Technical Report

NOISE MONITORING PROGRAM

This Technical Report presents the results of a noise monitoring program conducted around Louisville International Airport (the Airport) between June 2, and June 12, 1999. In addition to documenting the existing background noise conditions in communities surrounding the Airport, the results of the noise monitoring program provide a valuable comparison to the Day-Night Average Sound Level (DNL) noise exposure contours being prepared for the Federal Aviation Regulations (FAR) Part 150 Noise Compatibility Study at the Airport. Additionally, the noise monitoring program provided actual information regarding single-event data for various aircraft types, the potential for noise induced vibration from aircraft overflights, and noise levels from aircraft ground operations. The methodology and results of the noise monitoring program are discussed in the following sections:

- Characteristics of Sound and Noise Measurement
- Noise Monitoring Program Overview
- Aircraft Activity During Monitoring Program
- Single-Event Noise Measurements
- Cumulative Noise Measurements
- Comparison of Monitored and INM-Predicted Single-Event Noise Levels
- One-Third Octave Band Noise Measurements
- C-Weighted Noise Measurements
- Noise Induced Vibration

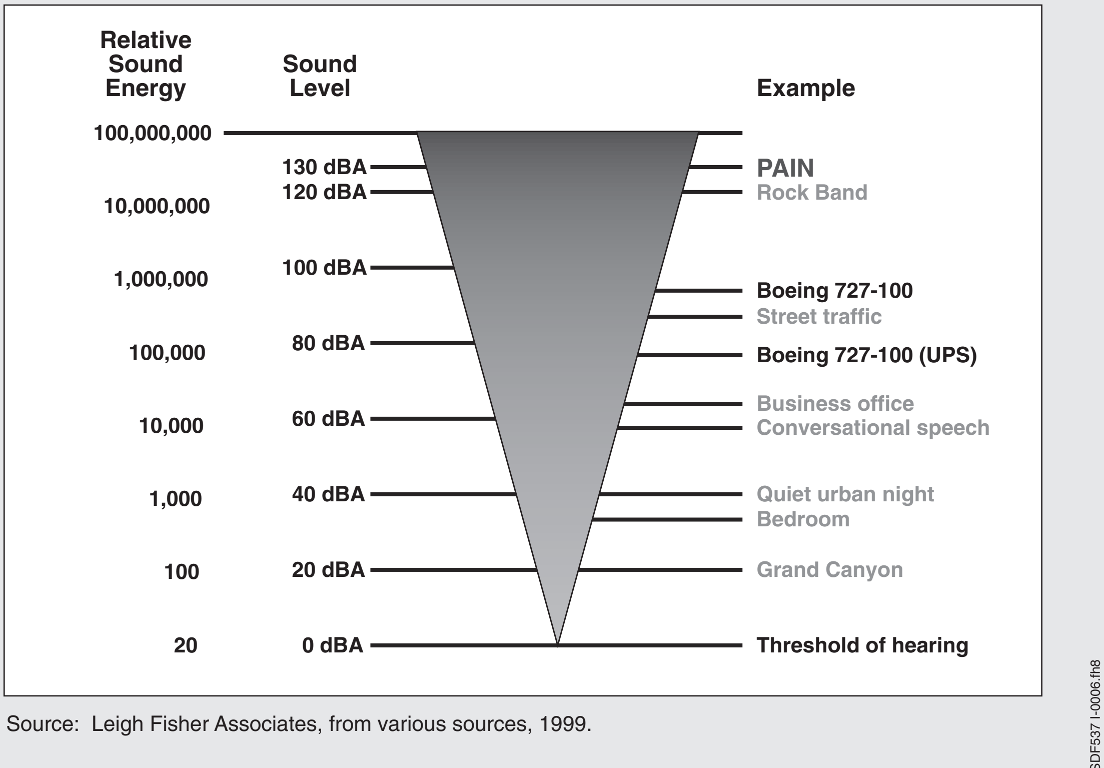
CHARACTERISTICS OF SOUND AND NOISE MEASUREMENT

Sound is transmitted by alternating compression and decompression in air pressure. The measurement and human perception of sound involves two physical characteristics—intensity and frequency. Intensity is a measure of the strength or magnitude of the sound vibrations. The other characteristic is sound frequency, or “pitch” the speed of vibration. Frequencies are expressed in terms of cycles per second or hertz (Hz). Examples of low frequency sounds might be characterized as a rumble or roar, while high frequency sounds are typified by sirens or screeches.

The human ear is sensitive to an extremely wide range of sound intensity which covers a relative scale from 1 to 100,000,000. Representation of sound intensity using a *linear* index becomes difficult due to this wide range. As a result, the decibel (dB) a logarithmic measure of the magnitude of sound is typically used. Sound intensity is measured in terms of sound levels ranging from 0 dB, which is approximately the threshold of hearing, to 130 dB, which is the threshold of pain. Figure 1 compares the sound pressure levels of typical events.

Figure 1

NOISE METRICS—TYPICAL SOUND LEVELS



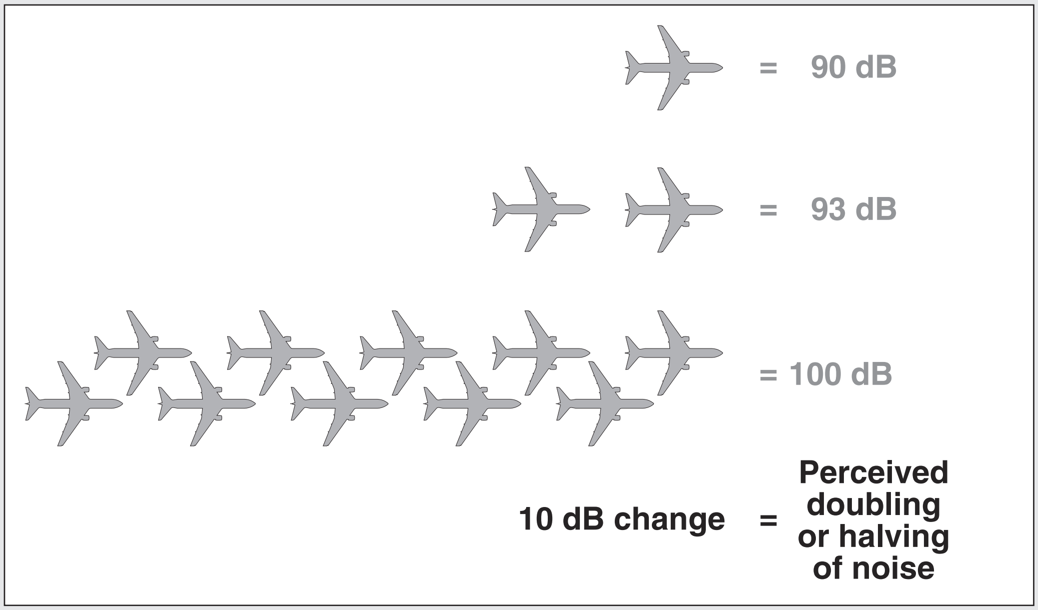
Source: Leigh Fisher Associates, from various sources, 1999.

