practices.

- For the two engine narrow-body aircraft (B737, DC9) the agreement between INM and observed noise levels is mixed, as seen in Table 1. While agreement for these two aircraft types is slightly better than that seen in earlier studies, it is not as good as the agreement seen with other types of aircraft in this study.

  For departures by B737s with untreated nacelles, the results in Table 1, and analyses considering distance from BRP, suggest the INM overestimates observed noise for departures by about 4 to 5 dB. For arrivals, it tends to underestimate by about 3 to 4 dB. It is difficult to draw conclusions based on these results alone, but it appears the INM SEL curves and/or the thrust levels for the untreated B737 may need to be revised to reduce INM estimates by about 4 to 5 dB in order to more accurately reflect observed noise levels for departures. It also appears likely that the INM-specified approach thrust level is too low and should be increased. For the B737 with treated nacelles, the results of several different analyses suggest that the INM SEL curves for this aircraft are adequate, and the large differences between INM and observed noise levels for the takeoff, cutback, and approach cases in Table 1 are due to erroneous thrust levels assumed by the INM.

For DC9s at climb and approach thrust, INM and observed noise levels agreed reasonably well. For DC9 departures at takeoff thrust it appeared the INM was overestimating observed noise levels by 6.83 dB, as seen in Table 1. However, these differences may be entirely due to the use of the reduced thrust takeoff procedure by the major operator of DC9s at SEA-TAC. It was not possible to determine from independent sources the proportion of departures which were, in fact, using the reduced thrust procedure, but observed noise data support the hypothesis that this procedure was used extensively. Therefore, it appears the INM SEL curves and thrust levels will produce acceptable agreement with observed noise levels where standard procedures are employed, but the predominance of the reduced thrust takeoff and its effect on overall noise calculations should be examined further. As for the B727, observed data and other evidence suggest that the FAA deep cutback thrust is rarely used in actual DC9 and B737 flight operations, and INM departure profiles should be changed to eliminate the deep cutback.

- Agreement for the two and three engine wide-body aircraft was excellent. As evident in Table 1 for operations conducted at takeoff or climb thrust, the INM SEL estimates were, on average, within 2 dB of observed noise levels. For the A300 and DC10, agreement for the approach thrust case, though marginally acceptable, could be improved by increasing the thrust level assumed for approaches.

- For the B747, agreement for departures was acceptable. For approaches, the INM tended to underestimate observed noise levels by approximately 5 dB. Because the SEL curves appeared to be accurate for other thrust ranges, the INM approach thrust level should be increased to produce better agreement for approaches.

In this study, the INM SEL curves and INM thrust profiles (which are part of the arrival and departure flight profiles) were examined and found to accurately reflect actual operations for most of the aircraft types studied. However, the overall performance of the INM as a whole should still be determined, and a study designed to do that is a logical follow-up to the analyses reported in this document. Such a study should address the three issues presented below:

- It should investigate the accuracy of independent INM predictions of single-event noise levels where no information surrounding the observed noise events is used to calculate the INM estimate. The study presented in this document considered the observed velocity, elevation angle, and slant range when each INM noise level estimate was made. This was done to eliminate sources of variation and to permit analyses to focus on the INM SEL curves and thrust profiles. Now that greater confidence can be placed in the SEL curves and thrust profiles, the combined effect of using standard INM flight profiles, thrust profiles, and SEL curves in independent noise predictions should be investigated.

- The study should investigate the sensitivity of the INM estimates and observed noise levels to variations in input variables. It should identify those variables to which the INM is most sensitive and determine the effects of randomly changing the value of those variables around an accepted mean value. The INM currently works on the assumption that all of the input variables used in noise estimation (such as aircraft velocity, altitude, or thrust) are adequately modelled by a single average or mean value. However, in practice, a host of factors usually prevent observed flights from operating according to average performance. It should be determined if the overall noise estimation of a given number of flyovers all operating at the mean values of the input variables yields the same results as for the same number of flyovers where input values are randomly sampled from distributions having those same mean values.

- The overall performance of the INM should be checked in an airport case study, where observed noise levels for a given day are aggregated to yield a 24 hour-based noise metric and compared to the INM result. This would be an examination of the INM at the highest level.

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1. INTRODUCTION

The Federal Aviation Administration Integrated Noise Model (INM) is a series of computer programs designed to forecast the noise environment in the vicinity of an airport. The INM user provides data on the airport and runway layout, and the number and types of aircraft and the ground tracks they fly over. The INM then computes and reveals the noise environment in terms of a noise metric of the user's choice. As part of MITRE's efforts to check the validity of the results of INM computations for the FAA, an analysis was performed to compare single event noise levels measured during actual aircraft overflights with noise levels estimated by the INM for identical circumstances. The observed noise data, which included aircraft position information recorded by ARTS-III radar and single event noise levels recorded by an automatic noise monitoring system, were collected at the Seattle-Tacoma International Airport (SEA-TAC).

1.1 Background

In the course of calculating noise exposures in the vicinity of an airport, the INM performs four primary functions. It first estimates the noise generated by each aircraft's engines based on the engine type and an assumed thrust level. Second, it determines the distance from the aircraft to various points on the ground where a noise estimate is to be computed. It then computes various adjustments to the noise as it travels to the ground. In the fourth and final function, it compounds the effects of multiple aircraft operations to provide a time-based environmental noise descriptor or metric. In performing these functions, the INM uses information supplied by the user and data contained in its own extensive data base, including thrust-distance-noise relationships and departure and arrival flight profiles for common commercial, military, and general aviation aircraft. A more detailed description of the INM and its method of calculating aircraft noise is presented in Appendix A.

1.2 Previous Investigations

Since the earliest version of the INM (Version I) was released in January 1978, the FAA has aimed several efforts at validating the INM data base and noise calculations. The INM, as a result of these efforts, has been continuously refined and modified to more accurately forecast actual noise environments. In 1978, MITRE completed a study entitled "Analysis of Integrated Noise Model Calculations for Concorde Flyovers," (Reference 1). One major goal of the study was to test and refine methodologies to be used in subsequent, more extensive validation analyses. In the course of the study, appropriate analytical tools were found which were eventually used in later noise validation studies.

Data collected at Washington National and Dulles International Airports were used in an extensive effort to validate Version 2 of the INM, which was released in September 1979 (Reference 2). In that study, comparisons were made between observed aircraft single event noise levels and those calculated by the Version 2 INM. The major findings of this study were that INM-calculated single event noise levels did not agree very well with observed noise levels, and that, in order to produce better agreement, the INM thrust-distance-noise relationships should be revised. In a related part of the overall validation effort, an analysis of aircraft arrival and departure profiles was carried out and presented in "Comparison of FAA Integrated Noise Model Flight Profiles with Observed Altitudes and Velocities at Dulles Airport," (Reference 3). In this analysis, differences between INM flight profiles and observed flight profiles were noted and attributed to airline operating practices which differed somewhat from assumptions made by the INM profiles. Differences between observed and INM profiles were especially noticeable for departure operations, where changes in the thrust management procedures of most U.S. airlines resulted in different climb characteristics than assumed by the INM.

Using the results of these and other studies, the FAA undertook an extensive INM refinement program and produced the latest version of the INM (Version 3). The data base used by this latest version has also been revised and expanded, and is referred to as the Number 8 INM data base. Together, the Version 3 INM and the Number 8 INM data base represent the FAA's best available method for forecasting aircraft noise levels.

In December 1981, the altitude and velocity profiles contained in the Number 8 data base were compared with profiles observed at the Seattle-Tacoma International Airport (Reference 4). Results of this comparison revealed that the INM profiles of the newer Number 8 data base agreed significantly better overall with observed profiles than profiles from older versions. However, revisions to the INM profiles were suggested for narrow-body aircraft to enhance agreement, and were later incorporated into the data base.

1.3 Objectives of This Research Effort

The specific objectives of this study were to determine the level of agreement or disagreement between INM-calculated single event noise levels with noise levels observed in actual operations, and, if necessary, to determine enhancements to the INM which would improve agreement. Single event INM noise levels are largely influenced by both the thrust-distance-noise curves and the thrust levels assumed for the conduct of standard arrivals and departures, as contained in the Number 8 data base. Therefore, these items were carefully examined to determine if modifications to them might improve INM and observed noise level agreement. By reviewing and incorporating such modifications in the INM and its data base, the overall objective of providing a more accurate airport noise forecasting tool is met.

2. METHODOLOGY

The general approach employed in this study is a refinement and an extension of that used in earlier INM validation studies (References 1 and 2). Actual aircraft noise levels and supporting data were recorded for many thousand aircraft overflights at an active airport serviced by a variety of transport-category aircraft. The INM was then used to calculate a noise level for the same conditions surrounding each observed overflight. The differences between the INM noise levels and the observed noise levels were then computed and statistically analyzed for various types of aircraft.

The differences between the INM and observed noise levels have meaning only if all other factors are held equal. The actual aircraft involved were engaged in normal, everyday, air transportation flights and were not instructed to fly in any specific manner while noise levels were being recorded. Hence, the variability of these noise data includes a number of sources of variation not normally encountered in controlled experiments. The INM accounts for many of the variables having a large impact on noise estimation as shown in Table 2-1, which illustrates both real sources of variation in observed noise levels and those modelled by the INM. Therefore, to make certain that differences between INM and observed noise levels were not caused by variables not being examined, special effort was taken to assure that INM noise levels were calculated for the same set of conditions as those associated with the observed noise event. The overall validation methodology is presented in Figure 2-1.

The Sound Exposure Level (SEL) was selected as the metric for comparison of INM and observed single event noise levels. SEL is an energy summation metric which includes as factors the duration of the noise event as well as the sound pressure level. SEL is obtained by performing a time integration of the A-weighted sound pressure level time history. It was selected because it could be easily recorded by the noise monitoring system used to collect the observed noise data, and because it is one of the basic metrics used by the INM to calculate many other noise metrics which consider the number of occurences of noise events and the time of day that the events occur. According to some industry conventions, the symbol L_{AE} is used instead of the term SEL but the two are equivalent.

TABLE 2-1

METHODS USED BY INM TO ACCOUNT FOR VARIATION IN NOISE LEVELS

MAJOR SOURCES OF VARIATION	INM METHODS TO ACCOUNT FOR VARIATION
Aircraft Related Variables	
1. Aircraft (a/c) Type	1. INM data base describes 64 a/c types
2. Engine Type	2. For each a/c type, INM offers one or two engine configurations
3. Thrust Setting	3. INM has several thrust profiles for each a/c type
4. Velocity	4. INM has several velocity profiles for each a/c type, employs velocity corrrection
Propagation Related Variables	
1. Distance to Receiver	1. INM has several standard altitude profiles for each a/c type - uses profile geometry to determine distance
2. Transmission Losses (Spherical divergence, absorption)	2. INM has standard thrust-distance-noise relationships for each engine type - accounts for transmission losses
Receiver-Related Variables	
Ground Attenuation	INM employes lateral attenuation algorithm

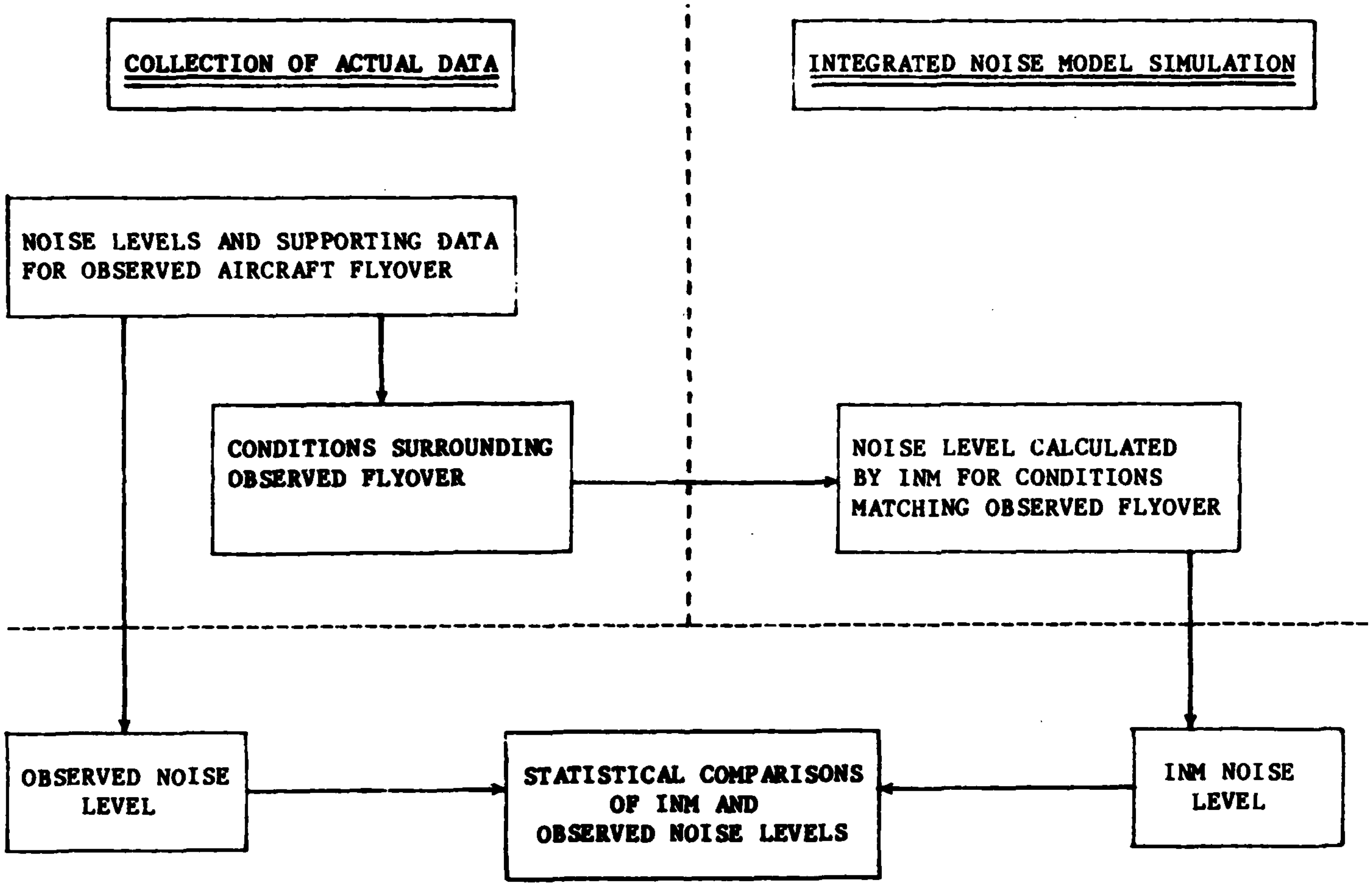


FIGURE 2-1
OVERALL VALIDATION METHODOLOGY

2.1 Collection of Actual Aircraft Sound Exposure Levels

The collection of observed SELs required the selection of an appropriate airport, and the establishment of a collection and reduction mechanism to process and store observed noise data for later comparison with INM noise levels. The desired end product of this task was a sizeable data base of observed, measured noise levels, and supporting data, for a variety of types of aircraft.

2.1.1 Site Selection - Seattle-Tacoma International Airport

One of the recommendations of an earlier INM validation study (Reference 2) was that observed noise data be collected at an airport other than Dulles International or Washington National Airports. This recommendation was made to insure that any unknown, airport-related biases in observed noise levels would be exposed in future validation efforts. All INM validation studies to that time had been conducted at Dulles and/or National Airports. To be consistent with this recommendation and to assure that the study objectives were met, a site selection process was initiated. The selected site was the Seattle-Tacoma International Airport (SEA-TAC) near Seattle, Washington.

