Study of Low Frequency Takeoff Noise at Baltimore - Washington International Airport

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1. EXECUTIVE SUMMARY

This study had 3 objectives:

1. Quantify the start of takeoff sound levels at a house in the Allwood area adjacent to Baltimore-Washington International Airport,
2. Quantify a resident's judgement of these start of takeoff sound levels, and
3. Measure the propagation rate into the community of the start of takeoff sound levels.

These objectives were met through continuous monitoring of sound levels at three different houses near Baltimore-Washington International Airport (BWI) and having one of the homeowners rate the objectionable quality of many of the start of takeoff sound events. Additionally, at the closest home, wall vibration data were measured for many of the events, and full frequency tape recordings made of a sample of takeoff sound events.

General conclusions from this study may be summarized as follows:

1. Automated measurement of takeoff event sound levels is not reliable; many of the events occur too close in time to permit standard identification using fixed threshold exceedence as an indicator of start and end of event. That is, using a fixed threshold could result in more than one takeoff being included in one measured "event".

2. It appears that, though low frequency sound energy is important in determining how a person may react to the noise, higher frequencies also play a role - if there is enough energy in the higher frequencies, events can also be bothersome. In other words, human reaction does not depend totally on the low frequency content of the event.

3. C-weighted metrics (Lmax and SEL) correlate better than the same A-weighted metrics with human judgements of the objectionable degree of an event.

4. Maximum wall vibration levels (max rms particle acceleration) correlate strongly with C-weighted maximum outdoor sound levels, and do so somewhat better than with maximum A-weighted levels.

5. The average drop off of C-weighted maximum levels, from Site 7 at 3200 feet from Runway 28 to Site 3 at 7800 feet is very close to "spherical spreading" - that is, the maximum C-weighted levels drop about 6 dB for each doubling of distance.

6. The homeowner ratings of the events, (ratings from 0 to 100, higher ratings signifying the more objectionable events) together with simultaneous sound measurements of the events can be used to estimate how this homeowner (or a person of similar sensitivity to the events) might rate the events as heard at greater distances from the airport. The homeowner, living in a home approximately 3200 feet from the runway, rated about 75% of the events as more objectionable than 40. If the same resident lived at the furthest measurement site, about 7800 feet from the runway, approximately 50% of the events would be rated as more objectionable than 40.

2. INTRODUCTION

Residents of the community of Allwood, northeast of Baltimore-Washington International Airport (BWI), have long been concerned about the sound levels they regularly experience from jet aircraft departing on Runway 28, see Figure 1, page 5. In 1990, portions of Allwood were computed to lie outside the "Airport Noise Zone" - a contour of sound exposure computed with the Federal Aviation Administration's (FAA's) Integrated Noise Model (INM). Measurements made by the Maryland Aviation Administration (MAA) in these portions consistently showed levels in Allwood to be higher than the computed levels. As a consequence, MAA and FAA jointly funded a study of the start-of-takeoff sound levels, a report was produced[1], and the INM was ultimately revised to more accurately compute sound levels in this region around an airport.

After revision of the INM and computation of sound exposure contours, some of the residences in Allwood fell within the Airport Noise Zone and, according to MAA policy, were then eligible for sound insulation. Sound measurements made before providing sound insulation showed in some residences that indoor criteria (achieving a Day-Night Average Sound Level, DNL, of 45 dB in all habitable rooms[2]) were met without additional sound insulation. However, MAA staff making the measurements noted that aircraft noise levels sounded loud, and that the houses seemed to vibrate. Similar observations and studies made at other airports[3] suggested that the standard A-weighted method of measurement did not fully account for the perceived effects of takeoff noise, and MAA and FAA elected to conduct this study of sound levels, vibration levels and human judgement of sound levels in and near Allwood.

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[1] Horonjeff, R.D., "Analysis of Aircraft Noise Levels in the Vicinity of Start-of-Takeoff Roll at Baltimore-Washington International Airport," FAA-EE-92-01, May 1992.

[2] FAA Order 5100.38A, "Airport Improvement Program (AIP) Handbook, Chapter 7, Section 2, Noise Compatibility Projects.

[3] San Francisco International Airport: Alverson, S.R., *et al*, "Development of Single Event Noise Metrics for use in Identifying Aircraft Operations for Possible Mitigation," HMMH Report No. 294090, January 1996.

Boston Logan International Airport: Horonjeff, R.D., *et al*, "Logan Low-Frequency Noise Study," HMMH Report No. 293810.04, June 1996.

2.1 Objectives

This study had 3 objectives:

1. To quantify takeoff sound levels in the Allwood area,
2. To quantify the human judgement of takeoff sound levels, and
3. To determine the propagation rate of C-weighted sound levels.

2.1.1 Quantify Takeoff Sound Levels in Allwood

Similar studies[3] have shown that takeoff sound can have considerable energy in the lower frequencies which may add to the perceived loudness and produce the vibration of structures. Because A-weighted levels de-emphasize the lower frequencies and C-weighted levels do not, the study was conducted to measure C-weighted levels of start-of-takeoff noise in the Allwood area, as well as A-weighted levels. Additionally, wall vibration levels were also measured, and sample tape recordings made to capture the full frequency information about representative departures.

2.1.2 Quantify Human Judgement of Sound Levels

Since no data exist that correlate the aircraft noise events with human perception of the events, one person, who resides in the Allwood area, rated events while noise monitors acquired sound and vibration data inside and outside that person's residence. The homeowner was instructed to use a scale of 0 to 100 for rating the least to most objectionable events, generally using multiples of 10 in assigning ratings. It was suggested that they should try to use ratings of 10 to 90 for least to most objectionable so that there would be "room" for the rare exceptionally quiet or exceptionally objectionable events. A few events were rated between the multiple of 10 ratings and denoted by ending in 5. Appendix A details the instructions given to the person rating the events.

2.1.3 Determine Propagation Rate

To determine how C-weighted levels propagate in residential communities, three noise monitors were placed in the Allwood area at varying distances along a line from the start-of-takeoff roll at the end of Runway 28, Figure 1.