Because of the logarithmic unit of measurement, decibels cannot be added or subtracted arithmatically (see Figure 2); however, a number simple rules of thumb are useful.

- If two sounds of the same level are added, the sound level increases by approximately 3 dB. For example: 60 dB + 60 dB = 63 dB.
- The sum of two sounds of a different level is only slightly higher than the louder level. For example: 60 dB + 70 dB = 70.4 dB.
- Sound from a “point source,” such as an aircraft, decreases approximately 6 dB for each doubling of distance.
- Although the human ear can detect a sound as faint as 1 dB, the typical person does not perceive changes of less than approximately 3 dB.
- A 10 dB change in sound level is perceived by the average person as a doubling, or halving of the sound’s loudness.

Figure 2

NOISE METRICS—DECIBEL (dB) ADDITION



Source: Leigh Fisher Associates, 1999.

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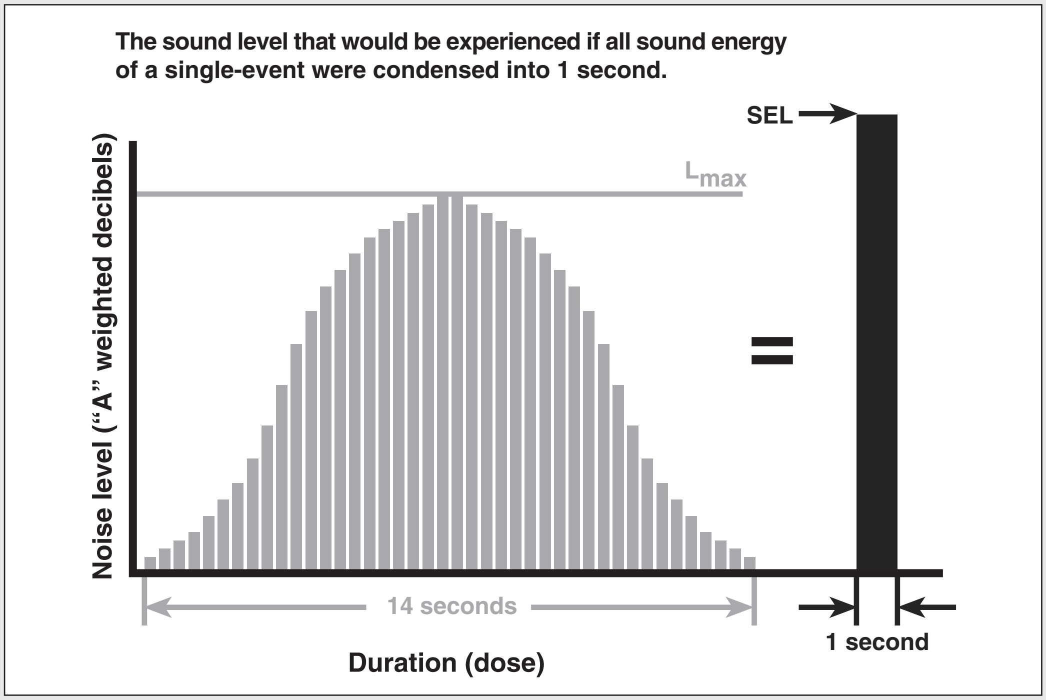
Humans are most sensitive to frequencies near the normal range of speech communications. "A-weighting" reflects this sensitivity by emphasizing mid-range frequencies and de-emphasizing high and low frequencies (see Figure 3). Therefore, the A-weighted decibel (dBA) provides a better preXdiction of human reaction to environmental noise than the unweighted decibel. The C-weighted decibel (dBC) emphasizes the lower frequencies.

One way of describing noise is to measure the maximum sound level (Lmax). However, Lmax does not account for the duration of a sound event, and studies have shown that human response to noise involves both the maximum level as well as the duration. Clearly, the longer a noise lasts the more it disrupts activity and the more annoying it is likely to be. Accordingly, a second manner of describing noise is to measure the sound exposure level (SEL), which is the total sound energy of a single sound event. By accounting for both intensity and duration, the SEL allows one to compare the "annoyance" of different events. The SEL expresses all of the sound energy of a sound event occurred in one second (see Figure 3). This normalization to a duration of one second allows the direct comparison of sounds of different duration.

Figure 3

NOISE METRICS—SOUND EXPOSURE LEVEL (SEL)



Source: Leigh Fisher Associates, 1999.

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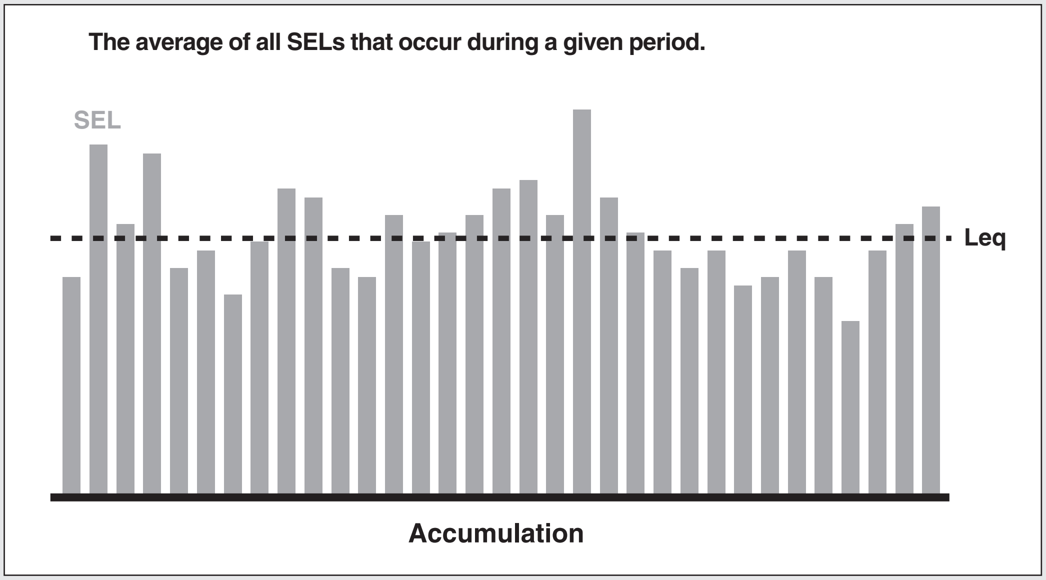
The Lmax and SEL measure individual events. But the number of events is also an important consideration in measuring noise. One way to describe this factor might be to count the number of events exceeding SEL 80 dBA, plus the number that exceed SEL 75 dBA, plus the number that exceed SEL 70 dBA, etc. A more efficient way to describe both the number of such events and the sound exposure level of each is the time-average of the total sound energy over a specified period (see Figure 4), referred to as the equivalent sound level (L_{eq}). Research indicates that community reaction to noise corresponds to the total acoustic energy that is represented by the L_{eq}. In the example shown on Figure 4, the L_{eq} provides a single-number description of all of the sound energy during the sample period.