SEA-TAC was an appropriate airport for this validation study for a number of reasons. First, it had an established noise monitor system with automatic data recording capabilities. The noise monitor sites were situated in strategic locations beyond the north and south ends of the parallel runways (Figure 2-2), which permitted the recording of noise levels for aircraft at various distances from the airport for both arrival and departure operations. SEA-TAC also had an ARTS-III radar facility from which aircraft position, altitude, and velocity information could be obtained. The accurate determination of aircraft position and range with respect to the noise monitor sites, using the ARTS-III radar data, distinguishes this validation study, and earlier studies conducted at Dulles and National, from other studies where aircraft position was only estimated using various approximation methods. The format in which the noise and radar data were recorded at Seattle allowed existing software, with slight modifications, to be used to reduce it.

SEA-TAC was also an appropriate site from the standpoint of operational issues. First, the air traffic at SEA-TAC was composed of a representative mix of two-, three-, and four-engined wide-body and narrow-body aircraft. In addition,

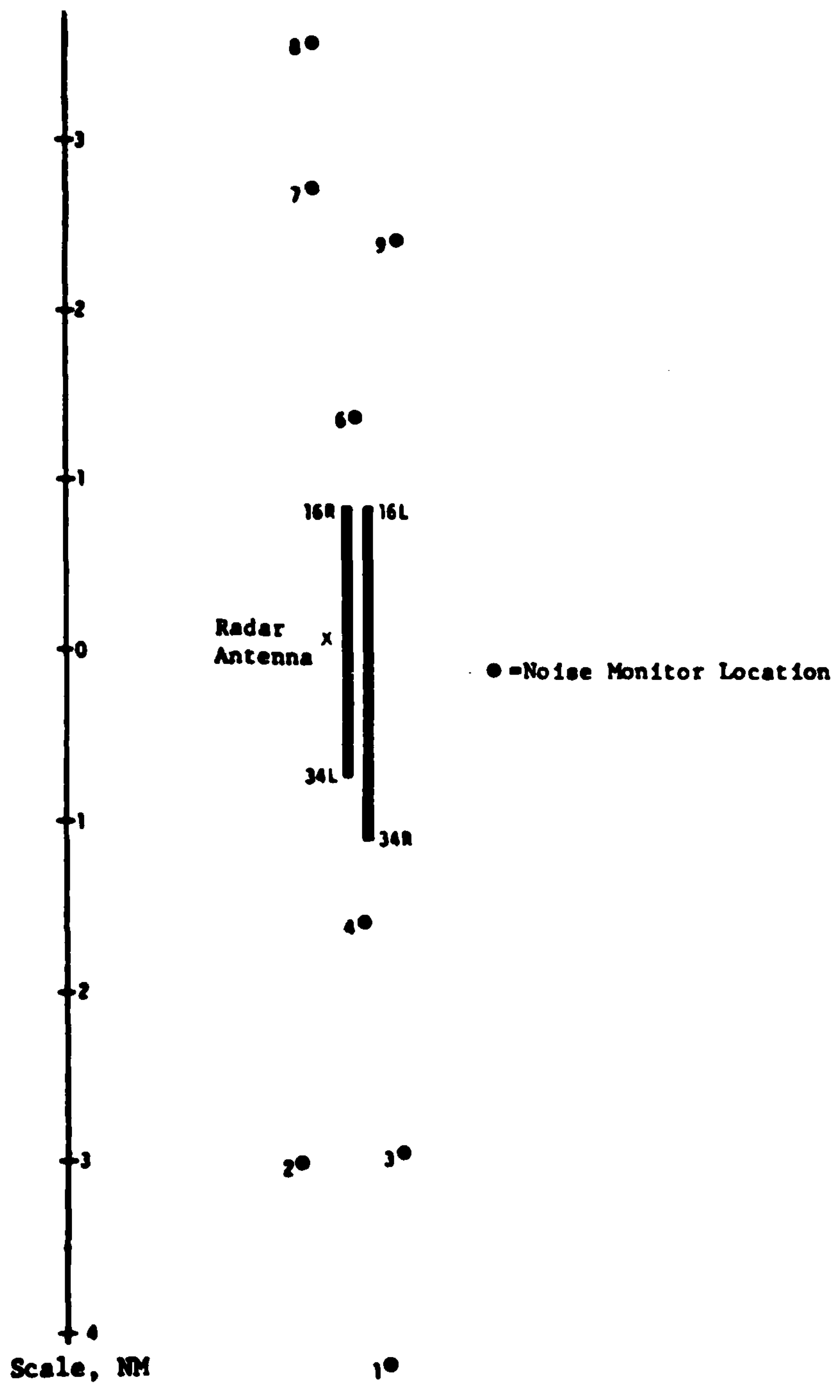


FIGURE 2-2
SEATTLE-TACOMA INTERNATIONAL AIRPORT AND NOISE MONITORING SITES

there was a representative mix of stage lengths (the non-stop flight distances) of aircraft departing the airport. SEA-TAC is serviced by airlines which fly long-haul, trans-oceanic routes and short-haul commuter routes. Finally, the arrival and departure procedures in use at SEA-TAC were fairly standard and did not require any unusual manuevering before landing or after takeoff for noise abatement or obstruction clearance. Figure 2-3 presents a distribution of ground tracks of aircraft operations for a typical day at SEA-TAC.

2.1.2 Data Collection and Reduction

The collection and reduction of the necessary observed noise data followed a three-step process: 1) collection and reduction of radar position data, 2) collection and reduction of observed noise level data, and 3) correlation of the position and noise data to make a single, complete description of a given "noise event." A noise event is defined as a recorded noise measurement which could be attributed to an aircraft flyover. The entire collection and reduction process is outlined in Figure 2-4.

As an aircraft departed or arrived at SEA-TAC, its position and altitude were determined by the FAA ARTS-III system and stored on a 9-track tape. The information on the tape included the azimuth angle and range from the radar antenna to the aircraft, Mode C altitude, time, and information from which the aircraft's identification and equipment type could be determined. The azimuth, range, and altitude were updated at approximately 4.7 second intervals. The 9-track tapes were shipped to the Washington Metropolitan Airports Noise Monitoring System Laboratory at Dulles Airport where the radar data were further processed into tracks. This involved converting the position data to a cartesian coordinate system and ordering all the postition data so that the aircraft's path as it approached or departed SEA-TAC was described by a chronologically-ordered series of position data.

At the same time the aircraft's position was recorded by the radar system, the noise it was producing at the underlying noise monitor sites was measured and recorded by the Seattle Noise Monitoring System, which is owned and operated by the Port Authority of Seattle. The eight noise monitors are positioned in such a way that departing or arriving aircraft will pass over, at most, four of them. Hence, up to four noise measurements may be recorded for each departure or arrival, with each measurement made at a different point in the operation.

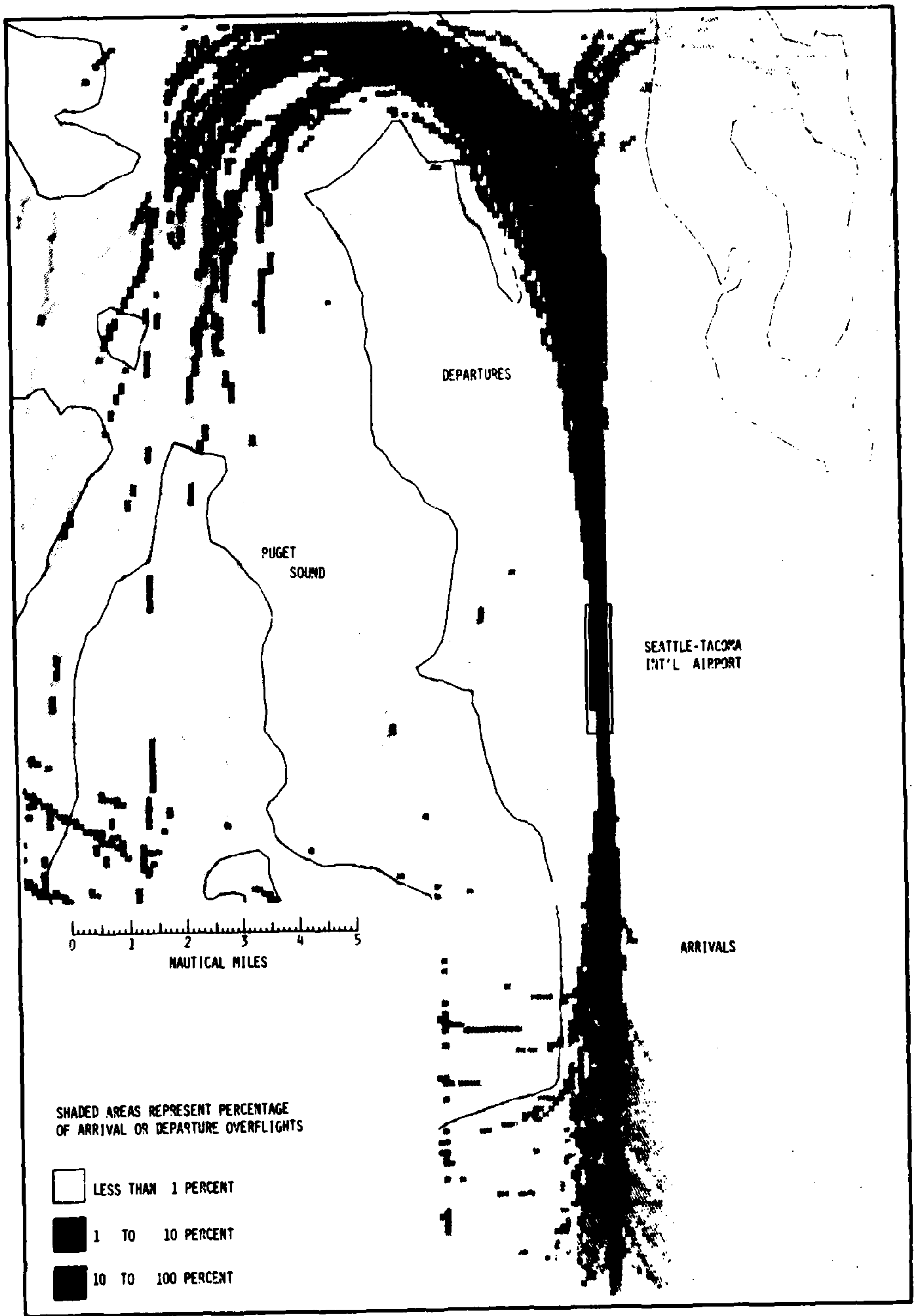


FIGURE 2-3
DISTRIBUTION OF GROUND TRACKS FOR TYPICAL DAY

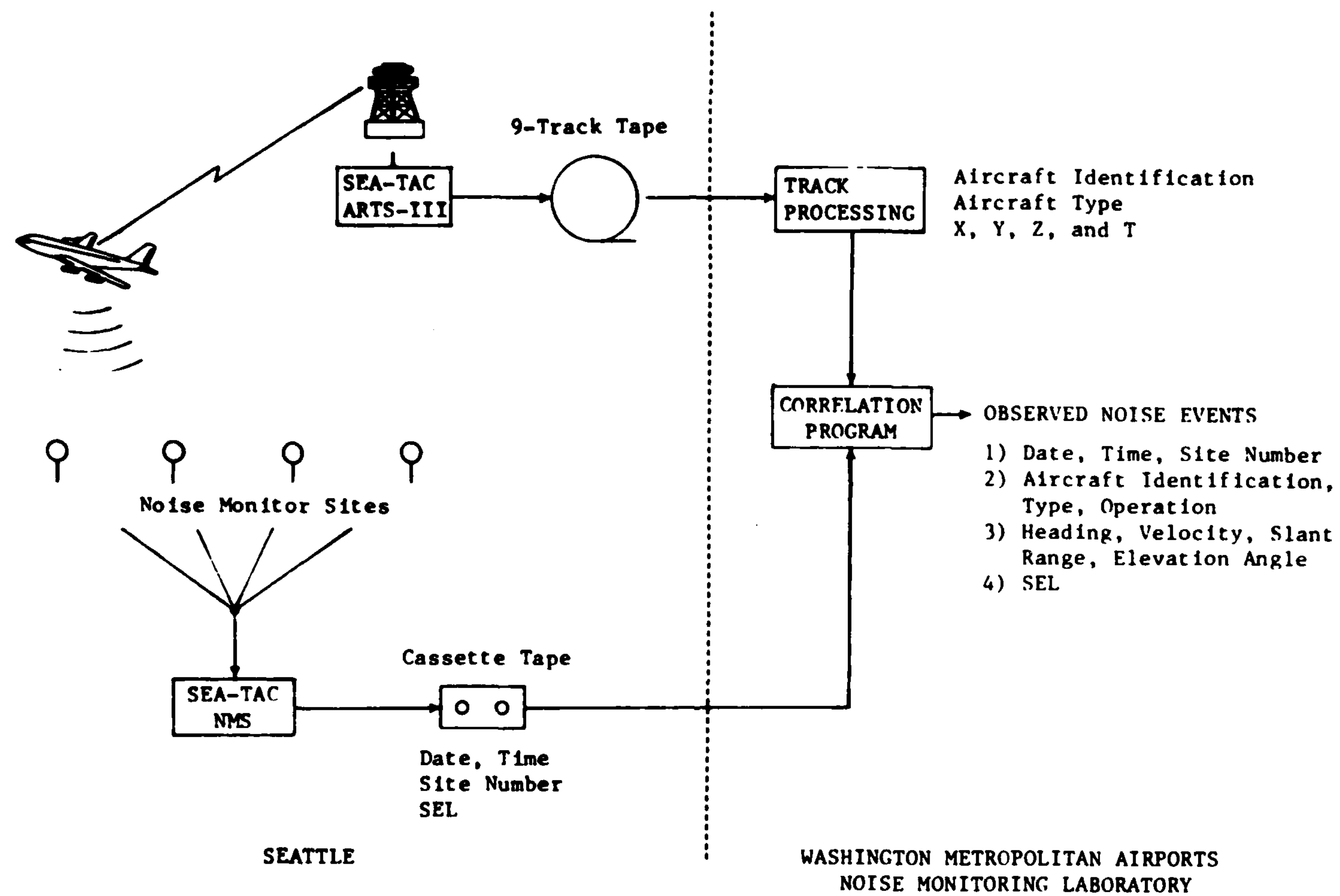


FIGURE 2-4
DATA COLLECTION AND REDUCTION FLOWCHART

In order to eliminate from consideration those noises not likely to have been caused by an aircraft flyover (such as a loud truck or street traffic), the Noise Monitor System screened observed noises on the basis of two characteristics. First, the noise level had to exceed 70 dB(A) for a prescribed minimum time which depended on the noise monitor site. Second, the sequence of times at which candidate noise events were measured at monitor sites on an arrival or departure path had to follow the pattern of times one would expect for a normal arriving or departing aircraft, travelling at an average speed, to fly over those sites. If a measured noise met these two requirements, it was qualified as a noise event attributable to an aircraft flyover.

Data for all qualified noise events were recorded on a magnetic cassette tape which was also shipped to the Noise Monitoring System Laboratory at Dulles Airport. The information recorded on the tape for each noise event include the sound exposure level, the maximum A-weighted sound pressure level (max dB(A)), the duration of time for which the sound pressure level was above 70 dB(A) (TA70), and supporting data such as the time and site number.