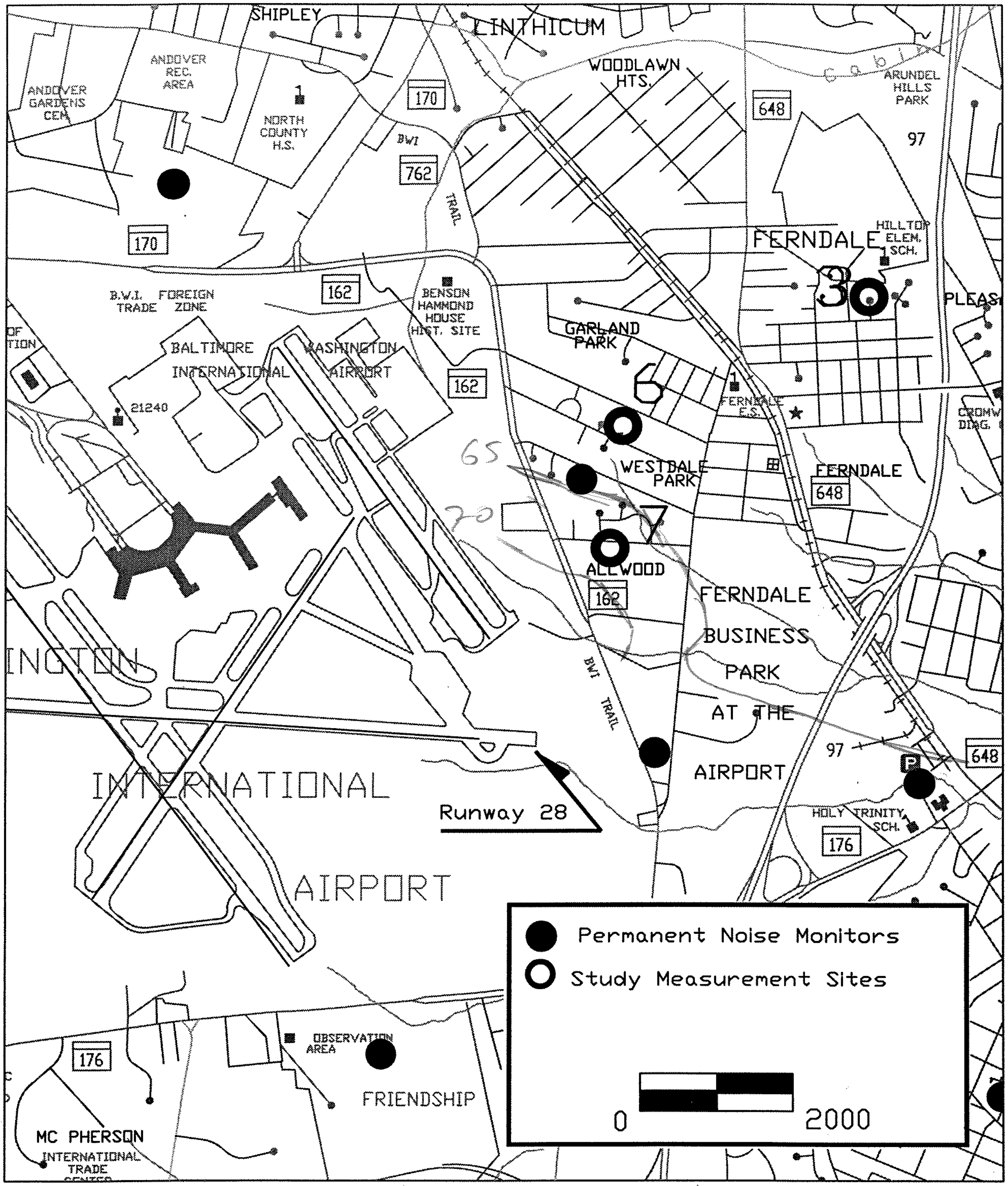

Figure 1. BWI Airport Area Layout Map with Measurement Sites

2.2 Method

To complete the objectives, three measurement locations in the Allwood area were required; one location close in to the start-of-takeoff roll with a detailed measurement scheme, and two further out locations. The residence of the person rating the events was selected for the close in location, Site 7, Figure 1. At this measurement location a total of five (5) noise monitors were utilized; A-weighted and C-weighted sound levels outside the residence, C-weighted sound level inside the residence, un-weighted vibration levels on the south wall (facing the airport) and on the east wall of the residence. Only C-weighted sound levels were obtained at the two further out locations using similar noise monitors. Sample simultaneous indoor and outdoor tape recordings were also made at Site 7.

3. METHOD

Three measurement locations were selected to be on, or nearly on, a line oriented approximately 120° from the Runway 28 heading, see Figure 1. The three locations along the line were at distinct distances away from the start-of-takeoff roll, as given in Table 1. The two further out locations were intended solely for the purpose of determining the propagation rate of C-weighted sound levels when used in conjunction with the outside C-weighted levels at the innermost location. The closest location to the start-of-takeoff roll, Site 7, was used to quantify the takeoff sound levels that correspond with the human judgements of those levels. A total of seven (7) monitors were utilized to accomplish this objective; five (5) at the nearest location and one (1) at each of the remaining two locations. The two further out monitors were setup to measure continuous C-weighted sound levels and to capture C-weighted noise events, whereas the closest location monitors were set up to measure C- and A-weighted sound levels and un-weighted, or flat, vibration levels as given in Table 1.

Inside the residence, measurements were made in the living room where the resident rated aircraft takeoff events.

Table 1. Measurement Locations and Data Acquired at Each Site

Site Number	Distance from Start of Runway 28	Quantities Measured @ Monitor #:
7	3200 ft	**Outdoors** 7 C-weighted, continuous; Sample tape recordings. 4 A-weighted, events. **Indoors** 8 C-weighted, continuous; Sample tape recordings. 1 Vibration, south wall. 2 Vibration, east wall.
6	4600 ft	6 C-weighted, continuous.
3	7800 ft	3 C-weighted, continuous.

4. RESULTS

Data analysis lead to three basic results:

1. Outdoor C-weighted Lmax is identified as the preferred metric for evaluating takeoff sound levels for correlation with human judgements;
2. Measured vibration levels support the use of C-weighting to quantify the effccts of start of takeoff sound levels;
3. The propagation rate of C-weighted Lmax sound levels was determined through and beyond the Allwood area.