Figure 4

NOISE METRICS—EQUIVALENT SOUND LEVEL (Leq)



Source: Leigh Fisher Associates, 1999.

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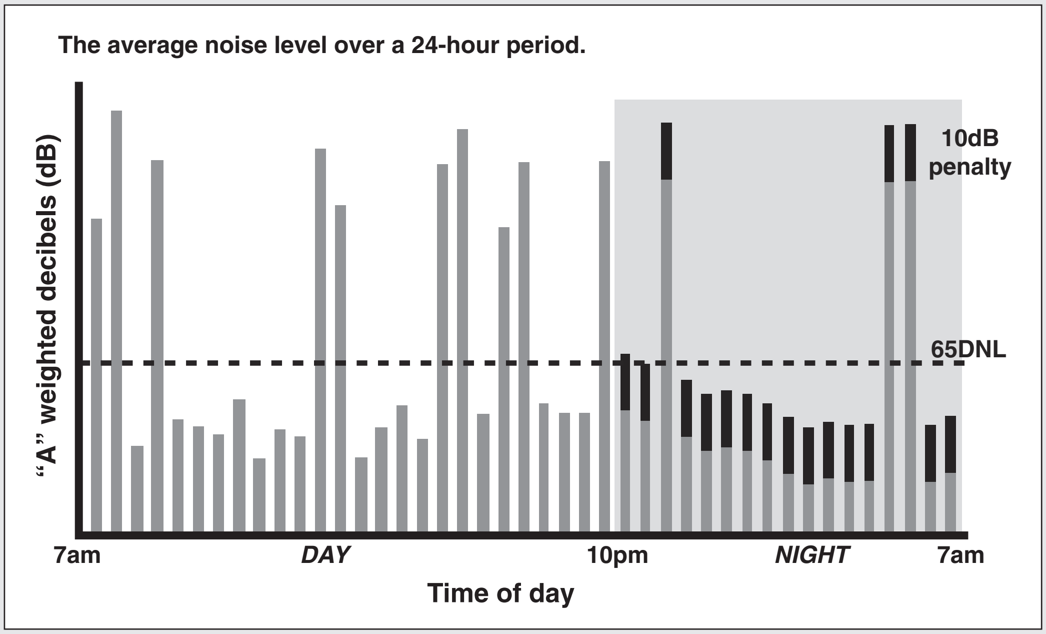
One additional factor is also important in measuring a sound—the occurrence of sound events that occur during nighttime hours (defined as the hours between 10:00 p.m. and 7:00 a.m.). People are normally more sensitive to intrusive sound events at night, and the background sound levels are normally lower at night because of decreased human activity. Therefore, noise events during the nighttime hours are likely to be more annoying than noise events at other times. To account for these factors, the DNL adds a 10 dB penalty to sound levels occurring between 10:00 p.m. and 7:00 a.m. (see Figure 5). In essence, the DNL is the 24-hour equivalent sound level (or L_{eq} 24), including this 10 dB penalty. This 10 dB penalty means that one nighttime sound event is equivalent to 10 daytime events of the same level. The DNL has been identified by the U.S. Environmental Protection Agency (U.S. EPA) as the principal metric for airport noise analysis.*

*U. S. Environmental Protection Agency, *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*, U.S. EPA Report No. 550/9-74-004, 1974.

Figure 5

NOISE METRICS—DAY-NIGHT AVERAGE SOUND LEVEL (DNL)



Source: Leigh Fisher Associates, 1999.

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DNL is expressed as an average noise level on the basis of annual aircraft operations for a calendar year. To calculate the DNL at a specific location, SELs for that particular location are determined for each aircraft operation (landing or takeoff). The SEL for each operation is then adjusted to reflect the duration of the operation and arrive at a "partial" DNL for the operation. The partial DNLs are then added logarithmically—with the appropriate penalty for those operations occurring during the nighttime hours—to determine total noise exposure levels for the average day of the year.

The logarithmic addition process described earlier also applies to DNL. For example, an increase or decrease of DNL 3 dB would require either a doubling or halving of aircraft operations (assuming the same types of aircraft and the same proportion of nighttime activity). This same change of DNL 3 dB could also be achieved by an average change of 3 dB per aircraft operation.

DNL is used to describe the existing and predicted cumulative noise exposure for communities in airport environs in most of the United States, and to estimate the effects of airport operations on land use compatibility. DNL has been widely accepted as the best available method to describe aircraft noise exposure and is the noise descriptor required by the FAA for use in aircraft noise exposure analyses and noise compatibility planning.*

NOISE MONITORING PROGRAM OVERVIEW

A total of 20 monitoring sites were selected for the noise monitoring program through a collaborative effort between the Consultant Team and the Noise Compatibility Study Group Noise Monitoring and Metrics committees to best represent the communities surrounding the Airport. The location of the noise monitoring sites are shown graphically on Figure 6.

Because most of the aircraft activity at the Airport occurs on parallel Runways 17R-35L and 17L-35R, the majority of noise monitoring sites were located along the centerlines of these north / south runways. Eleven of the sites were located north of the Airport, which is densely populated; while 6 of the noise monitoring sites were located south of the Airport, which is less densely populated. Two sites were located along Runway 11-29 to cover operations on the cross wind runway. One site was located to obtain sideline noise levels from aircraft start of takeoff roll on Runway 17R-35L. Eighteen of the 20 sites were located in Jefferson County, one was located in Bullitt County, and one was located in Southern Indiana.

Noise measurements were obtained over a 24-hour period at each site. At two sites, noise measurements were obtained over a longer period of time. At Site 1, located south of the Airport, noise measurements were obtained over a 72-hour (3-day) period. At Site 17, located north of the Airport, noise measurements were obtained over a 48-hour (2-day) period. In addition, noise measurements were obtained over an additional 24-hour period at Sites 2 and 7 since these sites were initially monitored over the weekend when aircraft activity is lower than average. Figure 7 shows the schedule of noise monitoring activity at the 20 noise monitoring sites.

*Federal Aviation Administration, Federal Aviation Regulations Part 150, Appendix A, 1984.