In the final data processing step, aircraft tracks derived from the radar system and noise data recorded by the noise monitoring system were correlated on the basis of time. The point at which the track came closest to each noise monitor site (also called the closest point of approach, or CPA) was determined, and at those points aircraft velocity, slant range, and other parameters were calculated. A complete list of all the data recorded and calculated for each observed noise event is given in Table 2-2.

2.1.3 Summary of Collected Data

Observed noise data was collected at SEA-TAC over the period from April to October of 1981. Within this period data were collected on 82 days for an average duration of 12 hours per day. The noise events recorded during the entire collection effort numbered over 58,000. This is many times larger than any observed noise data base collected in earlier aircraft noise studies. The weather conditions prevailing at the time data was being collected ranged from low ceilings and visibility to clear weather, and winds were generally less than 10 knots.

At two times during the data collection effort at SEA-TAC, checks were performed to ascertain that the observed noise data were reasonable and free from biases. The checks were performed

TABLE 2-2
DATA ITEMS FOR EACH OBSERVED NOISE EVENT

ITEM	UNITS (if applicable)	REMARKS
Noise Monitor Site Number		
Date	(year/month/day)	
Time	(hours/minutes/seconds)	
Aircraft Identification		As it appeared on ARTS-III flight plan
Aircraft Type		As it appeared on ARTS-III flight plan
Operation		Arrival or Departure
Elevation Angle	degrees from Horizon	From Noise Site to Aircraft at CPA
Slant Range	0.01 nautical miles	From Noise Site to Aircraft at CPA
Azimuth Angle	degrees from True Noth	From Noise Site to Aircraft at CPA
Aircraft Heading	degrees from True North	at CPA
Aircraft Velocity	knots	at CPA
Vertical Velocity	feet/minute	at CPA
Max dB(A)	decibels	at CPA
TA70	seconds	at CPA
SEL	decibels	at CPA

NOTE: CPA = the Closest Point of Approach of aircraft to noise monitor site.

on samples of data collected at the beginning and end of the collection period. The statistical properties of the noise levels in these samples were compared with the properties of similar samples collected at Dulles Airport. The checks indicated that the Seattle and Dulles data were consistent, and there were no discernible, systematic changes with Seattle data collected at the beginning and end of the data collection period. The conclusions of the reasonbleness checks, then, were that the Seattle Noise Monitoring System and the data reduction techniques used yielded reliable and consistent noise data.

Before calculating an INM noise level for each observed noise event, the observed noise data were filtered for two reasons: 1) to reduce variation in observed noise levels introduced by "site-specific" local phenomena such as reflection by the ground or buildings, or absorption by vegetation and 2) to eliminate events where it is more difficult to estimate the thrust at which the aircraft is operating, such as level flight segments during arrivals or departures. The filtering conditions were:

1. The slant distance from the monitor site to the aircraft had to be at least 300 feet and not more than 10,000 feet.

2. The elevation angle of the aircraft relative to the monitor site had to be at least 30^{o} above the horizon.

3. The absolute value of the aircraft's vertical velocity had to be at least 200 feet per minute.

4. The length of time for which the sound pressure level exceeded 70 dB(A) had to be at least 15 seconds.

After the observed noise data base was filtered according to these criteria, seven transport-category aircraft types had sample sizes adequate for statistical treatment. The aircraft types, and the number of observed noise events for each after filtering, are given in Table 2-3. Because the noise levels associated with arrival operations are generally much lower than for departures, on several instances aircraft passed over noise monitors on arrival without being measured as a noise event. For this reason, the number of departure events in Table 2-3 always exceeds the number of arrival events.

2.2 Calculation of INM Sound Exposure Levels

For each observed overflight of the seven transport-category aircraft types in Table 2-3, an INM SEL estimate was calculated. A computer program was written to mimic INM

TABLE 2-3
SEVEN TRANSPORT-CATEGORY AIRCRAFT AND SAMPLE SIZES

AIRCRAFT TYPE	# NOISE EVENTS FOR DEPARTURES	# NOISE EVENTS FOR ARRIVALS	TOTAL # NOISE EVENTS
Wide-Body Aircraft:			
A300	221	104	325
B747	709	392	1,101
DC10	2,544	1,565	4,109
L1011	803	398	1,201
Narrow-Body Aircraft:			
B727	12,021	6,173	18,194
B737	2,240	918	3,158
DC9	2,769	1,326	4,095

calculations for single event SELs. Before the calculation was made, however, special procedures were employed to insure that the values of variables involved in INM SEL calculations most closely matched the conditions surrounding the real noise event. This was performed for each INM noise calculation in the selection of a set of INM thrust-distance-noise curves (also referred to as SEL curves), in the selection of an INM flight profile, and in the selection of an INM thrust level. (Normally these items are chosen by the INM user in an airport case study). When these three input variables were determined, an INM SEL calculation was performed. The entire INM SEL calculation process is outlined in Figure 2-5 and described in detail below.

2.2.1 INM SEL Curve Selection

The INM has 38 sets of SEL curves in the Number 8 data base which describe the thrust-distance-noise relationships of common commercial, military and general aviation aircraft. Each popular transport-category aircraft is assigned at least one set of SEL curves to describe its noise characteristics, and, in some cases, two or three sets are assigned to describe different noise properties. For instance, two sets of curves are specified for the B727: one for B727s with untreated, hardwall engine nacelles, and one for B727s with acoustically-treated quiet nacelles. As another example, three sets are specified for the DC8: one for DC8s with untreated Pratt & Whitney JT3D type engines, one for DC8s with acoustically-treated JT3D engines, and one for DC8s with CFM-56 type engines. In these and other cases, variations in the noise properties of different engine configurations justified the development of a separate set of INM SEL curves. In some instances, two different types of aircraft share the same set of curves. For example, both the DC9 and the B737 use the same curves for either the dual JT8D engines with untreated nacelles or the dual JT8D engines with treated nacelles. It was necessary, then, to make certain the appropriate set of INM SEL curves was used for each INM noise level estimate.

At the time data were being collected, however, it was not possible to determine the engine configuration of each observed overflight. Therefore, an INM SEL curve set selection process was developed which used the FAA FAR 36 Compliance Data Base. This data base contains information from which the proportion of each airline's fleet powered by a given engine configuration can be determined. Therefore, for a given observed airline and aircraft type, the INM SEL curve set pertaining to the predominant engine configuration in the airline's fleet of the given aircraft type was used.

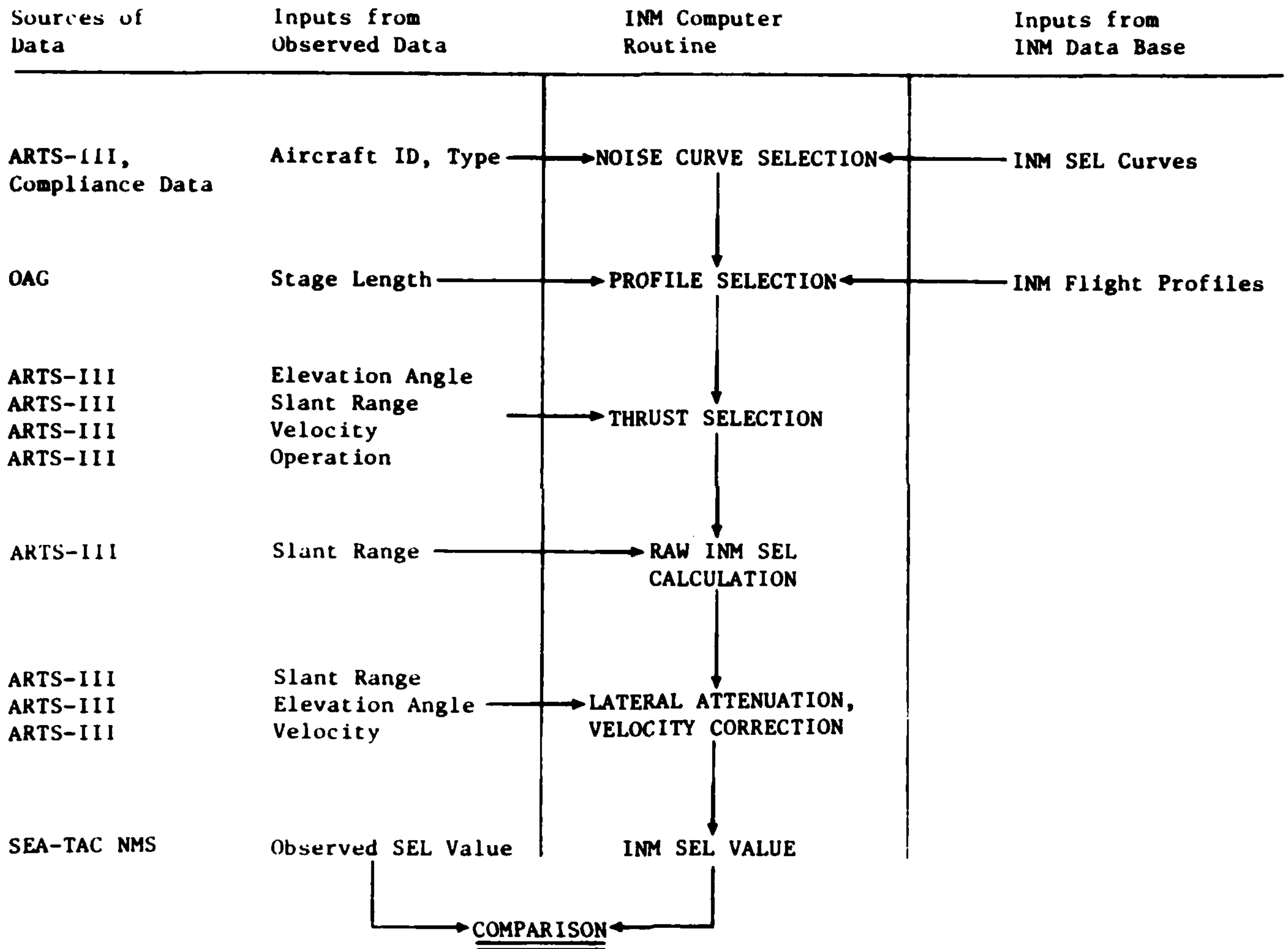


FIGURE 2-5
INM SEL CALCULATION FLOWCHART

2.2.2 INM Flight Profile Selection

The INM has 55 approach profiles and 198 takeoff profiles in the Number 8 data base. The profiles describe velocity, altitude, and thrust level of the aircraft as a function of horizontal distance from a point on the runway. The altitude and velocity sections of the profiles were checked in the profile validation study (Reference 4) and were found to be reasonably accurate. However, the thrust portions of the profiles had not yet been examined and that remained an objective of the study described in this document. Therefore, there was still a need to determine the appropriate departure or arrival profile (in order to obtain the thrust profile) before an INM SEL calculation could be made.

Each aircraft type is assigned one approach profile but, due to the effects of weight on departure performance, each aircraft type can have up to seven takeoff profiles. An INM user specifies the weight of each departing aircraft indirectly by stating the stage-length (the non-stop distance) of the flight. Hence, the INM uses stage-length as an index to weight under the assumption that weight and stage-length are proportional. Profiles for different stage-length categories for a given aircraft type will portray different climb performance and require different thrust levels.

To assure thrust levels from the appropriate takeoff profile were used in INM SEL calculations, the itineraries of airline flights departing SEA-TAC, as contained in the Official Airline Guide (OAG), were examined. The first point of intended landing was determined and the non-stop flying distance was measured. This distance was used to assign the departure to a stage-length category, and the thrust profiles from the appropriate profile were used. Over 80% of the departures in the observed noise data base were assigned a takeoff profile in this manner. In some instances, however, the first point of intended landing, and hence the stage-length, could not be determined for a departure. In this case, the stage-length which was most common for the other departures for a given aircraft type was assigned.

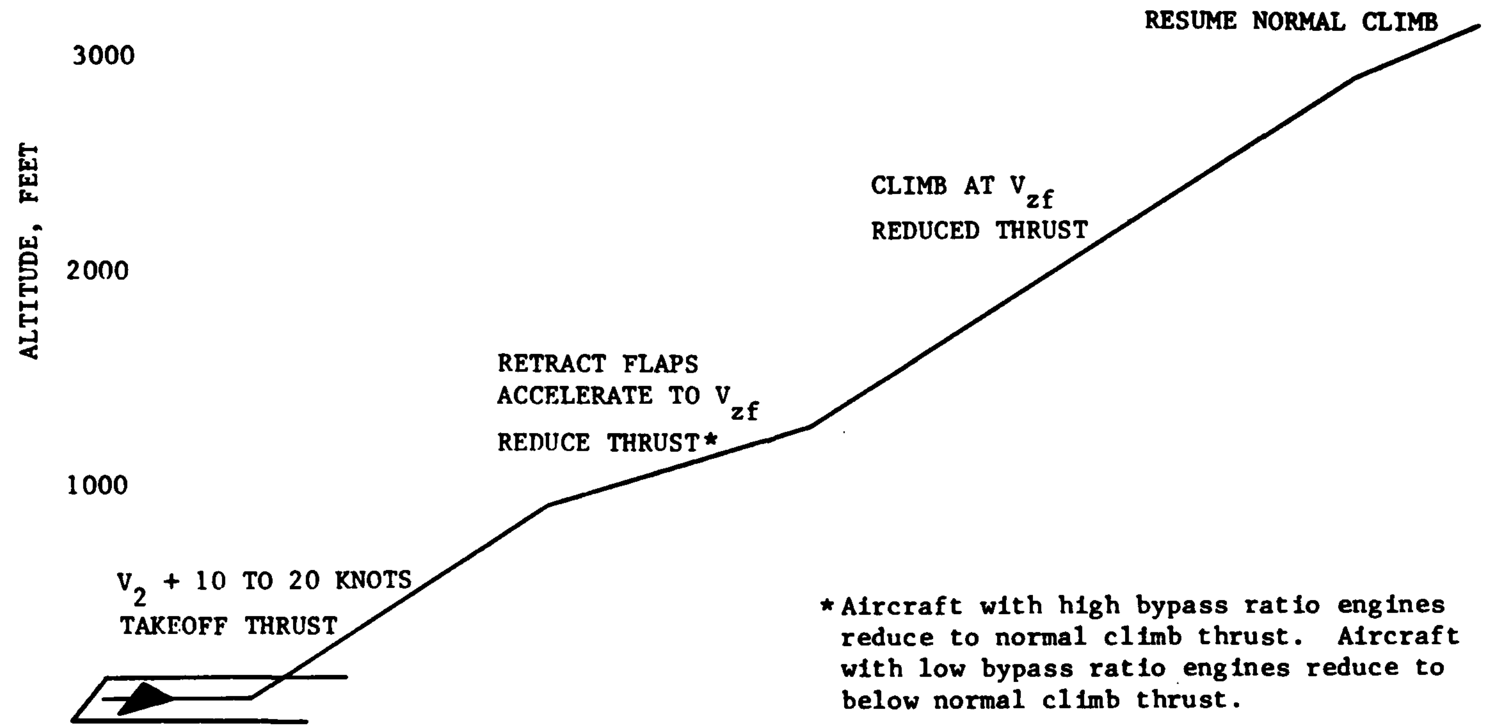
2.2.3 INM Thrust Level Selection

Once the appropriate profile was selected for each observed noise event, a thrust level from that profile had to be chosen. For the case of arrivals, this was a fairly straightforward task. Because all of the noise monitor sites at SEA-TAC are located within 3.5 nautical miles of the runway thresholds, they all underlie that portion of the landing approach where most aircraft are stabilized on a 3^{o} glide slope in the landing configuration. The thrust level in the INM approach profiles pertaining to this landing configuration was used in the calculation of an INM SEL.