4.1 C-weighted Lmax Sound Levels

4.1.1 Initial Analysis

The first step in determining the preferred metric for evaluating the takeoff noise events was to correlate the resident rated events with the various measured events at the residence. The rated event data were entered into a spreadsheet and the times of the rated events were automatically correlated with the noise monitor event Lmax times. A filtering method was used on the correlated data to discard invalid matches due to event length and/or the time difference between the event Lmax time and the rated event time. The valid data were then plotted with the rating as the dependant variable. The plots showed no direct correlation of event rating to sound or vibration level, see Figure 2 as an example.

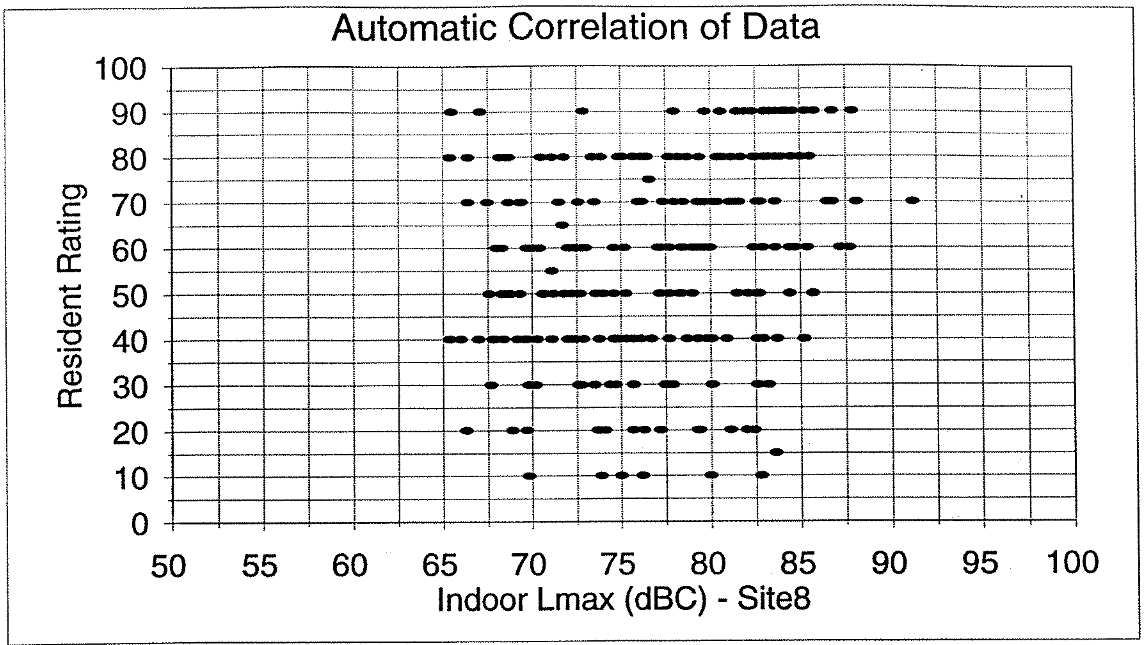

Figure 2. Resident Rating versus Indoor C-weighted Lmax - Auto Correlated

As an attempt to understand the ratings assigned to each event, the tape recordings of departures were used to playback a sample of events and listen to them in the laboratory. A total of 14 rated events were recorded, put on a demonstration tape, and listened to in a small room with the output calibrated to approximate the level actually heard indoors by the resident. Figure 3 shows the C-weighted Lmax level of these events and the ratings assigned by the resident. Three consultants independently listened to the tape and rated the events as they listened. This test resulted in the conclusion that the events were rated similarly by everyone; the higher rated events were rated higher by the listeners as well. The recordings were also analyzed for frequency content using a Larson-Davis 2900 spectrum analyzer. The analysis confirmed the existence of low frequency content in the data; the reason for measuring with C-weighting. Figures 4, 5, and 6 show the frequency content of three of the events labeled 1, 2, and 3 in Figure 3. Figures 7, 8, and 9 show the corresponding time histories.

Figure 4 shows the spectra for event number 1, rated as 80 and Figure 5 shows this information for event 2, rated 90. Interestingly, the C-weighted values for both events are almost identical, while the higher rated event, event 2, has higher A-weighted levels. Though this result may be true for only some events, it suggests that more than low frequency noise contributes to the overall rating of an event. It is likely that when events are loud enough, a wide range of frequencies contribute to the human judgement of the objectionable quality of the sound.