Figure 6 Location of the Noise Monitoring Sites

Figure 7 Noise Monitoring Schedule

AIRCRAFT ACTIVITY DURING MONITORING PROGRAM

Aircraft typically arrive at the Airport from the north on Runways 17R and 17L, and departs to the south on Runways 17R and 17L. Because the traffic flow is predominantly from the north to the south, noise monitoring sites north of the Airport primarily reflected aircraft arrivals on Runways 17L and 17R during the two week noise monitoring period. Sites south of the Airport primarily reflected aircraft departures on these same two runways. During contraflow conditions during nighttime hours, noise monitoring sites south of the Airport reflect both departures and arrivals.

Observations during the monitoring program were supplemented with Federal Aviation Administration (FAA) Automated Radar Terminal Systems (ARTS) III flight track data. The ARTS data indicated that during a typical 24-hour period during the noise monitoring program, there were an average of 358 total aircraft operations at the Airport. Of this total, there were an average of 193 aircraft arrivals (107 daytime and 86 nighttime), and 165 aircraft departures (103 daytime and 62 nighttime). Observed runway uses during the monitoring program is provided in Table 1.

The following scheduled runway closures occurred during the noise monitoring period:

- June 2—Runway 17R-35L between 12:00 p.m. and 3:00 p.m. for FAA and RAA maintenance
- June 3—Runway 17R-35L between 8:00 a.m. and 12:00 p.m. for FAA and RAA maintenance
- June 7—Runway 17L-35R between 11:00 a.m. and 3:00 p.m. for FAA and RAA maintenance
- June 8—Runway 17R-35L between 8:00 a.m. and 12:00 p.m. for FAA and RAA maintenance
- June 12—Runway 17R-35L between 8:00 a.m. and 3:30 p.m. for runway grooving

SINGLE-EVENT NOISE MEASUREMENTS

During noise monitoring at each site, the noise monitors were configured to obtain single-event aircraft noise data, including Lmax and SEL. By setting a threshold level on the sound meter, any aircraft operation that generated a noise level that exceeded the threshold level registered a noise event.

Table 1

AIRPORT RUNWAY USE DURING NOISE MONITORING PROGRAM

		Daytime runway use							Nighttime runway use						
Date	Day of week	Total operations *(a)*	17L	17R	35L	35R	11	29	Total operations	17L	17R	35L	35R	11	29
Arrivals															
6/2/99	Wednesday	138	61%	30%	5%	4%	0%	0%	89	16%	0%	43%	40%	0%	1%
6/3/99	Thursday	150	52	--	26	22	--	--	102	21	--	45	34	--	--
6/4/99	Friday	57	100	--	--	--	--	--	106	45	30	13	9	--	3
6/5/99	Saturday	80	90	10	--	--	--	--	22	77	--	14	9	--	--
6/6/99	Sunday	87	94	5	--	1	--	--	11	91	--	--	9	--	--
6/7/99	Monday	108	78	22	--	--	--	--	110	14	--	43	43	--	--
6/8/99	Tuesday	130	95	2	2	1	--	--	117	19	--	49	32	--	--
6/9/99	Wednesday	116	74	10	10	6	--	--	128	22	1	45	32	--	--
6/10/99	Thursday	132	89	10	--	1	--	--	126	29	11	29	31	--	--
6/11/99	Friday	103	90	8	1	1	--	--	109	17	1	44	38	--	--
6/12/99	Saturday	73	97	--	1	--	1	1	25	36	8	36	20	--	--
Departures															
6/2/99	Wednesday	130	42%	49%	0%	8%	0%	1%	79	58%	34%	3%	5%	0%	0%
6/3/99	Thursday	127	44	6	14	36	--	--	76	50	44	1	5	--	--
6/4/99	Friday	75	40	59	--	1	--	--	63	49	49	--	2	--	--
6/5/99	Saturday	80	56	44	--	--	--	--	28	57	35	4	4	--	--
6/6/99	Sunday	85	53	44	1	2	--	--	12	33	42	25	--	--	--
6/7/99	Monday	136	49	51	--	--	--	--	38	44	37	8	11	--	--
6/8/99	Tuesday	116	61	35	--	4	--	--	86	43	49	1	7	--	--
6/9/99	Wednesday	119	45	29	15	11	--	--	94	41	48	7	4	--	--
6/10/99	Thursday	124	58	41	1	--	--	--	88	59	30	3	8	--	--
6/11/99	Friday	87	49	51	--	--	--	--	59	50	37	3	10	--	--
6/12/99	Saturday	56	80	18	--	2	--	--	61	43	55	--	2	--	--

(a) Total arrivals and departures do not equal since some aircraft operations are not captured by the ARTS processing software; and flights having low quality signals and/or errant data are discarded from the sample.

Source: Analysis of FAA ARTS III data for June 1999.

The single-event data obtained at each site provided information on the noise generated by individual aircraft. In order to provide more useful information, the measured single-event noise levels were correlated with the FAA's ARTS data to provide information on aircraft type, aircraft operator, type of operation (takeoff or landing), time of operation (day or night) and runway used. By matching the time of the measured noise event with the time of the aircraft event from the ARTS data, it was possible to obtain a more detailed picture of the aircraft activity that generated the noise at each site. The identified aircraft events at each site are provided in Attachment 1 at the end of this Working Paper. Maximum noise levels, or Lmax, ranged from 77 dBA at Site 1 (a residence along National Turnpike Drive) to 95 dBA at Site 7 (a residence along Penguin Street).

Table 2 indicates the types of aircraft and aircraft operators that contributed to the loudest monitored noise events. FAR Part 36 Stage 2 aircraft such as the B-727, B-737, and DC-9 contributed nearly half (48%) of all the loudest noise events. Combined, these aircraft accounted for approximately 24% of all aircraft operation in 1998. The B-757 contributed to approximately 12% of all the loudest noise events, which is consistent with its 10% share of aircraft operations in 1998. Three aircraft operators, Delta Airlines, Southwest Airlines, and Trans World Airways, contributed nearly half (46%) of all the loudest noise events. Combined, these aircraft accounted for approximately 17% of all aircraft operation in 1998. United Parcel Service (UPS) contributed to approximately 35% of all the loudest noise events, but also accounted for 32% of all aircraft operation in 1998. It should be noted that many of the UPS operations occur at night when the annoyance caused by aircraft operations may be greater than the intensity of the noise would indicate.

CUMULATIVE NOISE MEASUREMENTS

At each noise monitoring site, the measured hourly equivalent noise levels (Leq) were used to calculate the overall DNL for each 24-hour measurement period. Figure 8 shows the DNL measured at each site. The measured DNL noise levels ranged from 58.0 dBA at Site 2, to 67.9 dBA at Site 16. Although a higher DNL was obtained at Site 15, these noise levels were generated primarily by vehicular traffic, other non-aircraft activity, and rooftop HVAC equipment.