Thrust level selection for departures was not such a simple matter. According to standard procedures, one can expect several changes in thrust level during a normal departure. In addition, air carrier pilots can exercise much more latitude in performing departures and can make tradeoffs between altitude, velocity, and thrust. At a given thrust setting, for example, a pilot could elect to climb at a faster airspeed and sacrifice his rate of climb, or vice versa. In an attempt to standardize departure performance and enhance the safety and noise compatability of such operations, airline flight operations manuals specify well-defined departure procedures. However, pilot-to-pilot variability and the presence of extenuating circumstances, such as turbulence or mountainous terrain near an airport, result in less than strict adherence to procedures.

For the purpose of making at least an initial INM SEL calculation, it was assumed that all departing aircraft were flown according to FAA Advisory Circular AC91-53 (Reference 5), which outlines recommended noise abatement departure procedures. This is also the procedure on which the departure profiles in the INM data base are fashioned. A diagram of the FAA departure is given in Figure 2-6.

Speed, thrust, and flap changes are scheduled according to gains in altitude. After lift-off all aircraft climb at a speed of V_2 plus 10 to 20 knots at takeoff thrust. The symbol V_2 is defined as the takeoff safety speed which varies with aircraft weight and flap setting for each aircraft type. When the airplane reaches 1000 feet above the airport, flaps are retracted and an acceleration is made to V_{zf}, the minimum zero-flap maneuvering speed. At this point in the departure, the FAA procedure specifies a thrust "cutback" which is based on the type of engine involved. Airplanes with high bypass ratio engines reduce power to normal climb thrust while those with low bypass ratio engines reduce to a thrust level which is somewhat lower than normal climb thrust. Aircraft with the quieter high bypass ratio engines are predominantly two, three, and four engine wide-bodied aircraft while most of the narrow-bodied fleet are powered by low bypass ratio engines. Regardless of which power setting is used, the FAA procedure calls for continued climb to 3000 feet at or near V_{zf}. At that altitude all aircraft accelerate to 250 knots and resume a normal en route climb configuration.



*Aircraft with high bypass ratio engines reduce to normal climb thrust. Aircraft with low bypass ratio engines reduce to below normal climb thrust.

FIGURE 2-6
FAA NOISE ABATEMENT DEPARTURE PROFILE

To incorporate this departure procedure into the INM thrust level selection, an algorithm was employed which considered observed altitude and velocity of departing aircraft as follows:

1. All aircraft which were less than 1000 feet above the airport or whose speed was less than the INM-specified V_{zf} were assumed to be at the INM takeoff thrust level for the purposes of making an INM SEL calculation.

2. All aircraft which were between 1000 feet and 3000 feet above the airport and at a velocity of greater than V_{zf} were assumed to be at the appropriate "cutback" thrust level: For high bypass engines, this was the INM-specified normal climb power, and, for low bypass engines, this was the INM-specified reduced climb thrust (also called "deep cutback" thrust).

3. All aircraft higher than 3000 feet above the airport were assumed to be at the INM-specified normal climb power.

According to a review of the flight operations manuals of several airlines operating at SEA-TAC, one has adopted the FAA departure procedure to a great extent, while others follow the procedure to a much lesser extent. The point at which most airlines disagree with the FAA procedure is the thrust cutback at 1000 feet altitude for low bypass ratio engines. For these aircraft, most airlines specify a reduction to normal climb power, rather than a greater reduction to below-normal climb thrust. For high bypass ratio engines, however, most airlines agree with the FAA departure.

Given the descrepancies between the procedures used by most airlines and the FAA procedure which was considered in the INM SEL estimates, one could anticipate the differences between INM and observed noise levels if the thrust-distance-noise relationships of the INM were accurate. For high bypass engines, one would expect fairly good agreement between observed and INM-calculated noise levels for all departure observations. This would be due to the similarity in thrust management procedures assumed by the INM and used by the airlines. For low bypass ratio engines, one should note fairly good agreement for aircraft assumed to be at takeoff thrust or climb thrust. For aircraft assumed to be at the deep cutback thrust, however, one should expect the observed noise levels to be much higher than the INM-calculated noise levels. This would be attributed to the fact that observed aircraft were operating at a higher (and noisier) thrust level for this segment of the departure than assumed for the INM noise calculation.

The procedures for selecting a thrust level for an INM SEL calculation, as outined in this section, were used only to make an initial INM noise estimate and to validate the thrust schedules contained in the INM flight profiles. If evidence suggested, after comparing INM and observed noise levels, that the thrust levels assumed for INM SEL calculation were inappropriate, other thrust levels and thrust selection algorithms were tried. This approach enabled a meaningful analysis of the thrust profiles, as mentioned in the objectives, to take place at the same time the INM SEL curves were being examined.

2.2.4 INM SEL Calculation

The calculation of an INM SEL was based on observed data and on INM-supplied data as outlined in Figure 2-5. The major inputs to this process were the INM SEL curve set and thrust level, as determined above, and the observed slant range, elevation angle, and velocity. A computer program was written to calculate, using these inputs, an INM SEL value that could be directly compared to the observed SEL value. A raw INM noise level was calculated first by performing a log-linear interpolation on the INM SEL curve for the observed slant range and assumed thrust level. The raw noise level was then corrected for the effects of lateral attenuation and velocity according to the INM correction algorithms (as described in Appendix A). The end product of this computer routine was a single-event SEL calculated as it would have been by the INM, given the same input data as that surrounding the observed noise event. This calculated INM SEL was then compared to the observed SEL.

2.3 Statistical Comparisons of INM and Observed SELs

INM and observed SELs were compared graphically and statistically in a number of ways to determine the level of agreement. Figure 2-7, as an example, is a scatterplot of INM and observed SELs for A300 aircraft assumed to be at takeoff thrust on departure from SEA-TAC. Also plotted in Figure 2-7 is the INM noise-distance curve corresponding to A300 operations conducted at takeoff thrust. The raw INM SEL estimates, calculated as mentioned above, would all fall exactly on this line if no corrections were made for lateral attenuation and velocity. As illustrated in Figure 2-7, when these corrections were applied, final INM SEL estimates tended to be approximately 2 to 5 dB below the uncorrected noise-distance curve.

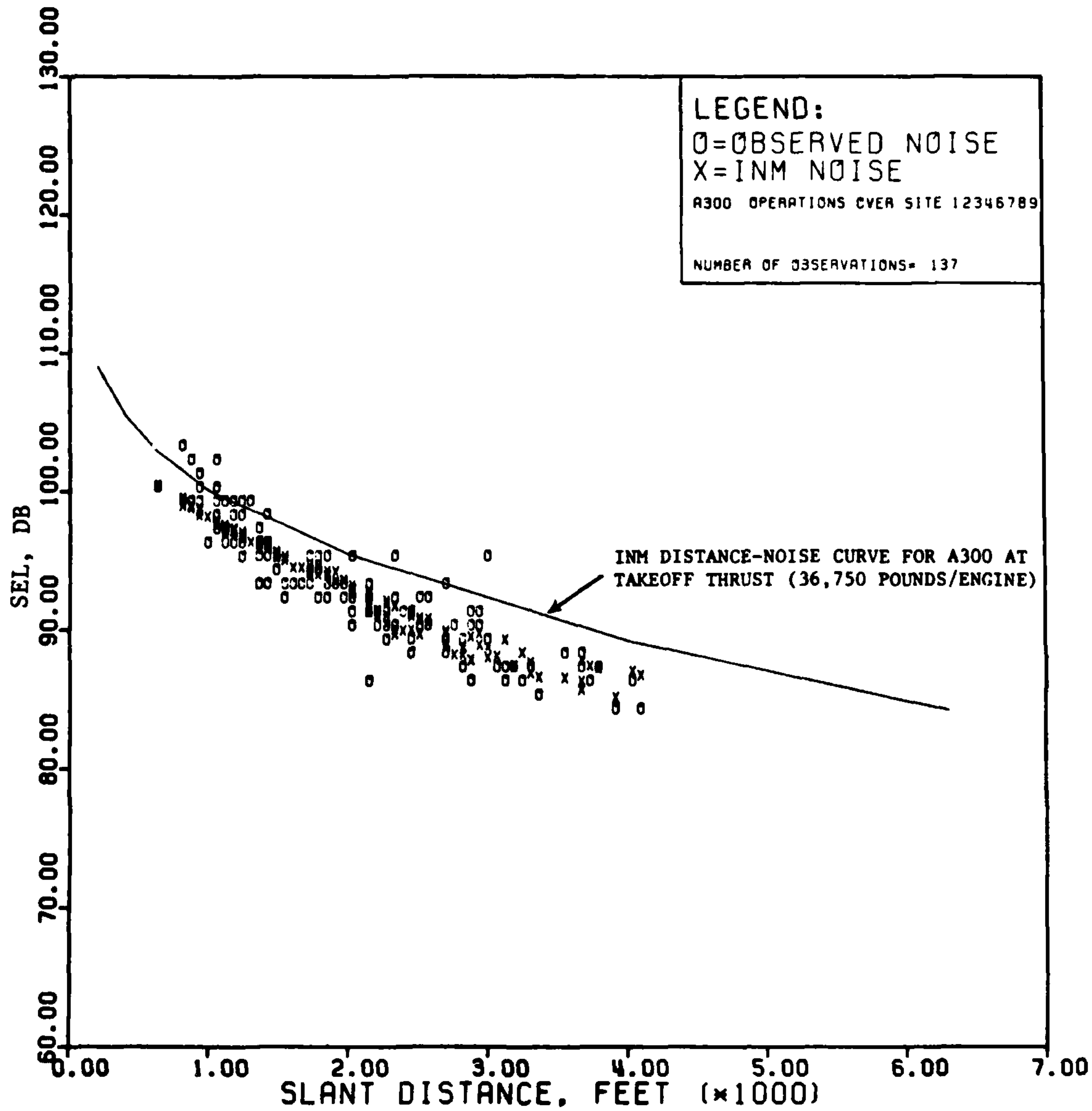


FIGURE 2-7
SAMPLE SCATTERPLOT OF INM AND OBSERVED SELS FOR A300 AT TAKEOFF THRUST

While the scatterplot of Figure 2-7 is useful in gaining a general notion of the level of agreement between INM and observed noise levels, it does not provide a quantifiable measure of agreement. To achieve this, the "paired comparison" technique was employed. Under this approach, the difference between the INM-calculated SEL and observed SEL was computed for each observed noise event. The "SEL difference", as it is commonly referred to, is equal to the INM-calculated SEL minus the observed SEL. Under the hypothesis that the INM perfectly predicts every single noise event, one would expect the SEL difference for each observed noise event to be zero.

However, no aircraft noise model can be expected to perfectly predict the noise level of every individual event. A valid model will, however, correctly predict the average noise level of a large number of flyovers. Therefore, to determine if the INM predicted noise events accurately on the average, the SEL differences were treated as values of an independent variable in a traditional experiment, and the mean, or arithmetic average, of the differences was computed for groups of similar noise events. A positive mean difference indicated the INM was, on the average, overestimating observed SELs, while a negative mean difference indicated it was underestimating observed SELs.

A plot of the relative frequencies of occurrence of SEL differences for the data presented in Figure 2-7 is given in Figure 2-8. It should be noted that this probability density function appears to be symmetrically distributed around the zero SEL difference. This is an indication that the INM-calculated SELs and observed SELs, on average, were very close to each other for the A300 aircraft assumed to be at takeoff thrust at SEA-TAC. The conclusion, then, would be that the INM accurately predicts noise levels for A300s at takeoff thrust.

As an aid to evaluating the relative magnitude of average SEL differences, a previous INM validation study (Reference 2) considered an average difference of three decibels (3 dB) or less as evidence of acceptable agreement between INM and observed SELs. This criterion for agreement was reached by trading off between establishing a narrow margin for close agreement and having a wide enough margin to account for variations associated with observed noise measurements taken in the field. Although there is no widely endorsed standard for agreement, the average difference of 3 dB may still be considered acceptable for the purposes of this study.

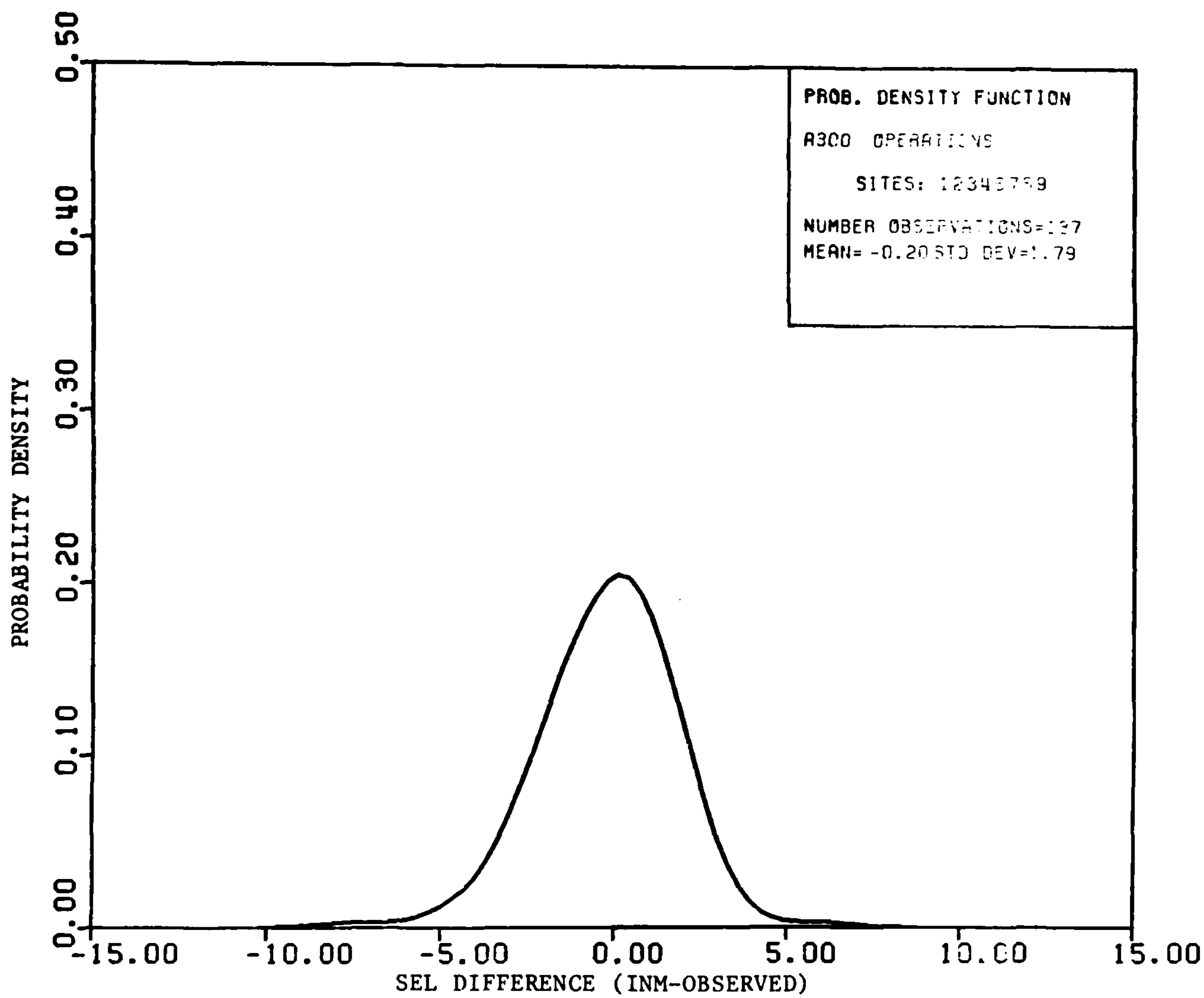


FIGURE 2-8
SAMPLE PROBABILITY DENSITY FUNCTION FOR A300 AT TAKEOFF THRUST

3. RESULTS

Discussion of the comparison of the INM and observed single noise events is facilitated by grouping the aircraft into general classes, namely, three engine narrow-body aircraft, two engine narrow-body aircraft, two and three engine wide-body aircraft, and four engine wide-body aircraft. Summaries of the results for each general class are given in the following tables. Included are the mean SEL differences for each aircraft type at the various INM thrust levels assumed for normal arrivals and departures.