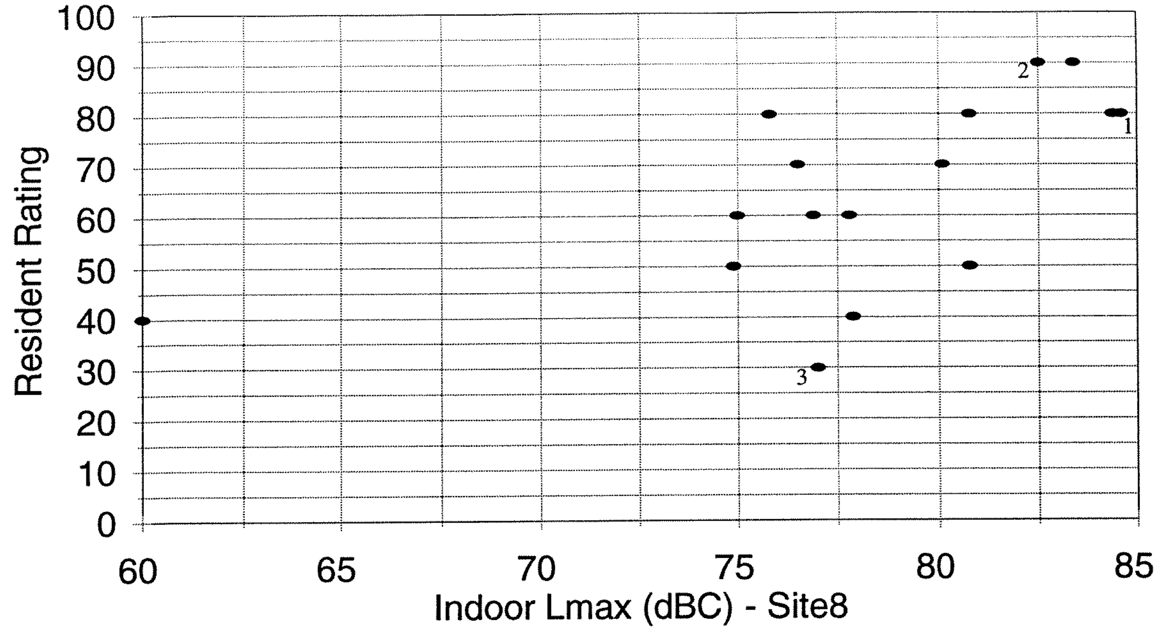

Figure 3. Resident Ratings of Tape Recorded Events versus Indoor C-weighted Lmax

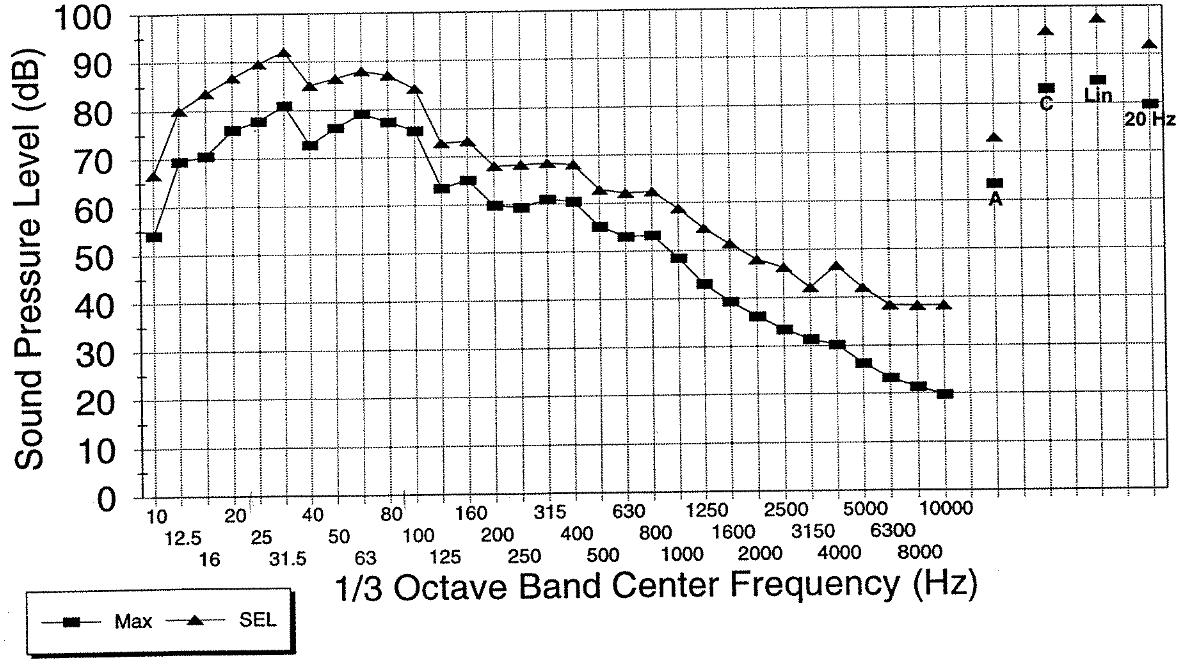

Figure 4. Spectra of Tape Recorded Event 1 - Resident Rating of 80

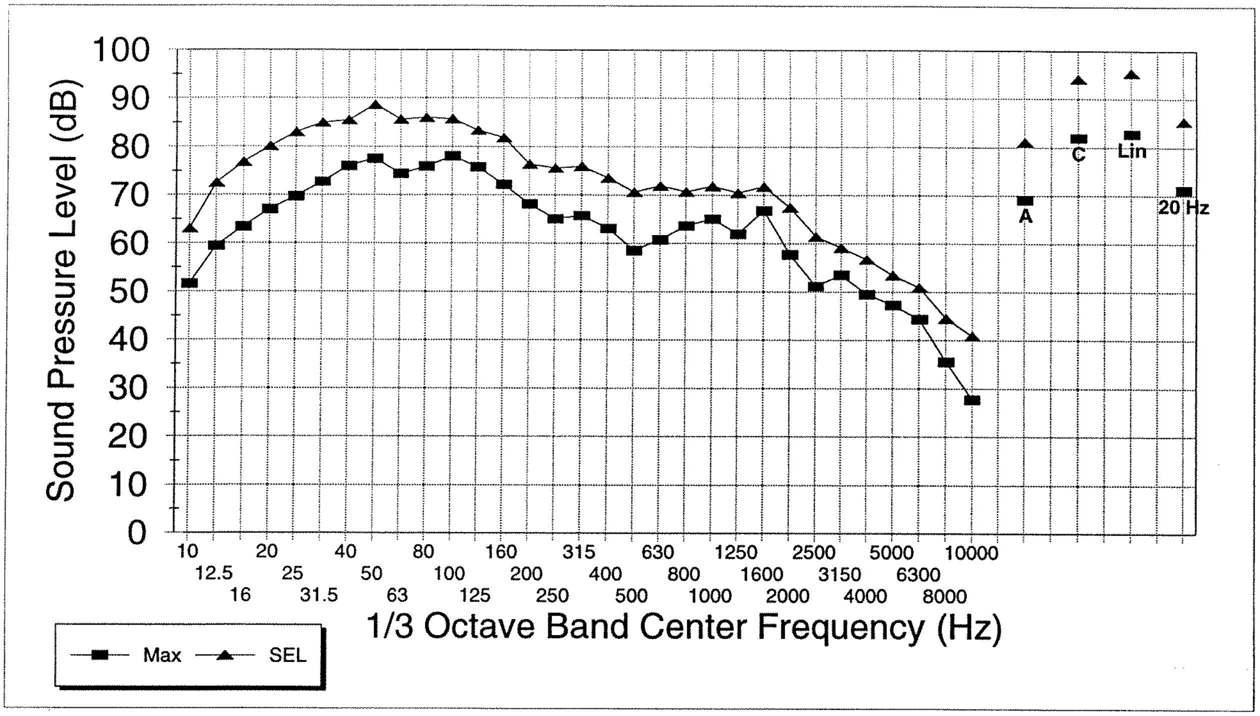

Figure 5. Spectra of Tape Recorded Event 2 - Resident Rating of 90

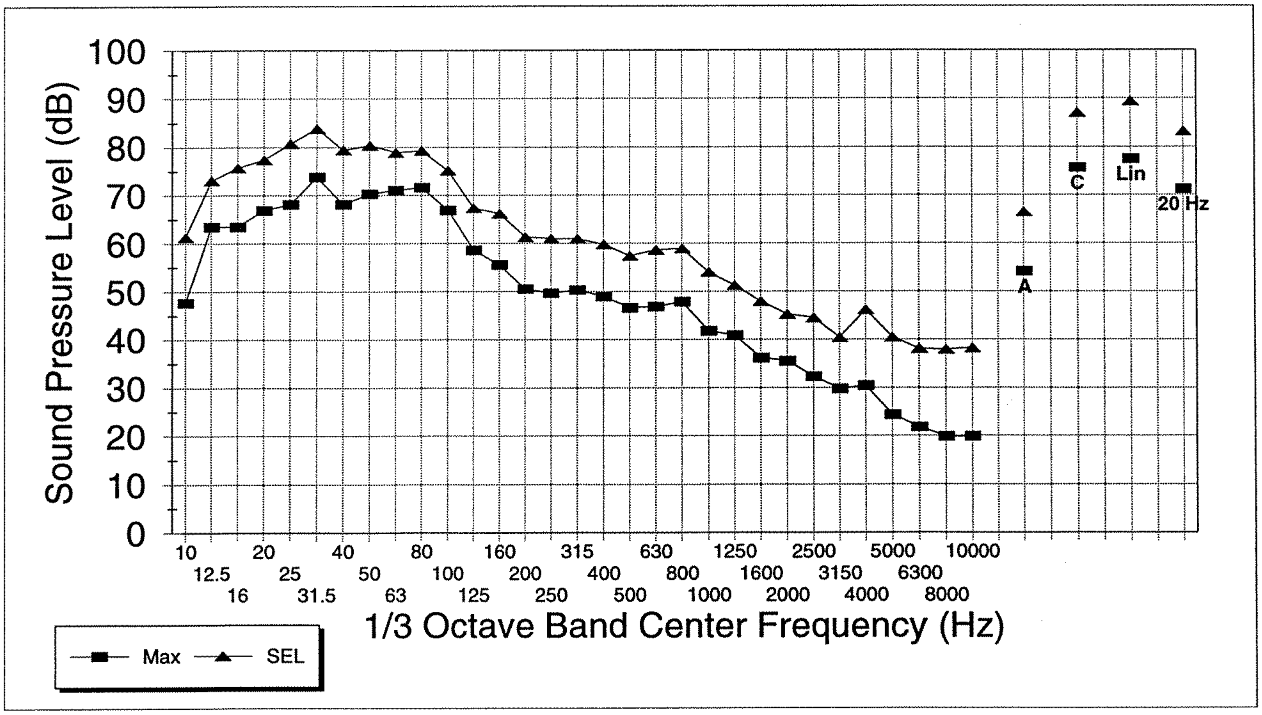

Figure 6. Spectra of Tape Recorded Event 3 - Resident Rating of 30

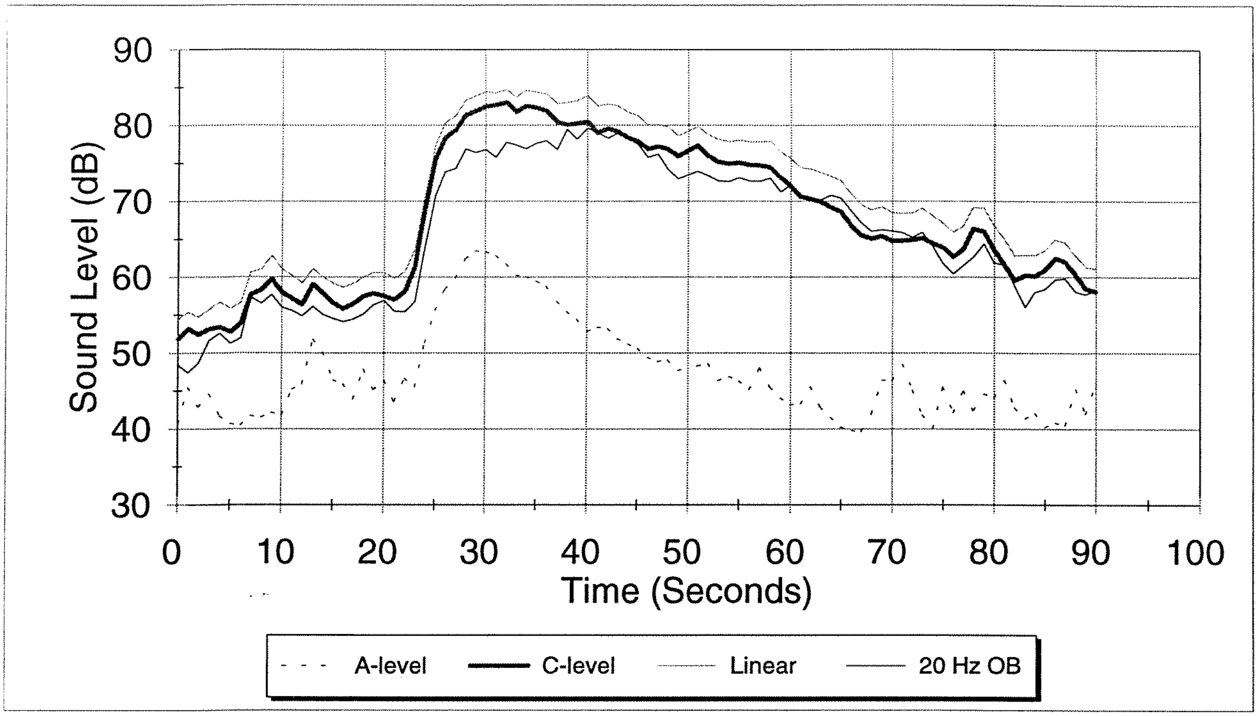