North of the Airport, the DNL correlate strongly with the location of the noise monitoring sites relative to arrival flight tracks. For example, at Site 17, which is located directly under the flight track for aircraft arriving on Runway 17L, the measured DNL was 65.9 dBA. Over roughly the same period of time, the DNL at Site 6, which was located farther from the centerline of the flight track, was 61.2 dBA. For all of the noise monitoring sites north of the Airport where arrival operations were the dominant aircraft activity, the measured DNL decreased as the distance from the centerline of the flight tracks increased. DNL obtained at Site 17 over two successive weekdays indicated that the measured DNL remained relatively constant at 65.4 dBA and 65.9 dBA, respectively. This consistency reflects the

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Table 2

CONTRIBUTION TO LOUDEST MONITORED NOISE EVENTS AND SHARE OF TOTAL AIRCRAFT OPERATIONS (1998)

Aircraft types	% of loudest events	Share of total 1998 operations	Aircraft operators	% of loudest events	Share of total 1998 operations
DC-9-10/30/50 (Stage 2)	18%	8%	United Parcel Service	35%	32%
Boeing 727-100/200 (Stage 2)	16	7	Delta Airlines	21	6
Boeing 737-200 (Stage 2)	14	9	Trans World Airways	13	2
Boeing 757	12	10	Southwest Airlines	12	9
Boeing 767	9	7	General aviation jets	4	12
DC-8 freighter	8	9	Military	4	3
Boeing 747-100/200	6	2	US Airways	4	5
Boeing 737-300/500	5	4	Northwest Airlines	4	3
Lear 23/25	4	12	Commuters (various)	2	7
C-130 (military)	4	3	Continental Airlines	1	1
MD-80/82	4	3			
SF 340 (turboprop)	2	1			
Total	100%	74%		100%	80%

Note: Share of total 1998 operations based on assumed aircraft operations for an annual average day.

Source: Leigh Fisher Associates, December 1999.

Figure 8 Summary of Measured DNL Noise Levels relatively constant level of aircraft activity during the week. At Site 7, located between the two runways, the DNL ranged from 60.4 dBA on a weekend (when the level of aircraft activity at the Airport was lower), to 62.0 dBA during a weekday time period.

South of the Airport, the DNL also correlate with the aircraft flight tracks; however, the results show a greater degree of variability than to the north. This increased variability reflects the greater variety of aircraft altitudes and flight tracks associated with departures. The DNL ranged from 58.0 dBA at Site 2, to 65.8 dBA at Site 3 which was located directly under the approach and departure flight tracks. During contra flow conditions, Sites 3 and 10 are influenced by both takeoff and landing operations. During a weekday period with contra flow conditions in effect, the DNL at Site 3 was 65.8 dBA, while during a weekend period with very little nighttime aircraft activity, the DNL at Site 10 was 63.8 dBA. At Site 1, the DNL were relatively constant over the 2 weekday 24-hour periods, (63.3 dBA and 63.7 dBA, respectively). These DNL decreased to 59.8 dBA on the weekend when the level of activity at the Airport was lower.

Because of the limited use of Runway 11-29 during the noise monitoring program, the DNL was 62.5 dBA at Site 8, and 59.4 dBA at Site 5.

Exhibits A through Y in Attachment 2 at the end of this Technical Report provide the hourly measured L10 (the noise level exceeded 10% of the time), the ambient background noise level, or L90 (the level exceeded 90% of the time), hourly Lmax, and Leq for all 20 sites.

COMPARISON OF MONITORED AND INM-PREDICTED SINGLE-EVENT NOISE LEVELS

The FAA Integrated Noise Model (INM) used to develop noise contours for the Airport was to compare individual aircraft overflights, or single-event, noise levels with the results of the noise monitoring program. The detailed grid report function of the INM calculates the noise exposure that individual aircraft contribute to the DNL at selected sites. Because a very large number of aircraft are identified (on the order of 1,000 events per site), this section compares the 10 loudest monitored events with comparable events predicted by the INM.

It should be noted that monitored events reflect the weather and operational conditions at the time monitoring was conducted, while the INM-predicted events reflect annual average conditions. In addition, the INM was used to model 1998 conditions, while noise monitoring was conducted in June 1999. As a result, a one-to-one correlation between the INM-predicted noise events and the monitored events is not possible. Nevertheless, this comparison can provide a useful indication of the correlation between actual and modeled aircraft position, thrust setting, and altitude.

For this analysis, the monitored SEL was compared with the SEL calculated by the INM. As noted earlier, the SEL reflects both the intensity and duration of a noise event. Accordingly, the SEL provides a better estimate of how closely the INM analysis reflects operations during the monitoring period than would Lmax. Comparable monitored and predicted events are determined based on aircraft type, operation (arrival or departure), and runway used.

Table 3 compares the loudest monitored events that could be correlated with specific aircraft overflights at 10 selected sites with the loudest comparable single-events predicted for that site. Figure 9 depicts the 10 sites along with the INM-predicted DNL for 1998 conditions. As shown in Table 3, the difference between monitored and predicted levels show that the INM values are greater than monitored events in some cases and that the reverse is true in others. Overall, the predicted single-events correlate well with the monitored events, general industry guidelines used by the FAA suggest that an agreement of ±3 dBA between INM-predicted and measured noise levels in the vicinity of the DNL 75 contour, and an agreement of ±5 dBA in the vicinity of the DNL 65 contour is acceptable for Part 150 noise modeling purposes.* Greater deviation is expected at levels below 65 DNL. People typically do not perceive changes in sound levels of less than 2 or 3 decibels. These differences between monitored and predicted events are expected.

Attachment 3 presents the eight loudest events that could be correlated with a specific aircraft operation monitored at each of the selected sites. Because detailed flight track information is not available for monitored events, these monitored events could relate to a number of INM events. These INM events are listed for each monitored event. Attachment 4 lists the maximum SEL for every aircraft operation that the INM included in the noise calculation for each of the 20 monitoring sites.

ONE-THIRD OCTAVE BAND NOISE MEASUREMENTS

To better understand the acoustical dynamics of an aircraft overflight, 1/3 octave band noise levels were measured for representative aircraft during departure and arrival operations at Sites 10 and 17. The 1/3 octave band frequency spectrum more clearly describes the various components of the overall noise level by separating out individual frequencies. Figure 10 shows the noise profile for a B727 arrival at Site 17 (a residence north of the Airport on Eastern Parkway) for three specific frequencies, along with the overall A-weighted and C-weighted noise levels. The three frequencies displayed, 31.5-Hz, 250-Hz, and 1,000-Hz, represent typical low, middle, and high frequencies, respectively.