3.1 Results for Three Engine Narrow-Body Aircraft (B727)

More than 18,000 noise events associated with B727 operations were observed at SEA-TAC. Approximately half of the observed B727 noise events were made by aircraft which were assumed to have engines with untreated, hardwall nacelles, as determined by the methods outlined in Section 2.2.1. The other half of the observed noise events were generated by B727 aircraft which were assumed to have engines with acoustically-treated nacelles (commonly called "treated nacelles").

The difference between the untreated and treated nacelle for engines on the B727 is the addition of a sound-absorbent wire mesh to the interior cowling and nacelle of treated engines. This insulation is somewhat effective in reducing the noise caused by engines operating at a reduced power setting, such as approach thrust. However, because exhaust turbulence noise is the predominant factor at high power settings, and because many engines are concurrently upgraded to operate at a higher thrust level when the sound-absorbent material is installed, the treated engine is sometimes louder than an untreated one at maximum takeoff thrust. To account for these differences, the INM has a set of SEL curves for each of the two B727 engine configurations. B727 results are presented in Table 3-1 and discussed separately below for observed noise events assumed to be caused by each configuration.

3.1.1 Results for B727 with Untreated Nacelles

The mean SEL differences for the B727 with untreated nacelles are given on the first line of Table 3-1 for observed B727s assumed to be operating at either takeoff, cutback, climb, or approach thrust. The mean SEL difference is 2.13 dB for operations for which the INM takeoff thrust level was assumed. According to the thrust level assignment algorithm of Section 2.2.3, all of

TABLE 3-1
RESULTS FOR THREE ENGINE NARROW-BODY AIRCRAFT (B727)

AIRCRAFT/ENGINE		THRUST ASSUMED BY INM			
		TAKEOFF	CUTBACK	CLIMB	APPROACH
B727/Untreated	Mean SEL Difference, dB	2.13	-5.30	-1.07	1.62
	Standard Deviation, dB	3.33	3.94	2.30	3.56
	Number of Observations	5103	1138	114	3261
B727/Treated	Mean SEL Difference, dB	4.46	-6.07	-1.37	-0.94
	Standard Deviation, dB	3.30	3.24	2.15	3.59
	Number of Observations	4876	724	65	2912

the 5,103 observed departure noise events in this group of data were generated by aircraft which were below 1000 feet altitude or moving at a velocity of less than the INM-specified V_{zf} (210 knots for the B727). This mean SEL difference indicates that the INM overestimated observed noise levels by 2.13 dB, but it is considered acceptable by the standards used in earlier INM validation studies.

This relatively small mean SEL difference also offers evidence that the INM SEL curves used to compute the INM SELs are reasonably accurate at least in the takeoff thrust ranges. Because each INM SEL calculation was made for conditions which matched the observed noise event to the greatest extent possible, any resulting difference between the observed and INM-calculated noise levels must be attributed to deficiencies in either the assumed thrust level or the INM SEL curves themselves. However, the INM-specified thrust level for takeoff is likely to be very accurate because it is so near a known and fixed reference, the maximum thrust limit for any given engine. Therefore, it logically follows that, because the INM takeoff thrust level is fairly accurate, the INM SEL curves must also be accurate to produce the observed small mean SEL difference.

Before addressing the mean SEL difference for the cutback thrust case, it is useful to point out that small mean SEL differences were also obtained for aircraft assumed to be operating at both the climb thrust and approach thrust levels. For aircraft assumed to be operating at climb thrust, the mean difference is -1.07 dB, indicating that the INM-calculated SELs slightly underestimated observed noise levels. This indicates exceptionally good agreement and offers more evidence that the INM SEL curves for the untreated B727 are accurate. The 1.62 dB mean SEL difference for events conducted at the approach thrust level indicates a slight overestimation, on average, by the INM-calculated SEL. This is also an exceptionally good level of agreement and supports the previous contention that the INM SEL curves for this aircraft are accurate.

It is easier now to explain the relatively large mean SEL difference of -5.30 dB for observed overflights assumed to be at the cutback thrust level. This large negative mean difference indicates that the INM was, on the average, underestimating observed noise levels by a wide margin. Because there is considerable evidence that the SEL curves are accurate (from the takeoff, climb, and approach cases), the only remaining explanation of this difference is that the thrust level assumed for the INM SEL calculation is wrong.

Assuming the thrust level was in error, the large negative mean SEL difference indicates that the observed aircraft were probably operating at a significantly higher thrust than that assumed for the INM SEL calculation. This is consistent with what can be determined from the flight operations manuals of several airlines. Most airlines do not employ the deep thrust cutback assumed by the INM, but simply reduce thrust to normal climb power for all aircraft, regardless of engine type. Normal climb thrust is somewhat higher than the INM deep cutback thrust and would produce the large mean SEL difference noted.

To offer even more support to this notion that the deep cutback thrust level was not employed by observed departures, INM SELs were recalculated using new thrust assumptions. Under the new assumptions, all aircraft maintained takeoff thrust until reaching 1000 feet and a speed of V_{zf}, at which point thrust was reduced to normal climb power for the rest of the departure. The only difference between this revised assumption and the original one is that, as evident in many flight operations manuals, aircraft simply reduce to normal climb power rather than the deep cutback thrust.

After calculating new INM SELs with the revised thrust assumptions and recomputing the SEL differences for each observed event, the resulting mean SEL differences were as presented in Table 3-2. Of course, there is no change in the mean SEL differences for the takeoff or approach thrust cases because the revised thrust assumptions did not affect these cases. However, the assumption that the first power reduction is made simply to normal climb thrust yields a mean SEL difference of 2.00 dB, which is considerably better than under the original thrust assumptions. Thus, from all available evidence, it appears that the deep cutback suggested in Advisory Circular AC91-53, and assumed by the INM thrust schedules, is rarely used in actual operations. Most operators simply reduce thrust to normal climb power and continue the departure at that thrust setting.

With the exception of the deep cutback thrust assumption, the INM thrust schedules and SEL curves for the B727 with untreated nacelles are very accurate and yield results which agree very well with observed data. This is a significant improvement over earlier versions of the INM for this aircraft type and engine configuration.

TABLE 3-2
RESULTS FOR B727 (UNTREATED NACELLES) WITH REVISED THRUST ASSUMPTIONS

AIRCRAFT/ENGINE		THRUST ASSUMED BY INM			
		TAKEOFF	CUTBACK	CLIMB	APPROACH
B727/Untreated	Mean SEL Difference, dB	2.13	Not	2.00	1.62
	Standard Deviation, dB	3.33	Used	3.97	3.56
	Number of Observations	5103		1252	3261

3.1.2 Results for B727 with Treated Nacelles

The results for B727 aircraft with treated nacelles are also presented in Table 3-1. Unlike the case for B727s with untreated nacelles, the mean SEL difference for operations by aircraft considered to be at the takeoff thrust appears unacceptably high. The 4.46 dB mean SEL difference in this instance indicates the INM is overestimating observed noise levels by a considerable amount. However, the mean SEL differences for the cutback, climb, and approach thrust levels followed the same trends observed for the B727 with untreated engines: the INM, on average, underestimated noise levels for the cutback thrust case (by 6.07 dB) but came fairly close to observed noise levels for the climb and approach thrust cases. It would appear, then, that based on the results for these latter three thrust levels and the trends noted for the untreated B727s, that the INM SEL curves for the B727 with treated nacelles are accurate. This does not explain the large mean SEL difference for the takeoff thrust condition but two possibilities exist.

One possible explanation is that the thrust level specified by the INM for takeoffs is simply too high, or for some other reason it does not match the thrust levels used in the actual takeoffs. One source of the differences between INM-specified and actual thrust levels for takeoff could be due to the "reduced-thrust" takeoff procedure. This is a takeoff technique advocated in some form by many airlines for the purpose of reducing engine wear and increasing engine life. It involves the performance of a takeoff using less than the maximum allowed takeoff thrust. Its use is limited to situations where the runway and departure path are adequate, due to the longer takeoff roll, and where wind and atmospheric conditions are favorable. It is not known how many, if any, of the observed departures were performed with reduced thrust on takeoff. However, this remains a potential explanation.

Another possible explanation of the high SEL difference for the takeoff case concerns the criterion used to determine the point at which the first thrust reduction takes place. All the thrust selection algorithms used so far have scheduled thrust adjustments according to gains in altitude and speed, in accordance with customary procedures of the FAA or the airlines. However, many factors, such as workload, aircraft performance limitations, and pilot technique, may prevent the pilot from making the required thrust adjustments at exactly the time they are called for in the procedure. As a result of this variability, there is a "transition" area on the departure route at which some aircraft have completed their first power reduction, some are in the process of reducing power, and some are still at takeoff thrust. Without putting an observer in the cockpit, it is impossible to know exactly where the first power reduction is made on any one departure. The contention of this explanation, then, is that the large positive mean SEL difference of 4.46 dB observed for B727s at takeoff thrust is due to the likelihood that some of the aircraft in this group may have already initiated or completed the first power reduction.

To investigate this possibility more completely, another thrust selection algorithm was devised which considered only the distance the aircraft had travelled from the Brake Release Point (BRP). This term refers to the point at the beginning of the runway where the pilot first releases the wheel brakes and commences the takeoff roll. The revised algorithm was based on the assumption that as aircraft travelled further away from the BRP, they were more likely to be at climb power. In other words, aircraft which had travelled only a short distance from BRP on departure were likely to be at takeoff thrust. At some further distance from BRP, there was a transition area where some aircraft had reduced thrust while others had not. At an even further distance from BRP, however, most all aircraft had reduced to climb thrust.

It is important to note that this revised thrust assignment algorithm based on distance from BRP was used only to permit more confidence to be placed in the thrust values assumed for various stages of the departure. In the revised thrust algorithm used earlier for the B727 with untreated engines, the objective was to prove that procedural differences were the cause of the observed mean SEL differences for cutback thrust. In the current case, however, it is already certain that the deep cutback is not used, and there must be some explanation for the observed 4.46 dB mean SEL difference for the takeoff case for the B727 with treated engines. Therefore, to group the observed data in a way in which more certainty could be placed on the thrust level at which each departure event was assumed to be operating, the distance from BRP was incorporated into the thrust assignment algorithm. This permitted a segregation of data through which noise events in the transition area were isolated from those which, with high certainty, were at either takeoff thrust or climb thrust. This approach enabled an assessment of the INM thrust values to proceed.

Fortunately, the locations of the eight noise monitor sites at SEA-TAC, as illustrated in Figure 2-3, are such that some of them are near the BRP where aircraft are likely to be at takeoff thrust, some are in the transition range, and some are far enough from BRP that most overflights have had a chance to reduce thrust. Therefore, the revised thrust assignment algorithm assumed that all aircraft over sites 4 and 6, the sites closest to the BRP, were at takeoff thrust, and all aircraft over all other sites were at normal climb power. Using these assumptions, INM SEL values were recalculated for each departure noise event caused by a B727 with treated nacelles, and the SEL differences were recomputed. To isolate transition area effects, overflights assumed to be operating at climb thrust were statistically analyzed in two separate groups. Noise events generated over sites 2, 3, 7, and 9 made up one group and events generated over sites 1 and 8 made up the other group. The former group includes events occurring in the transition area where some aircraft have reduced power while others have not. However, noise events in the latter group are most likely to have been caused by aircraft which have already reduced power to climb thrust. The results of this analysis are shown in Figure 3-1.

As evident in Figure 3-1, the mean SEL differences for both the takeoff and normal climb power cases are considerably improved over results obtained with the original thrust assumptions. For operations over sites 6 and 4, where takeoff thrust was assumed, the mean SEL difference has dropped to 2.00 dB. Over the transition area where climb thrust had been assumed (sites 2, 3, 7, and 9), the mean SEL difference is -0.17 dB, indicating a slight underestimation of observed noise levels by the INM. It is likely that some of the overflights in this group were actually at takeoff thrust though climb thrust was assumed, which would result in INM underestimation. The mean SEL difference for overflights of sites 1 and 8, for which climb power was also assumed, is 0.38 dB. This is, again, exceptional level of agreement between INM and observed SELs.

The results of these analyses for the B727 with treated nacelles are, in general, quite favorable. It appears that the deep thrust cutback is not used, as was earlier determined for the B727 with untreated engines.

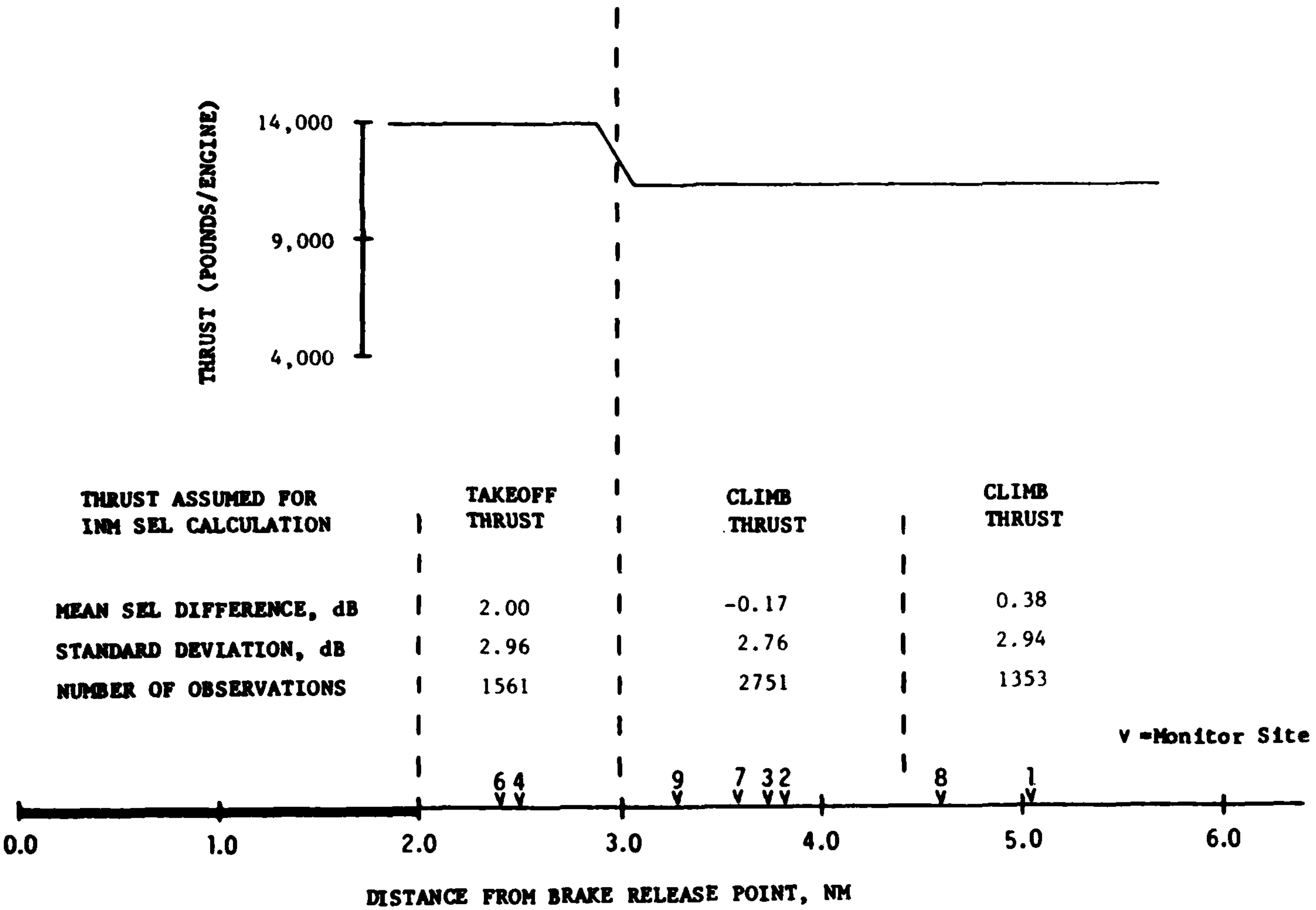


FIGURE 3-1
RESULTS FOR B727 (TREATED NACELLE) WITH REVISED THRUST ASSUMPTIONS

3.2 Results for Two Engine Narrow-Body Aircraft

The B737 and DC9 were observed in sufficient numbers at Seattle to permit meaningful statistical analyses. They are both powered by two Pratt & Whitney JT8D engines for which add-on quiet nacelle treatment is available (the treatment is identical to that used on the B727). Separate sets of curves are used for the DC9 and B737 with treated nacelles. The DC9 and B737 share the same sets of curves on the assumption that, because they have the same engines, they should have the same noise characteristics. There are engine installation differences, such as the location of the engines (on the wing vs. on the tail) which could have an appreciable effect on noise properties. Nonetheless, it may still be possible to effectively use the one set of SEL curves for both aircraft by adjusting INM-specified thrust levels to account for any noise differences. This would be equivalent to calibrating the noise level with thrust as the adjustment variable.