Figure 7. Time History of Tape Recorded Event 1 - Resident Rating of 80

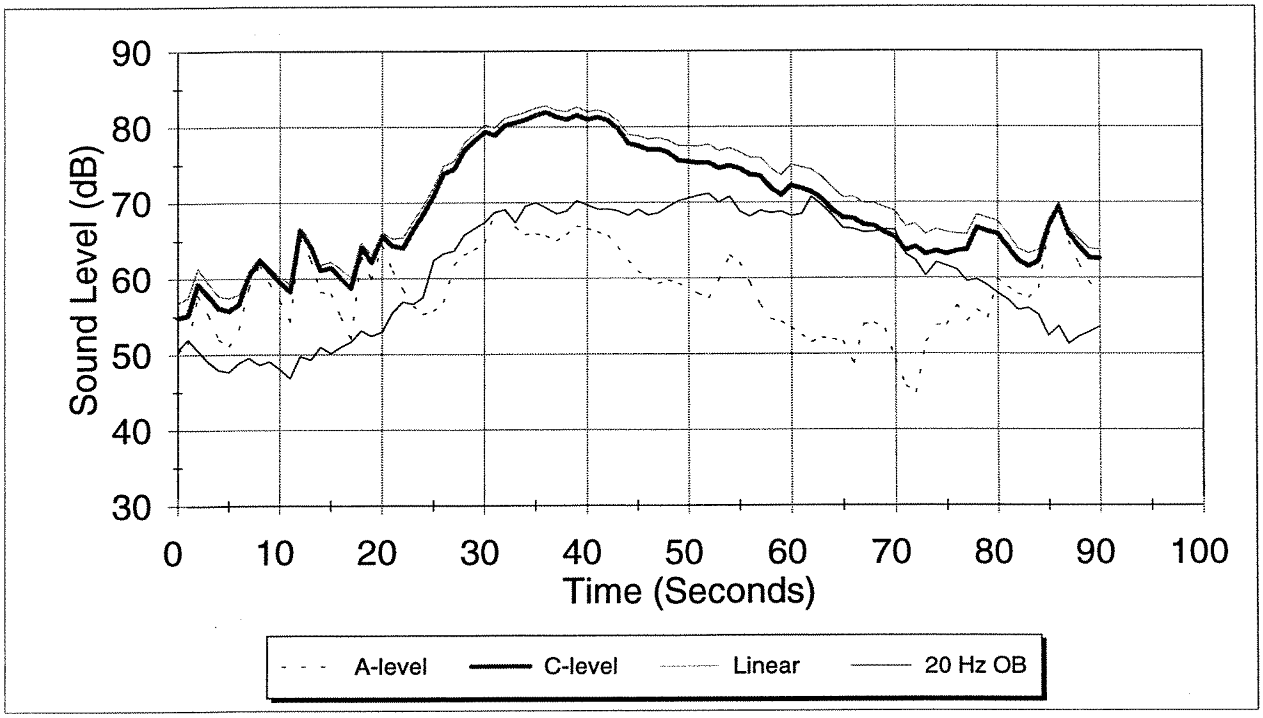

Figure 8. Time History of Tape Recorded Event 2 - Resident Rating of 90

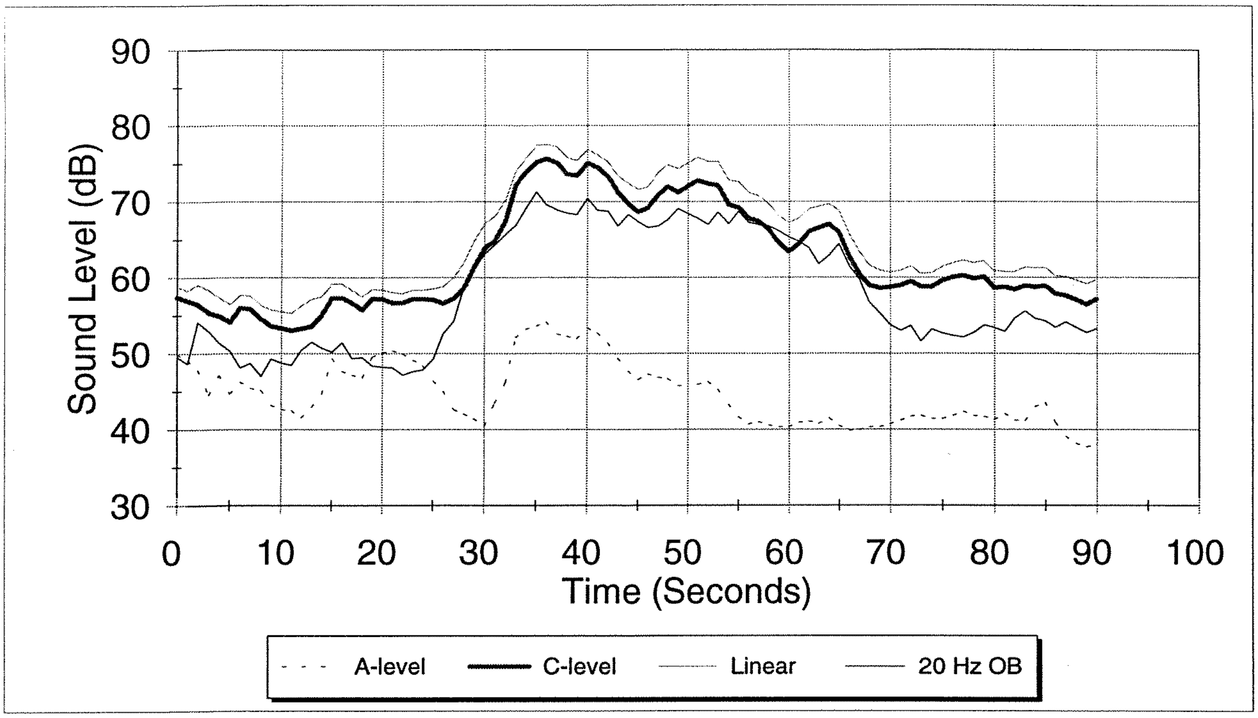

Figure 9. Time History of Tape Recorded Event 3 - Resident Rating of 30

Because the resident ratings of the 14 recorded events seemed consistent with the judgements we made, that is, the events that sounded louder to us also received the higher ratings by the resident, we concluded that the lack of correlation with the sound levels shown in Figure 2 could be due to the imprecision of the automated identification of events. In other words, the events of Figure 2 might be incorrectly associated with the ratings, or the automated event identification could have grouped more than one takeoff in an "event". This listening trial also confirmed for us that there did not seem to be any unusual qualities of the sound, such as loud rattle, that might affect the ratings.