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*American Society of Automotive Engineers, Aerospace Information Report #1845, *Procedures for the Calculation of Airplane Noise in the Vicinity of Airports*, Appendix F, Accuracy of Cumulative Sound Level Measurements.

Table 3

COMPARISON OF MONITORED AND MODELED NOISE EVENTS AT TEN SELECTED NOISE MONITORING SITES

	Noise monitoring data				INM data				
Site	Aircraft	Arrival/ departure	Runway	SEL	Aircraft	Arrival/ departure	Runway	Track	SEL
1	B733 - SW	D	17L	91.6	737300	D	17L	D4	74.4
	B763 - UPS	D	17R	89.1	767CF6	D	17R	D1	81.6
	B72Q - UPS	D	17R	86.7	727EM2	D	17R	D1	91.1
	DC8Q - UPS	D	17L	85.8	DC870	D	17L	D2	82.5
	B741 - UPS	D	17R	85.7	74710Q	D	17R	D1	88.8
	B742 - UPS	D	17R	85.2	74720B	D	17R	D1	90.4
	DC9Q - TW	D	17L	85.2	DC9Q7	D	17L	D1	85.0
	DC9Q - TW	D	17L	85.2	DC9Q7	D	17L	D1	85.0
	DC9Q - TW	D	17L	85.2	DC9Q9	D	17L	D1	88.0
	B752 - UPS	D	17R	84.9	757PW	D	17R	D1	75.9
	B763 - UPS	A	35L	83.3	767CF6	A	35L	A1	85.5
	DC8Q - UPS	D	17R	82.3	DC870	D	17R	D1	85.8
	B752 - UPS	D	17L	81.8	757PW	D	17L	D2	62.4
	B732 - SW	D	17R	81.6	737D17	D	17R	D1	91.0
	MD80 - DL	D	17L	81.5	MD82	D	17L	D1	82.9
	DC9Q - NW	D	17R	81.1	DC9Q7	D	17R	D1	87.3
	DC8Q - UPS	A	35L	80.9	DC870	A	35L	A1	84.6
	B732 - DL	D	17L	80.6	737D17	D	17L	D1	88.5
	B763 - UPS	A	35R	80.5	767CF6	A	35R	A1	74.0
2	DC9Q - US	D	17L	91.7	DC9Q7	D	17L	D1	84.1
	B72Q - DL	D	17L	89.0	727Q15	D	17L	D1	93.2
	DC9 - CO	D	17L	87.1	DC9Q9	D	17L	D1	81.7
	B732 - DL	D	17L	86.7	737D17	D	17L	D1	87.7
	B732 - US	D	17R	86.0	737D17	D	17R	D1	87.4
	B73Q - SW	D	17R	85.3	737QN	D	17L	D1	84.6
	DC9Q - NW	D	17R	85.2	DC9Q7	D	17R	D1	83.8
	DC9Q - US	D	17R	84.8	DC9Q7	D	17R	D1	83.8
3	B733 - SW	D	17R	93.3	737300	D	17R	D1	80.1
	B72Q - DL	D	17L	92.8	727Q15	D	17L	D1	97.1
	B741- UPS	D	17R	91.3	74710Q	D	17R	D1	91.1
	DC9Q - TW	D	17L	90.5	DC9Q7	D	17L	D1	88.3
	MD80 - DL	D	17L	90.0	MD82	D	17L	D1	86.6
	B72Q - DL	D	17L	89.9	727Q15	D	17L	D1	97.1
	B722 - DL	D	17L	89.4	727Q15	D	17L	D1	97.1
	DC9Q - TW	D	17L	89.4	DC9Q7	D	17L	D1	88.3
	LJ23 - GA	D	17L	89.1	LEAR25	D	17L	D1	93.3
5	B742 - UPS	D	35L	95.7	74720B	D	35L	D3	94.1
	B732 - SW	D	35L	91.0	737D17	D	35L	D1	96.3
	DC8Q - UPS	D	35L	86.3	DC870	D	35L	D1	89.7
	B763 - UPS	D	35L	86.2	767CF6	D	35L	D1	87.9
	B763 - UPS	D	35L	86.0	767CF6	D	35L	D1	87.9
	B752 - UPS	D	35L	84.6	757PW	D	35L	D1	82.8
	B763 - UPS	D	35L	83.9	767CF6	D	35L	D1	87.9
	B763 - UPS	D	35L	83.5	767CF6	D	35L	D1	87.9
	B752 - UPS	D	35L	83.4	757PW	D	35L	D1	82.8
	DC8Q - UPS	D	35L	83.2	DC870	D	35L	D1	89.7

Table 3 *(page 2 of 3)*

COMPARISON OF MONITORED AND MODELED NOISE EVENTS AT TEN SELECTED NOISE MONITORING SITES

	Noise monitoring data				INM data				
Site	Aircraft	Arrival/ departure	Runway	SEL	Aircraft	Arrival/ departure	Runway	Track	SEL
6	LJ25 - GA	D	35R	98.0	LEAR25	D	35R	D1	97.4
	B732 - SW	D	35R	95.8	737QN	D	35R	D1	93.9
	LJ24 - GA	D	35R	94.7	LEAR25	D	35R	D1	97.4
	DC9Q - TW	A	17L	94.2	DC9Q7	A	17L	A1	79.3
	DC8Q - UPS	D	35R	91.2	DC870	D	35R	D1	93.4
	MD80 - DL	D	35R	90.9	MD82	D	35R	D1	91.0
	B732 - SW	D	35R	90.8	737QN	D	35R	D1	93.9
	B722 - DL	D	35R	90.0	727Q15	D	35R	D1	102.1
	B73Q - SW	D	35R	89.6	737QN	D	35R	D1	93.9
	B733 - US	D	35R	89.0	737300	D	35R	D1	84.0
	DC9Q - US	D	35R	89.0	DC9Q7	D	35R	D1	91.9
8	B732 - DL	D	17L	93.5	737D17	D	17L	D1	97.4
	B722 - DL	D	17L	91.9	727Q15	D	17L	D1	95.9
	DC9Q - NW	D	17L	90.3	DC9Q7	D	17L	D1	90.3
	B732 - DL	D	17L	89.8	737D17	D	17L	D1	97.4
	B73Q - DL	D	17L	89.2	737D17	D	17L	D1	97.4
	DC9Q - TW	D	17R	87.9	DC9Q7	D	17R	D1	77.1
	B722 - TW	D	17L	87.5	727Q9	D	17L	D4	90.2
	B72Q - DL	D	17L	87.4	727Q15	D	17L	D1	95.9
10	DC9 - TW	D	17L	100.9	DC9Q7	D	17L	D1	91.9
	B722 - DL	D	17L	99.8	727Q15	D	17L	D1	102.0
	DC9Q - TW	D	17L	98.4	DC9Q7	D	17L	D1	91.9
	B72Q - DL	D	17L	96.5	727Q15	D	17L	D1	102.0
	B722 - DL	D	17L	95.9	727Q15	D	17L	D1	102.0
	C130 - MIL	D	17L	94.9	C130	D	17L	D1	88.3
	DC9 - TW	D	17L	92.6	DC9Q7	D	17L	D1	91.9
	B732 - DL	D	17L	92.5	737D17	D	17L	D1	96.3
	B72Q - DL	D	17L	92.2	727Q15	D	17L	D1	102.0
	B722 - TW	D	17L	92.1	727Q9	D	17L	D1	101.8
15	DC9 - TW	D	35R	95.6	DC9Q7	D	35R	D1	87.9
	B763 - UPS	A	17L	87.5	767CF6	A	17L	A1	82.9
	DC8Q - UPS	A	17L	86.9	DC870	A	17L	A1	82.3
	B763 - UPS	A	17L	86.8	767CF6	A	17L	A1	82.9
	C130 - MIL	A	17L	86.0	C130	A	17L	A1	82.1
	B722 - TW	A	17L	85.7	727Q15	A	17L	A1	83.3
	C130 - MIL	A	17L	85.7	C130	A	17L	A1	82.1
	B733 - SW	A	17L	85.6	737300	A	17L	A1	80.3
	MD80 - DL	A	17L	85.3	MD82	A	17L	A1	77.3
	B752 - UPS	A	17L	84.6	757PW	A	17L	A1	81.0