Of the 3,158 noise events generated by B737 aircraft, 1,969 events were caused by B737s with treated nacelles and 254 were caused by B737s with untreated nacelles. The remaining 935 B737 noise events were caused by aircraft for which the engine configuration and status could not be determined because they were not flown by a scheduled air carrier, and the FAR 36 Compliance Data Base did not contain information on them. For the DC9, 4,095 noise events were recorded and all were attributed to aircraft with untreated nacelles.

3.2.1 Results for B737 with Untreated Nacelles

The mean SEL differences are given in Table 3-3 for B737 aircraft with untreated engines for the takeoff, cutback, and approach thrust conditions. The mean SEL difference of 6.65 dB for those operations assumed to be at takeoff thrust indicates the INM is overestimating those observed noise events by a wide margin. For those operations assumed to be operating at the FAA deep cutback thrust level, the mean SEL difference is only -1.54 dB, indicating a slight underestimation. However, a review of airline flight operations manuals again reveals that, for the B737, the FAA deep cutback is not used and most airlines simply reduce to normal climb power. With this in mind, the resulting mean SEL difference for the cutback thrust case should be approximately -5 to -6 dB if the SEL curves were correct and the thrust assumption was wrong. This would parallel the results

TABLE 3-3
RESULTS FOR TWO ENGINE NARROW-BODY AIRCRAFT

AIRCRAFT/ENGINE		THRUST ASSUMED BY INM			
		TAKEOFF	CUTBACK	CLIMB	APPROACH
B737/Untreated	Mean SEL Difference, dB	6.65	-1.54		-3.40
	Standard Deviation, dB	2.93	2.10	No Data	3.51
	Number of Observations	159	44		47
B737/Treated	Mean SEL Difference, dB	7.01	-6.28	0.06	-4.08
	Standard Deviation, dB	3.05	3.20	2.71	3.73
	Number Of Observations	1118	252	25	573
DC9/Untreated	Mean SEL Difference, dB	6.83	-0.54	0.23	0.34
	Standard Deviation, dB	3.42	3.63	2.08	3.81
	Number of Observations	2477	230	62	1326

found for the B727. The observed mean SEL difference of -1.54 dB, then, must be interpreted as a consistent 4 to 5 dB overestimate by the INM SEL values. Coupled with the 6.65 dB average overestimate of observed noise levels at takeoff thrust, it appears that either the INM SEL curves for the aircraft are 4 to 5 dB too high, or that both takeoff and cutback thrust levels in the INM data base are high by equivalent amounts.

When thrust assumptions on departure are revised to consider only the distance from brake release point, as done for the B727 with treated nacelles, the trend becomes more apparent. As shown in Figure 3-2, all operations over the near two sites are, again, considered to be operating at takeoff thrust and over all other sites at climb thrust. Whereas this revised assumption significantly improved the agreement for the B727, Figure 3-2 shows the INM consistently overestimating observed noise by approximately 4 dB at both takeoff and climb thrust. Therefore, one must conclude that the INM consistently overestimates observed noise because either the INM SEL curves are too high or because the INM thrust levels are uniformly too high. It cannot be determined with this data which of the two explanations is more likely.

Referring again to Table 3-3, the mean SEL difference for untreated B737s on approach is -3.40 dB, which indicates the INM is underestimating observed noise levels. In light of the results for takeoff and climb thrust, this is incongruous as one would expect the INM to overestimate observed noise levels for approach by about 4 to 5 dB. However, a review of actual airline operating practices reveals that the thrust assumed by the INM for approach may be too low. This would account for some of the observed underestimation by the INM, but it would not account for the entire difference between the resulting mean SEL difference and expected SEL difference.

In summary, for the B737 with untreated engines it appears the INM consistently overestimated observed noise levels by about 4 to 5 dB for operations assumed to be at takeoff or climb thrust. In addition, all evidence suggests that the FAA deep cutback thrust is not used. For approaches, however, the INM SELs tended to be lower than observed SELs by an average of 3.04 dB. These differences are not considered within acceptable ranges and suggest a review of the INM SEL curves and thrust profiles for this aircraft is in order.

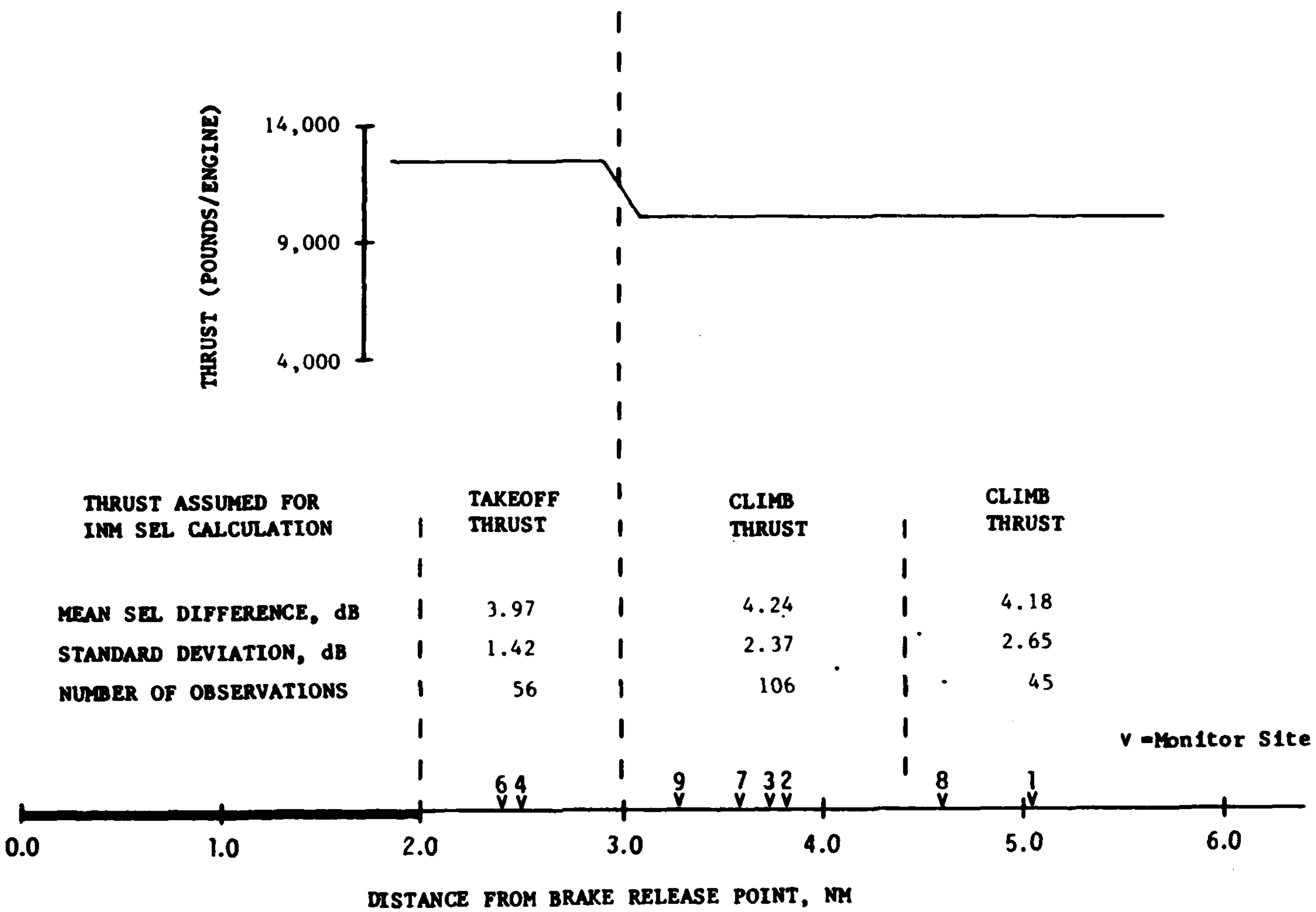


FIGURE 3-2
RESULTS FOR B737 (UNTREATED NACELLE) WITH REVISED THRUST ASSUMPTIONS

3.2.2 Results for B737 with Treated Nacelles

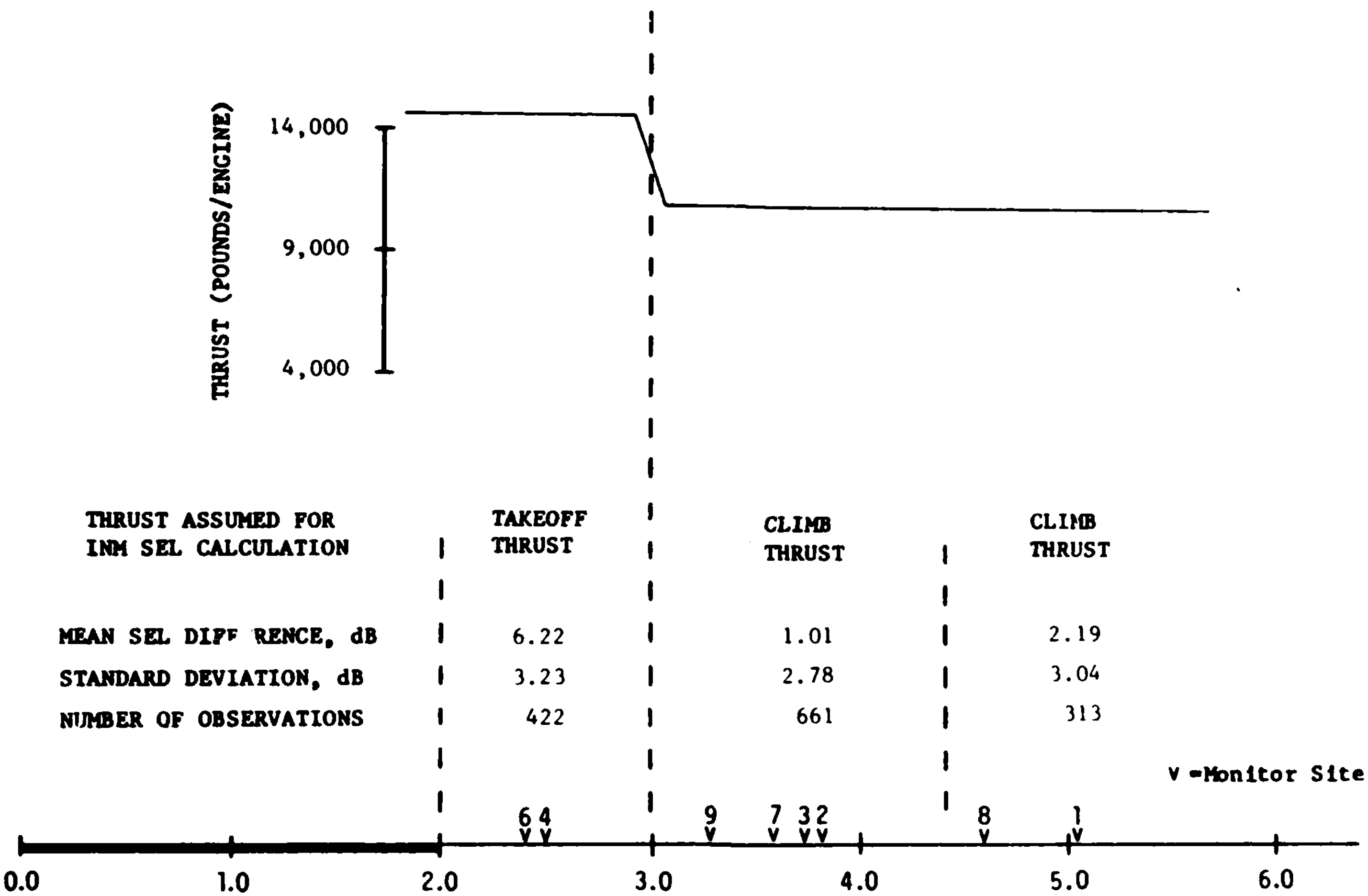
Table 3-3 summarizes the results obtained for the B737 with treated nacelles. For the takeoff, cutback, and climb thrust cases, the mean SEL differences are 7.01, -6.28, and 0.06 dB respectively. For those operations assumed to be at takeoff thrust, the INM overestimates noise levels by the widest margin observed for any aircraft in this study. For operations assumed to be at cutback and climb thrust, however, the mean SEL differences are quite similar to those obtained for the B727. This suggests that by revising the thrust assumptions to consider only the distance from brake release point, INM and observed noise levels would be more in agreement. When this was done, the mean SEL differences were reduced to 1.01 and 2.19 dB for operations at climb thrust as seen in Figure 3-3. However, even under the revised thrust assumption, the INM overestimates observed noise by an average of 6.22 dB for operations assumed to be at takeoff thrust. Because the INM SEL curves appear to be adequate for operations at climb thust, the resulting overshoot of INM noise estimates at takeoff thrust is probably due to either an inaccurate takeoff thrust value or the use of the reduced thrust takeoff procedure.

As for the B737 with untreated engines, on approaches the INM underestimated observed noise levels by an average of 4.08 dB. This difference is most likely due to the INM specification of a thrust value that is too low for the observed approaches. A review of the data from which thrust values were originally derived reveals that the approach thrust level selected from the INM pertains to landings performed with partially extended flaps. However, under most conditions air carrier landings are conducted with fully extended flaps which result in a greater amount of aerodynamic drag. To offset this drag, pilots must approach the runway with a greater amount of thrust.

To summarize results for the treated B737, it appears the INM SEL curves are reasonably accurate, but the thrust levels assumed for the takeoff and approach cases should be revised to produce acceptable agreement. Again, observed data and evidence from available flight operations manuals suggest that the FAA deep thrust cutback is not used.