Consequently, we elected to use a non-automated approach to identify and compute the desired sound level metrics for a larger set of rated events. HMMH software was used that displays the monitored time histories on-screen and permits user-selection and calculation of metrics for any chosen time interval. Such an approach permits detailed identification and quantification of closely spaced events.

Two days were selected that had a wide range of ratings and a large number of rated events; August 25th and 26th, 1997. For each rated event, the continuous time histories from each monitor that acquired full time histories were viewed and analyzed for SEL and Lmax. For the monitors without full time histories, the single event data were reviewed and for every event that correlated with a rated event and had a reasonable event length and Lmax time, the SEL and Lmax for the event were recorded[4]. This two-day period of data showed stronger correlation with the ratings. The ratings versus the measured data for this two-day period are presented in Figures 10-17.

Inspection of these plots suggests that the best correlation of metrics with the ratings appears to be the outside C-weighted Lmax and SEL, and the South Wall vibration levels. This correlation is judged by looking for the most defined pattern between rating and metric. In these cases, the pattern is one with points plotting from the lower left (low rating, low level) to the upper right (high rating, high level). To mathematically confirm this presumed correlation using a larger data sample, additional days of data were analyzed.

Specifically, additional data were reduced to permit a more rigorous analysis of the following relationships:

1. Resident rating compared with outdoor A-weighted Lmax.
2. Resident rating compared with outdoor C-weighted Lmax.
3. South wall vibration levels compared with outdoor A-weighted Lmax.
4. South wall vibration levels compared with outdoor C-weighted Lmax.

The outdoor levels are chosen because of the (relative) ease of measuring and predicting them as compared with interior levels. Also, listening to tape recordings of the interior sounds showed that other noise sources (television, radio and voices) may have affected the measured indoor levels. The comparison of resident ratings with outdoor sound levels is presented below in Section 4.1.2.

The vibration levels of the south wall are of primary interest because this wall faces the runway, and it is the one for which the vibration levels appear better correlated with resident ratings, compare Figures 16 and 17. Comparison of measured wall vibration and outdoor sound levels is of value because if they are closely correlated, then they may be used interchangeably in analysis. For example, to the extent that C-weighted levels correlate with south wall vibration, then the C-weighted levels predict the vibration levels and can substitute for them. Further, if C-weighted levels correlate with the ratings, then it can be inferred that the vibration levels will also correlate with the ratings. These vibration levels are discussed in detail below in Section 4.2.

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[4] Monitors 7, 8, and 3 ran continuous time histories; monitors 4, 1, and 2 were triggered by monitor 7 and recorded data only when the outside C-weighted level exceeded 65 dB(C).