Table 3 *(page 3 of 3)*
COMPARISON OF MONITORED AND MODELED NOISE EVENTS AT TEN SELECTED NOISE MONITORING SITES

	Noise monitoring data				INM data				
Site	Aircraft	Arrival/departure	Runway	SEL	Aircraft	Arrival/departure	Runway	Track	SEL
18	B72Q - DL	A	17R	91.8	727Q15	A	17R	A1	92.0
	B752 - UPS	A	17R	89.7	757PW	A	17R	A1	88.3
	B733 - US	A	17R	89.4	737300	A	17R	A1	87.6
	B735 - SW	A	17R	87.3	737500	A	17R	A2	87.5
	B73Q - DL	A	17R	86.0	737D17	A	17R	A1	88.3
	SF340 - EA	A	17R	84.0	SF340	A	17R	A1	80.3
	LJ25 - GA	A	17R	79.8	LEAR25	A	17L	A1	93.8
	B722 - TW	A	17L	75.9	727Q15	A	17L	A1	71.9
	DC9 - TW	A	17L	75.9	DC9Q7	A	17L	A1	66.7
19	DC8Q - UPS	D	35L	87.6	DC870	D	35L	D1	81.3
	B742 - UPS	A	17L	87.3	74720B	A	17L	A1	86.4
	C130 - MIL	A	17L	84.3	C130	A	17L	A1	79.2
	B742 - UPS	D	35L	83.6	74720B	D	35L	D1	87.9
	B722 - DL	A	17L	82.9	727Q15	A	17L	A1	80.3
	B741 - UPS	A	17L	82.7	74710Q	A	17L	A1	82.5
	B732 - SW	D	35L	82.3	737QN	D	35L	D1	81.8
	B73Q - SW	A	17L	81.0	737QN	A	17L	A1	77.3
	DC8Q - UPS	A	17L	81.0	DC870	A	17L	A1	78.7

CO = Continental Airlines
DL = Delta Air Lines
GA = General aviation
MIL = Kentucky Air National Guard
NW = Northwest Airlines
SW = Southwest Airlines
TW = Trans World Airways
UPS = United Parcel Service
US = US Airways

Note: Aircraft types listed under the noise-monitoring data are obtained from FAA ARTS III data and represent FAA aircraft classifications. Aircraft listed under the INM data are INM equivalent aircraft types as included in the INM database.

Source: Noise monitoring data - KM Chng Environmental, Inc., October 1999.
INM data - Leigh Fisher Associates, December 1999.

Figure 9 1998 Predicted Noise Exposure Contours

As shown on Figure 10, initial noise levels during a B727 arrival overflight are dominated by the middle to high frequencies (250-Hz and 1,000-Hz). However, the 31.5-Hz low frequency noise level clearly dominates once the aircraft passes the receptor location. Similarly, a B727 departure noise profile at Site 10 (an elementary school south of the Airport), shown on Figure 11, also demonstrates this changing frequency characteristic. Again, the middle to higher frequencies dominate at the beginning of the overflight while the lower frequency dominates during the end.

C-WEIGHTED NOISE MEASUREMENTS

Although the A-weighted noise level is typically used to describe the human response to noise events, it emphasize the middle range frequencies to which the human ear is most sensitive. C-weighted noise levels were measured at several locations to account for the low frequency component of aircraft noise. Low frequency noise is of interest because it is associated with structural vibration. As shown on Figures 10 and 11, the C-weighted noise level mimics the low frequency (31.5-Hz) profile for both arrival and departure operations. Similarly, the A-weighted noise level more accurately represents the middle to higher frequencies which correspond better to human response.

The measured range of C-weighted and A-weighted noise levels at each measurement location is shown in Table 4. An average difference between observed individual aircraft noise events was developed to identify the relationship between the A-weighted and C-weighted noise levels. Because the low frequency noise attenuates less than the higher frequencies, receptors located further from an observed aircraft event will demonstrate a larger difference between the A-weighted and the C-weighted noise levels. For example, the average difference between the A-weighted and the C-weighted noise levels at Sites 5 and 12 (located along the sideline of the prevalent runways) ranges from 10 to 12 dB while at Sites 16 and 17 (along the direct flight track to Runway 17L-35R) range from 3 to almost 6 dB. This relationship of distance to the noise source and difference between the overall A-weighted and C-weighted noise levels is further illustrated by the B727 noise profiles shown on Figures 10 and 11. As the aircraft travels further away from the measurement location, not only do the overall A-weighted and C-weighted noise levels decrease but the difference between them increases. In addition, these figures show that, as the aircraft passes the monitor, the difference between A- and C-weighting becomes more pronounced because lower frequency exhaust noise predominates. Table 4 shows that, depending on location, C-weighted noise levels are typically 5 to 10 dB higher than A-weighted levels.