3.2.3 Results for DC9 with Untreated Nacelles

The mean SEL differences for the DC9 for operations assumed to be at takeoff, cutback, and climb thrusts are 6.83 dB, -0.54 dB, and 0.23 dB respectively, as shown in Table 3-3. These results



THRUST ASSUMED FOR INM SEL CALCULATION	TAKEOFF THRUST	CLIMB THRUST	CLIMB THRUST
MEAN SEL DIFF RENCE, dB	6.22	1.01	2.19
STANDARD DEVIATION, dB	3.23	2.78	3.04
NUMBER OF OBSERVATIONS	422	661	313

FIGURE 3-3
RESULTS FOR B737 (TREATED NACELLE) WITH REVISED THRUST ASSUMPTIONS

are rather puzzling because they indicate the INM overestimates observed noise for operations at takeoff thrust, but accurately estimates observed noise for the deep cutback, climb, and approach thrust cases. As for all the other narrow-body jets examined here, the deep cutback is rarely used in the DC9 according to available flight operations manuals. It is unusual, then, to see such close agreement between INM and observed noise levels for both cutback thrust and climb thrust.

A review of the values specified by the INM reveals that climb thrust is 10,821 pounds per engine while cutback is approximately 9,200 pounds per engine (cutback thrust varies slightly with stage length). The difference between the two values is not particularly large, especially when compared to the cutback specified for other aircraft types. As a result, even if all observed departures were operating at climb thrust and INM SEL calculations had assumed the cutback thrust level, the resulting mean SEL difference would not be very great. It appears then, that the SEL curves are adequate for the DC9.

The overestimation of observed noise by the INM for DC9s assumed to be operating at takeoff thrust is most likely due to an inappropriate thrust assumption. Rather than being due to an erroneous INM-specified takeoff thrust value, however, the misassumption may be due to the use of the reduced-thrust takeoff procedure by aircraft observed at SEA-TAC. One airline accounted for over 95% of the DC9 noise events observed at SEA-TAC. It is known from other studies that this airline, like others, has a policy that reduced-thrust takeoffs be performed for every departure, except when, in the pilot's judgment, a full thrust takeoff is required for safety. It is not known how strictly this policy is followed, but the likelihood that some of the DC9 takeoffs may have been performed with reduced thrust remains a possible explanation of the observed mean SEL difference.

It appears, in general, that the INM SEL curves for the DC9 are fairly accurate. The INM-specified thrust level for takeoff may need to be modified to bring about more reasonable agreement.

3.3 Results for Two and Three Engine Wide-Body Aircraft

The A300, DC10, and L1011 were observed in sufficient numbers to permit meaningful statistical treatment, and the results for all three aircraft types are presented in Table 3-4. Unlike the case for the two and three engine narrow-body aircraft, the INM thrust schedules for departures for all wide body aircraft do not

TABLE 3-4

RESULTS FOR TWO AND THREE ENGINE WIDE-BODY AIRCRAFT

AIRCRAFT/ENGINE		THRUST ASSUMED BY INM		
		TAKEOFF	CLIMB	APPROACH
A300/CF6	Mean SEL Difference, dB	-0.20	-0.64	-2.20
	Standard Deviation, dB	1.79	2.62	2.35
	Number of Observations	137	84	104
DC10/CF6	Mean SEL Difference, dB	0.88	-0.38	-3.30
	Standard Deviation, dB	2.55	2.58	3.14
	Number of Observations	789	222	741
DC10/JT9D	Mean SEL Difference, dB	0.53	0.17	-3.06
	Standard Deviation, dB	3.20	2.91	2.43
	Number of Observations	701	820	815
L1011/RB211	Mean SEL Difference, dB	1.24	1.17	-1.93
	Standard Deviation, dB	1.61	2.51	2.22
	Number of Observations	640	163	398

specify a deep thrust cutback at 1000 feet. This is in accordance with the FAA recommended departure procedure which states that the first power reduction after takeoff should be to the normal climb thrust level for aircraft with high bypass ratio engines. Most all wide-body aircraft are equipped with high bypass engines. As a result, the thrust levels assumed for INM SEL computations are more likely to be accurate than was the case for the narrow-body aircraft where a deep cutback was suggested by the FAA procedure.

3.3.1 Results for A300

As evident in Table 3-4, the small mean SEL differences for the takeoff and climb thrust cases give evidence that the INM thrust levels and SEL curves for the A300 are exceptionally accurate. For approaches, the mean SEL difference is slightly greater and indicates that the INM is underestimating the noise levels of approaching aircraft by about 2.20 dB. Though this is well within acceptable limits, improved agreement can be achieved by slightly increasing the thrust level the INM uses for the approach case. This would have the effect of increasing the INM-calculated SELs to fall more in line with observed levels. Overall, however, the INM thrust levels and SEL curves for the A300 yield excellent results.

3.3.2 Results for DC10

Of the 4,109 observed noise events attributed to DC10 overflights, roughly half were generated by DC10s equipped with Pratt & Whitney JT9D-20 engines while the rest of the noise events were caused by DC10s equipped with General Electric CF6 engines. Because the noise characteristics of each type of engine are approximately the same, the INM data base contains one set of SEL curves to describe both. However, because there are tangible differences in the INM-specified thrust levels for the two engines, subsequent analyses were carried out for each engine type separately.

For DC10/CF6 aircraft, mean SEL differences are presented in Table 3-4. As for the A300, the small mean SEL differences of 0.88 dB and -0.38 dB for takeoff and climb thrust conditions provide evidence that both the INM thrust levels and SEL curves are exceptionally accurate for these thrust ranges. For approaches, however, the relatively high mean difference of -3.30 dB indicates the INM is underestimating observed noise levels. Because the SEL curves for the DC10/CF6 appear to be accurate for other thrust levels, however, the most likely cause for this discrepancy is an inordinately low value for the INM approach thrust level. Increasing this approach thrust level yields INM SEL values which fall more in line with observed data.

The exact same results are noted for the DC10/JT9D aircraft and are also presented in Table 3-4. For operations assumed to be at takeoff thrust or climb thrust, the INM yields noise levels which are very accurate. (It should be noted, in addition, that these INM-specified thrust levels for takeoff and climb are different from those used with the DC10/CF6, and the differences between the DC10/CF6 and DC10/JT9D are adequately managed by slightly modifying the thrust levels while using the same SEL curves.) As in the case of the DC10/CF6, the mean SEL difference is substantially greater for approaches. This, however, is again attributed to an inappropriate INM approach thrust level. By slightly increasing the approach thrust level used to calculate the INM SELs, the mean SEL difference can be brought into tolerable ranges for the approach thrust case.

With the exception of the INM approach thrust level, the INM-specified thrust levels and SEL curves for the DC10 appear to be very accurate.

3.3.3 Results for L1011

The results for the L1011 are presented in Table 3-4. The mean SEL differences of 1.24, 1.17, and -1.93 dB for operations conducted at takeoff, climb, and approach thrust, respectively, are all well within tolerable limits. Unlike the case for the A300 and DC10, the approach thrust noise levels, as calculated by the INM, agree reasonably well with observed data. Therefore, no changes to the INM thrust levels or SEL curves are necessary for the L1011.

3.4 Results for Four Engine Wide-Body Aircraft (B747)

The results for the B747 are presented in Table 3-5. Because of the relatively high zero flap maneuvering speed for this aircraft, (approximately 230 to 250 knots) none of the observed noise events were attributed to B747s operating at climb thrust. The point at which most B747 departures reduced to climb thrust occurred after they had passed all of the noise monitor sites. For the takeoff thrust case, INM and observed noise data agrees to within acceptable limits. The mean SEL

TABLE 3-5
RESULTS FOR FOUR ENGINE WIDE-BODY AIRCRAFT

AIRCRAFT/ENGINE		THRUST ASSUMED BY INM		
		TAKEOFF	CUTBACK	APPROACH
B747/JT9D	Mean SEL Difference, dB	-2.49	No	-5.45
	Standard Deviation, dB	3.32	Data	3.30
	Number of Observations	698		392

difference for the approach thrust case, however, is not within acceptable limits and indicates the INM is underestimating observed noise levels by 5.45 dB.

This large mean difference could be attributed to an inappropriately low thrust level specified by the INM for approaches. A review of available engineering data and flight operations manuals indicate that this may be the case. Thrust settings for approach and landing are not specified in manuals as they are for takeoffs and climbs: pilots merely adjust the thrust by trial and error until a stabilized state is achieved in the desired landing configuration. However, the average thrust required to maintain a stabilized approach in the landing configuration most airlines use for the B747 is probably higher than the one specified by the INM. As found for the B737 with treated nacelles, the INM thrust level for B747 approaches pertains to landings made with partially extended flaps, whereas in actual operation fully extended flaps are more often used. Therefore the actual thrust used for approaches would be somewhat higher.

Increasing the INM approach thrust level to account for the flap setting difference would resolve for some of the large mean SEL difference, but it would probably not improve agreement beyond a marginal level. Therefore, there is probably some additional systematic influence which may be causing B747 approaches to be conducted at higher than normal thrust levels. It is not possible from the observed data to determine potential causes however.

In summary, it appears the INM SEL curves are reasonably accurate for the B747. The thrust level specified for the takeoff case also appears to be accurate. For approaches the thrust level specified by the INM is lower than that likely used in actual operations. Part of the thrust discrepancy is attributable to the differences in flap extensions assumed by the INM and those used in actual operations.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the results outlined in the previous section and the results obtained in earlier INM validation studies (Reference 2), the new Version 3 INM and the Number 8 INM data base have considerably improved the agreement between observed and INM-calculated noise levels for individual noise events. Noise estimates from the older Version 2 INM frequently differed from observed noise levels by an average of 7 dB in earlier studies. Results presented in this current validation effort, however, revealed that the majority of mean SEL differences was less than 3 dB. The improved agreement between INM and observed noise levels is the result of enhancing the methods used by the INM to calculate noise levels, and revising the INM data base itself. In the latter effort, both the INM thrust-distance-noise curves and the flight profiles section (which includes thrust schedules) were completely restructured to more accurately reflect actual operations and data. The end result is a noise model and data base which, for most of the aircraft studied, are very accurate in the estimation of single event noise levels.

4.1 INM SEL Curves and Thrust Management Assumptions

In cases where a discrepancy was found between INM and observed noise levels, a number of techniques were employed to determine if it was due to an erroneous INM thrust assumption or a fault in the INM SEL curves. For the initial INM calculations, all departures were assumed to be conducted in accordance with the FAA departure procedure, which included a deep thrust cutback at 1000 feet for narrow-body aircraft. It was found that the INM seriously underestimated observed noise levels where the deep cutback thrust was assumed. To confirm that the underestimation was due to a procedural difference, thrust assumptions were revised to reflect actual operating procedures where the deep cutback thrust level is not used, and the INM SELs were recomputed. The lower mean SEL differences achieved with the revised thrust assumptions indicated that most airlines simply reduce to climb thrust rather than the deep cutback thrust. Therefore, it is recommended that the departure profiles of affected narrow-body aircraft be modified, by the elimination of the deep thrust cutback, to reflect more common operating practices.

In some instances, fairly large mean SEL differences were still observed, even though the procedures used for departures were known with a great amount of confidence from flight operations manuals and observed data. To determine if the differences were due to erroneous thrust values specified by the INM for a particular segment of the departure, a thrust assignment algorithm based on distance from BRP was employed. This permitted a grouping of the data in such a way that observed departure events operating either at takeoff thrust or at climb thrust could be isolated with a greater degree of confidence. In this way, it was possible to determine if the value specified by the INM as takeoff thrust, for example, was approximately the value used in actual operations.

These thrust assignment algorithms were useful in determining the accuracy of both the INM SEL curves and the INM thrust profiles. General conclusions and recommendations for each general class of aircraft studied are presented below:

1) For the three engine narrow-body aircraft (B727), INM and observed noise levels agree very well for operations considered to be at takeoff, climb, and approach thrust. The conclusion, then, is that the thrust levels and SEL curves for these thrust conditions are accurate. For overflights assumed to be operating at the INM-specified cutback thrust, however, the INM underestimated observed noise levels by a wide margin. As mentioned above, this finding, coupled with information from other sources such as airline flight operations manuals, offers convincing evidence that the deep thrust cutback is rarely employed in actual flight operations.

2.) For the two engine narrow-body aircraft (B737, DC9) the agreement between INM and observed noise levels is mixed. While agreement for these two aircraft types is slightly better than seen in earlier studies it is not as good as the agreement seen with other types of aircraft in this study.

    For departures by B737s with untreated nacelles, the INM tends to overestimate observed noise for departures by about 4 to 5 dB. For arrivals, it tends to underestimate by about 3 to 4 dB. It is difficult to draw conclusions based on these results alone, but it appears the INM SEL curves and/or the thrust levels for the untreated B737 need to be revised to reduce INM estimates, by about 4 to 5 dB, in order to more accurately reflect observations for departure. It also appears likely that the INM-specified approach thrust level is too low and should be increased. For the B737 with treated nacelles, the results of several different analyses suggest that the INM SEL curves for this aircraft are adequate and that the large differences between INM and observed noise levels for the takeoff, cutback, and approach cases are due to either erroneous thrust levels assumed by the INM, or the use of the reduced-thrust takeoff procedure.

For DC9s at climb and approach thrust, INM and observed noise levels agreed reasonably well. For DC9 departures at takeoff thrust it appeared the INM was overestimating observed noise levels by 6.83 dB. However, this difference may be entirely due to the use of the reduced-thrust takeoff procedure by the major operator of DC9s at SEA-TAC. It was not possible to determine from independent sources the proportion of departures which were, in fact, using the reduced-thrust procedure, but observed noise data support the hypothesis that this procedure was used extensively. Therefore, it appears the INM SEL curves and thrust levels will produce acceptable agreement with observed noise levels where standard procedures are employed, but the predominance of the reduced-thrust takeoff and its effect on overall noise calculations should be examined further. As for the B727, observed data and other evidence suggest that the FAA deep cutback thrust is rarely used in actual DC9 or B737 flight operations, and INM departure profiles should be changed to eliminate the deep cutback.

3) Agreement for the two and three engine wide-body aircraft was excellent. For operations conducted at takeoff or climb thrust, the INM SEL estimates were, on average, within 2 dB of observed noise levels. For the A300 and DC10, agreement for the approach thrust case, though acceptable, could be improved by increasing the thrust level assumed for approaches.

4) For the B747, agreement for departures was acceptable. For approaches, the INM tended to underestimate observed noise levels by approximately 5 dB. Because the SEL curves appeared to be accurate for other thrust ranges, the INM approach thrust level should be increased to produce better agreement for approaches.

4.2 Additional Analyses

All INM validation studies to date have been aimed at validating a certain section or piece of the INM and its data base. In this study, for instance, the INM SEL curves and INM thrust profiles (which are part of the arrival and departure flight profiles) were examined and found to accurately reflect actual operations for most of the aircraft types studied. However, the overall performance of the INM as a whole should still be determined, and a study designed to do that is a logical follow-up to the analyses reported in this document. Such a study should address the three issues presented below:

1) It should investigate the accuracy of independent INM noise predictions where no information surrounding the observed noise event is used to calculate the INM estimate. The study presented in this document considered the observed velocity, elevation angle, and slant range when each INM noise level estimate was made. This was done to eliminate sources of variation and to allow subsequent analyses to concentrate on the INM SEL curves and thrust profiles. Now that greater confidence can be placed in the SEL curves and thrust profiles, the combined effect of using standard INM flight profiles, thrust profiles, and SEL curves in independent noise predictions should be investigated.

2) The study should investigate the sensitivity of the INM estimates and observed noise levels to variations in input variables. It should identify those variables to which the INM is most sensitive and determine the effects of randomly changing the value of those variables around an accepted mean value. The INM currently works on the assumption that all of the input variables used in noise estimation (such as aircraft velocity, altitude, or thrust) are adequately modelled by a single average or mean value. However, in practice, a host of factors usually prevent observed flights from operating according to average performance, though the average of a large number of similar observations may approach the INM mean performance. It should be determined if the overall noise estimation of a given number of flyovers all operating at the mean values of the input variables yields the same results as for the same number of flyovers where input values are randomly sampled from distributions having those same mean values.

3) The overall performance of the INM should be checked in an airport case study, where observed noise levels for a given day are aggregated to yield a 24 hour-based noise metric and compared to the INM result. This would be an examination of the INM at the highest level.

APPENDIX A

DESCRIPTION OF THE INM

The INM is a series of computer routines which perform a variety of functions in the course of calculating noise levels in the vicinity of an airport. The subroutines can be grouped into three major areas:

1) Part of the INM is dedicated to the geometric analysis and integration of data from a number of sources. These include the user-supplied airport description and ground tracks, and the INM-supplied flight profiles which, in part, describe aircraft altitude as a function of distance from the airport. The primary purpose of this geometric analysis is to determine the source-to-receiver distances at several locations around the airport.

2) Some subroutines in the INM are aimed at evaluating the noise levels generated by each single aircraft flyover. For a given location near the airport, the INM determines the noise level at that location for each individual aircraft flyover.

3) The final function fulfilled by INM subroutines is the aggregation of all the noise levels calculated for individual flyovers to yield a single environmental noise metric. A number of environmental noise metrics have been developed, and the INM allows the user to choose any one of the four most widely accepted noise metrics. The available metrics include the Noise Exposure Forecast, the Equivalent Sound Level, the Day-Night Average Sound Level, and the Time Above (TA) a user-selected dB(A) threshold.

Because this study is concerned primarily with INM single event noise estimates, the functions involved in the second group are described in more detail. Three major variables are associated with the calculation of an INM single event noise level, namely, the assumed thrust level at which the aircraft is operating, the distance from the aircraft to an arbitrary point on the ground, and the thrust-distance-noise relationships (also called noise curves) which are part of the INM data base. The thrust level assumed for the noise calculation is usually obtained from the flight profiles section of the INM data base. These flight profiles describe aircraft altitude, speed, and thrust level as a function of distance from the airport. A sample flight profile is given in Figure A-1 for a B727 departure. For any point in the departure, the INM determines the thrust level by looking it up in the appropriate profile. The distance from the aircraft to an arbitrary point on the ground is determined through use of a series of geometric analyses.

When the thrust level and distance have been determined, the INM performs a log-linear interpolation on the INM noise curves to yield a single event noise estimate. A sample noise curve for a B727 for the Sound Exposure Level (SEL) metric is given in Figure A-2.

The noise curves in the INM data base are given in terms of an aircraft travelling at 160 knots. If an aircraft is travelling at another speed, as determined from the INM flight profiles, a velocity correction must be applied. The INM performs this velocity correction according to the following relationship and it is added to the calculated noise estimate.

$$\text{Velocity correction} = -10 \log_{10} (\text{Observed Velocity, in knots}/160)$$

To account for the effects of lateral attenuation, the INM also employs a noise correction based on both slant range and elevation angle from the source to the receiver. A plot of this lateral attenuation function versus elevation angle is given in Figure A-3 for three different slant ranges. In all of the INM noise estimates calculated in this study, both the velocity correction and lateral attenuation correction were applied as described here.

The INM description presented in this Appendix was intended to serve only as an aid to understanding the elements of the INM being investigated in this study and to set them in their proper perspective with respect to other parts of the INM. A complete description of the INM may be found in Reference 6.

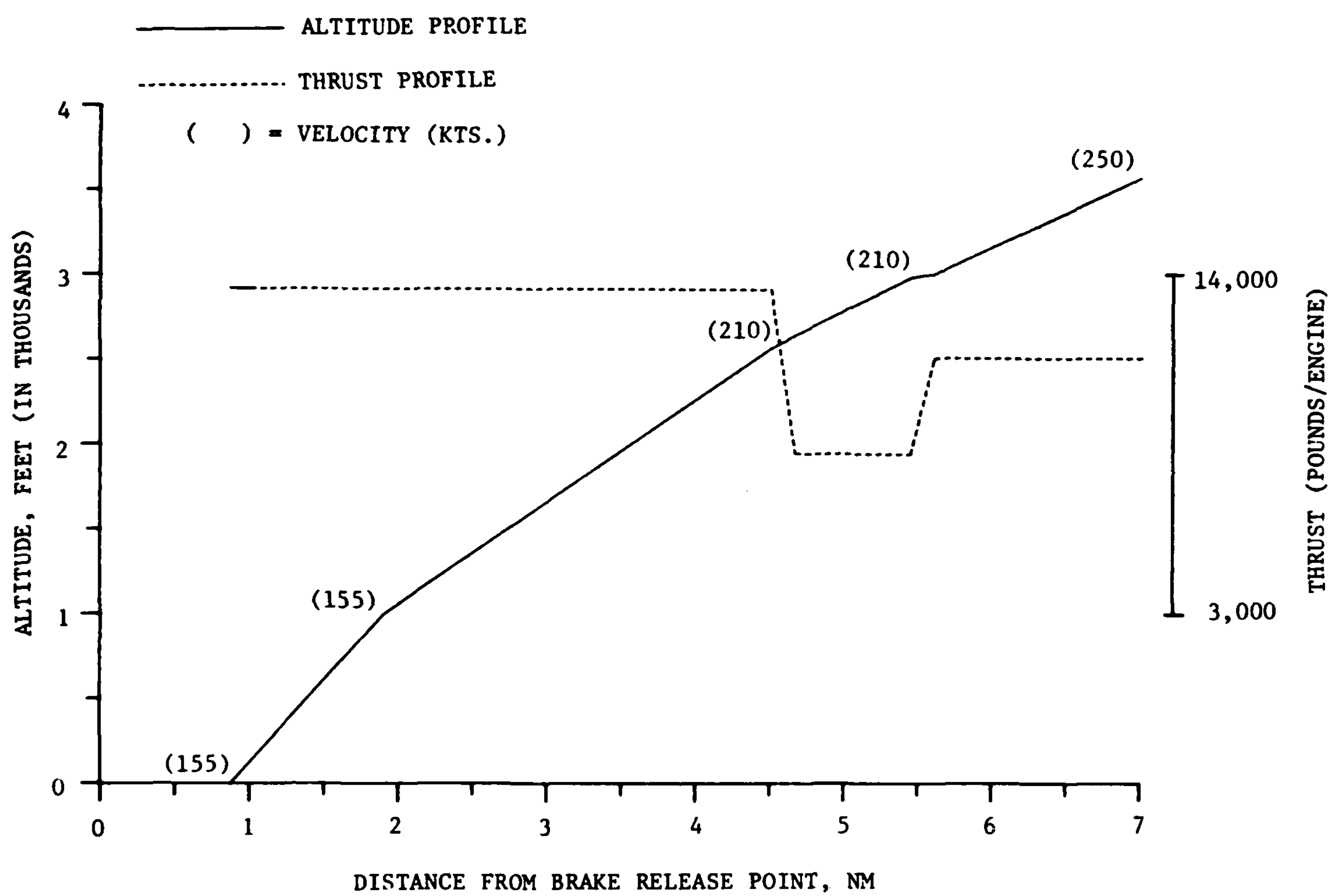


FIGURE A-1
SAMPLE INM FLIGHT PROFILE FOR B727 DEPARTURES

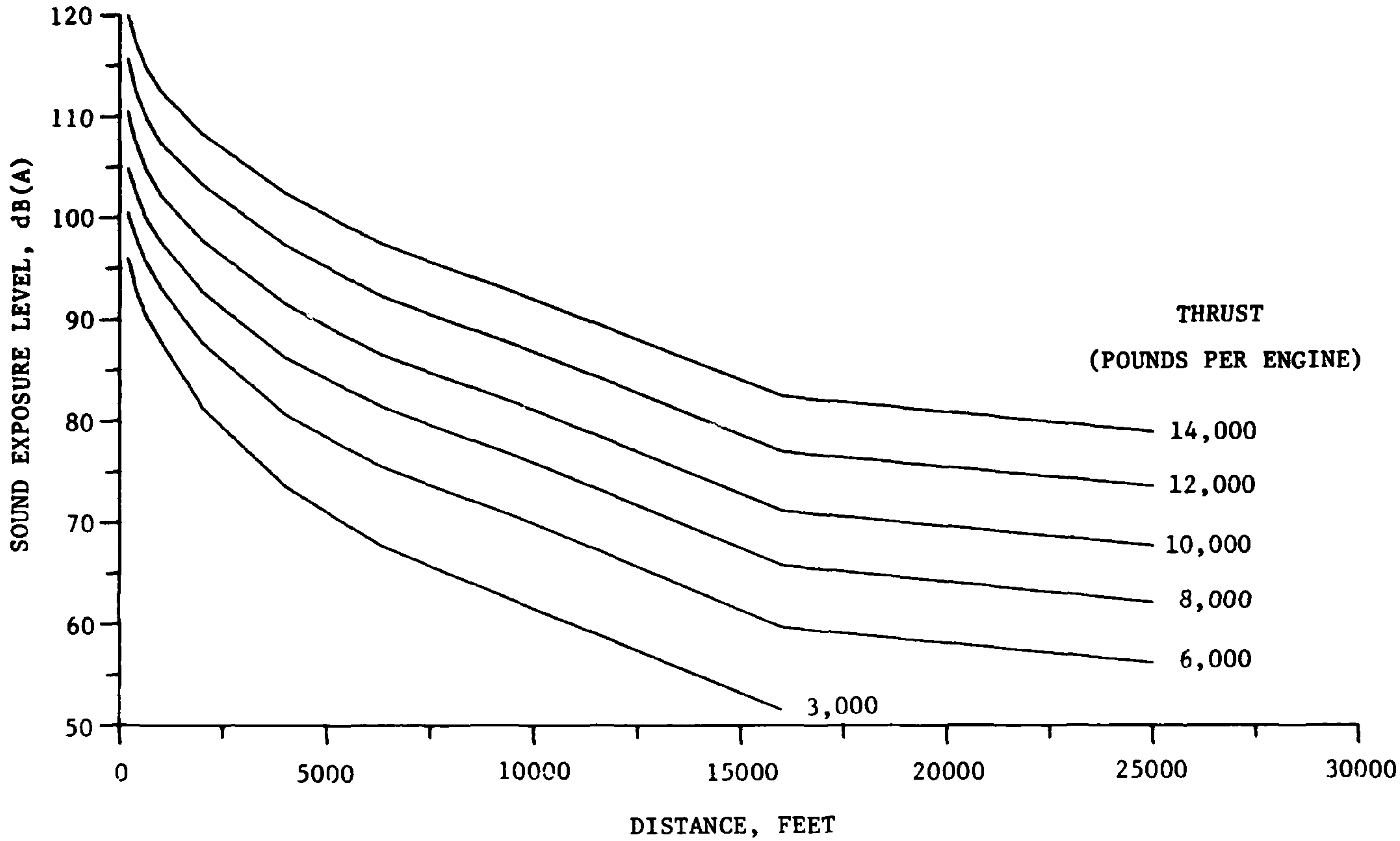


FIGURE A-2
SAMPLE NOISE CURVES FOR B727 WITH JT8D QUIET NACELLE ENGINES

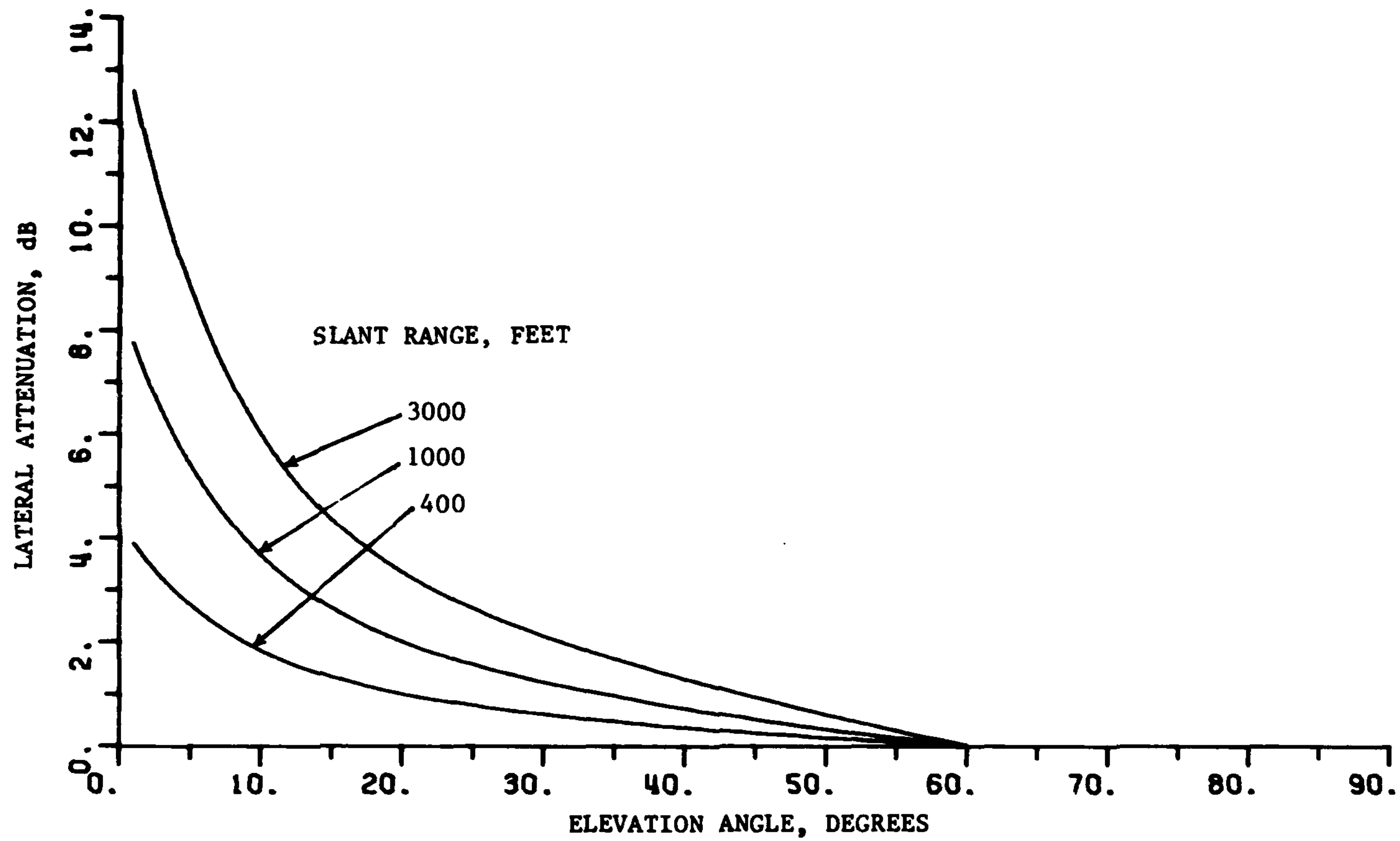


FIGURE A-3
INM LATERAL ATTENUATION CURVES

APPENDIX B

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