Figure 10 1/3 Octave Band Noise Profile for a B727 Arrival at Site 17

Figure 11 1/3 Octave Band Noise Profile for a B727 Departure at Site 10

Table 4

MEASURED A-WEIGHTED AND C-WEIGHTED NOISE LEVELS AT NOISE MONITORING LOCATIONS

Site #	A-Weighted Lmax	C-Weighted Lmax	Average Difference
1	71-86	79-91	5.5
2	63-85	69-89	8.3
3	71-86	79-91	5.5
4	75-85	82-91	6.0
5	62-88	80-97	11.6
6	68-93	75-100	7.2
7	72-80	79-83	4.8
8	66-90	77-94	7.2
9	72-89	78-91	6.5
10 *(a)*	71-85	78-88	5.0
11 *(b)*	71-85	78-88	5.0
12	69-86	75-92	10.0
13 *(c)*	71-85	78-88	5.0
14	72-83	82-92	11.2
15	75-86	83-91	6.3
16	75-90	91-93	5.5
17	81-91	84-93	3.1
18	71-85	78-88	5.0
19	67-79	78-90	8.2
20	67-82	82-88	9.3

(a) Equivalent levels were used since C-weighted levels were not measured at this site. Levels equivalent to Site 3 due to proximity.
(b) Equivalent levels were used since C-weighted levels were not measured at this site. Levels equivalent to Site 18 due to similar distance from the Airport.
(c) Equivalent levels were used since C-weighted levels were not measured at this site. Levels equivalent to Site 18 due to proximity.

Source: KM Chng Environmental, Inc., October 1999.

NOISE INDUCED VIBRATION

A recent study conducted at Boston Logan International Airport* identified the relationship between aircraft noise levels and the potential for noise induced vibration. Noise induced vibration, which may occur when the frequency of the noise source physically "excites" household objects, may cause windows, walls, and floors to rattle or vibrate.

A number of studies have been conducted over the past several decades to investigate the human perception of vibration as well as the response of structures to noise-induced vibration. Several important findings have come out of this research. First, the human perception threshold of vibration is far below the level needed to initiate surface cracking in structures. Second, the vibration level required to induce secondary acoustic emissions is also far below that needed to initiate cracking. Third, aircraft sound levels, even those very near an airport are of insufficient magnitude to approach damage risk criteria, even though they can be of sufficient intensity to cause audible and visible evidence of vibration.

Figure 12 shows 1/3 octave band sound levels measured at Site 17 from a B727 aircraft during arrival. Although the center frequency for each 1/3 octave band is plotted, the labels at the bottom of the figure represent whole octave intervals. Superimposed on this figure are additional sets of curves. The lower set of curves show the approximate onset of structural vibration for various interior surfaces. The more the measured sound levels exceed the curve, the greater the chance that vibration will be noticed inside the structure. These curves show average values over a number of construction types (wood, masonry, etc.). Specific construction types may vary. The figure shows that the measured 1/3 octave band sound levels at Site 17 from a B727 aircraft during arrival, exceeds the onset of vibration that could cause the windows and walls of a structure to vibrate.

The upper curve identifies a sound level threshold below which there has been shown to represent little, if any, noise-induced vibration damage risk. The measured B727 aircraft 1/3 octave band sound levels are so far below the minor damage threshold curve such that it is reasonable to conclude that the risk of damage from noise-induced vibration is not an issue. Similarly, Figure 13 shows the measured 1/3 octave band sound levels measured at Site 10 from a B727 aircraft during departure. Again these levels are well below the damage risk threshold, but exceed the onset of vibration that could cause the windows and walls of a structure to vibrate.

As noted earlier, the C-weighted noise level reflects the characteristics of low frequency noise because 1/3 octave band data was obtained at Sites 10 and 17 only, the measured C-weighted noise levels were used to determine whether the potential for noise induced vibration exists at the other receptor locations. Therefore, as

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**Logan Low-Frequency Noise Study*, HMMH, Inc., June 1996.

Figure 12 Noise Induced Vibration During a B727 Arrival at Site 17

Figure 13 Noise Induced Vibration During a B727 Departure at Site 10 shown in Table 5, the C-weighted noise levels measured at the other receptor locations was used to determine whether the onset of noise induced vibration may occur. Based on the measurement results, the potential for windows to rattle due to noise induced vibration exists at all receptor locations included in the monitoring program. The potential for wall and floor noise induced vibration, which require a higher threshold of low frequency noise, are expected as well at several receptor locations. As noted above, there is no likelihood of structural damage from aircraft noise induced vibration at any site.

Table 5

MAXIMUM OBSERVED AIRCRAFT NOISE LEVELS AND THE POTENTIAL FOR NOISE INDUCED VIBRATION AT EACH NOISE MONITORING LOCATION *(a)*

Site #	Description	Event Lmax *(b)* dBA	Event Lmax *(b)* dBC	Vibration onset *(c)*
1 *(d)*	10912 National Turnpike Drive	86	91	Windows, walls
2	4507 Summers Drive	86	89	Windows
3	3206 Hillview Drive	86	91	Windows, walls
4	Fairdale High School	85	91	Windows, walls
5	163 East Ashland Avenue	90	97	Windows, walls
6	927 Mulberry Street	83	100	Windows, walls, floors
7	607 Penguin Street	78	84	Windows
8	2824 Deshler Drive	87	94	Windows, walls
9	2810 Park Lawn Drive	79	94	Windows, walls
10 *(e)*	Minor Lane Elementary School	86	88	Windows
11 *(f)*	111 West Hill Street	86	88	Windows
12	Evergreen Cemetery	79	92	Windows, walls
13 *(f)*	1458 Ouerbacker Court	86	88	Windows
14	10107 Caven Avenue	77	92	Windows, walls
15	605 West Main Street	86	91	Windows, walls
16	3336 Robin Road	80	93	Windows, walls
17	840 Eastern Parkway	90	93	Windows, walls
18	1629 South 3rd Street	86	88	Windows
19	2606 Maplewood Drive	79	90	Windows, walls
20	2911 South 4th Street	81	88	Windows

(a) The relationship between overall C-weighted noise level and the 31.5 Hz octave band noise level was used to assess the potential for noise induced vibration.

(b) Maximum measured event noise levels reported are based on the low frequency dominated C-weighted noise level.

(c) The threshold for the onset of vibration is approximately 80 dBC for windows, 90 dBC for walls, and 99 dBC for floors.

(d) Equivalent levels were used since C-weighted levels were not measured at this site. Levels equivalent to Site 3 due to proximity.

(e) Equivalent levels were used since C-weighted levels were not measured at this site. Levels equivalent to Site 18 due to similar distance from the Airport.

(f) Equivalent levels were used since C-weighted levels were not measured at this site. Levels equivalent to Site 18 due to proximity.

Source: KM Chng Environmental, Inc., October 1999.

Attachment 1

MEASURED NOISE EVENTS MATCHED WITH ACTUAL AIRCRAFT OPERATIONS

Attachment 2

HOURLY MEASURED NOISE LEVELS

(Exhibits A through Y)

Attachment 3

COMPARISON BETWEEN MONITORED AND MODELED SINGLE EVENTS

Attachment 4

INM PREDICTED MAX SEL AT ALL 20 NOISE MONITORING SITES