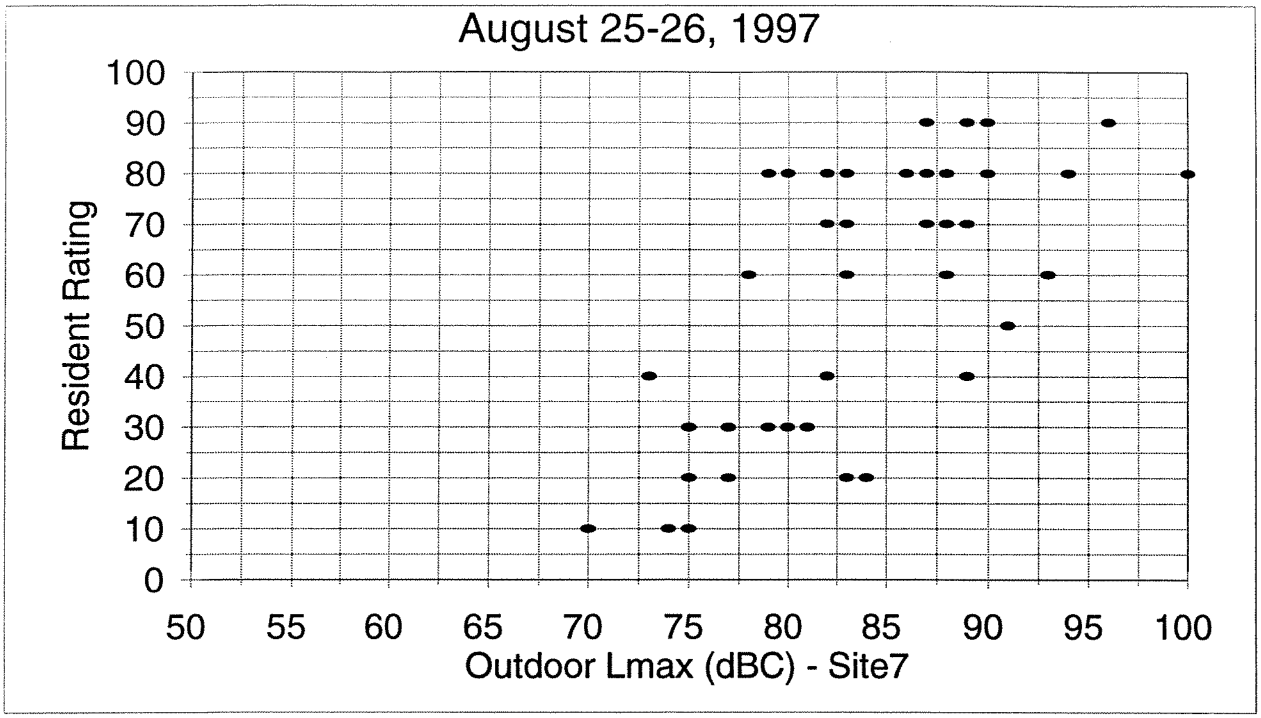

Figure 10. Resident Rating versus Outdoor C-weighted Lmax - Two Days

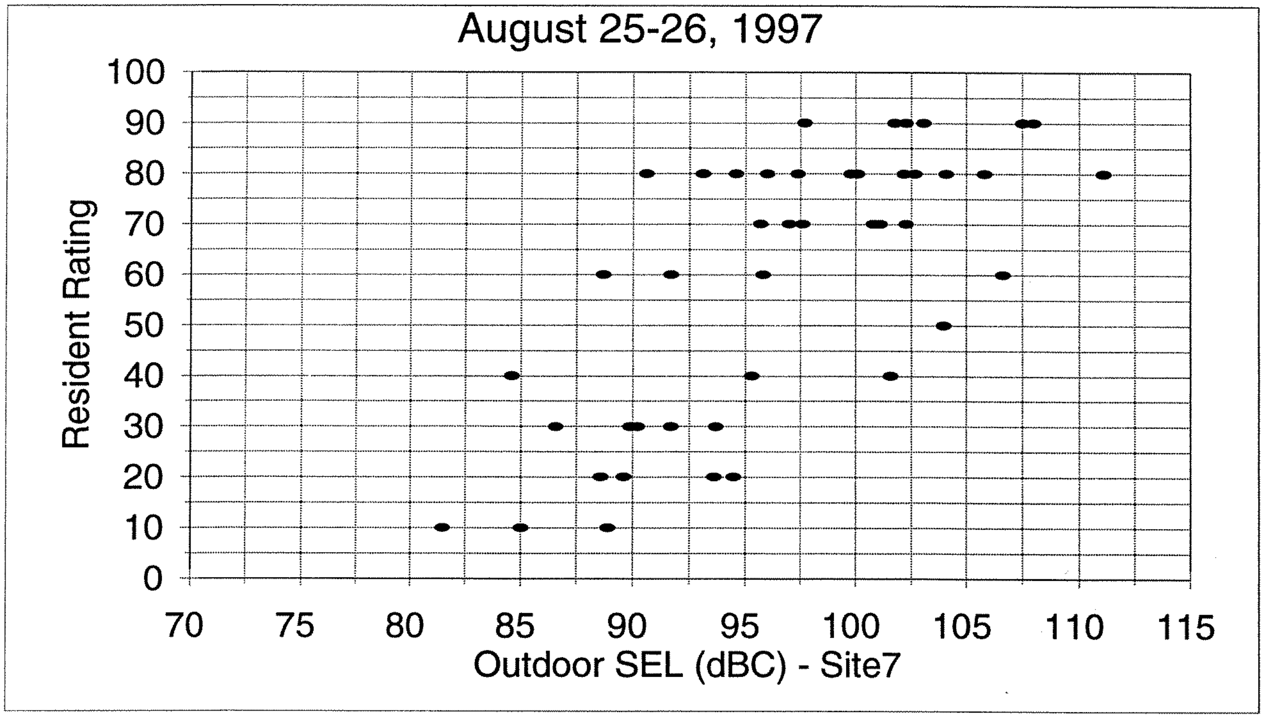

Figure 11. Resident Rating versus Outdoor C-weighted SEL - Two Days

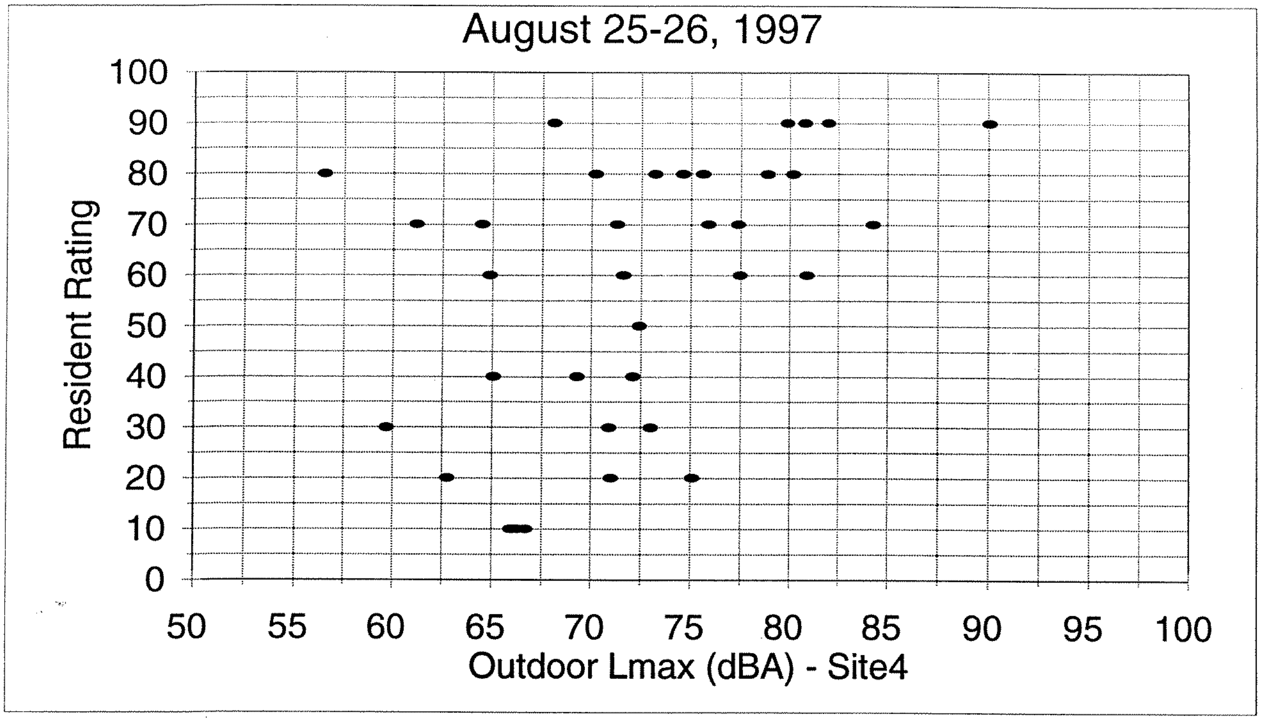

Figure 12. Resident Rating versus Outdoor A-weighted Lmax - Two Days

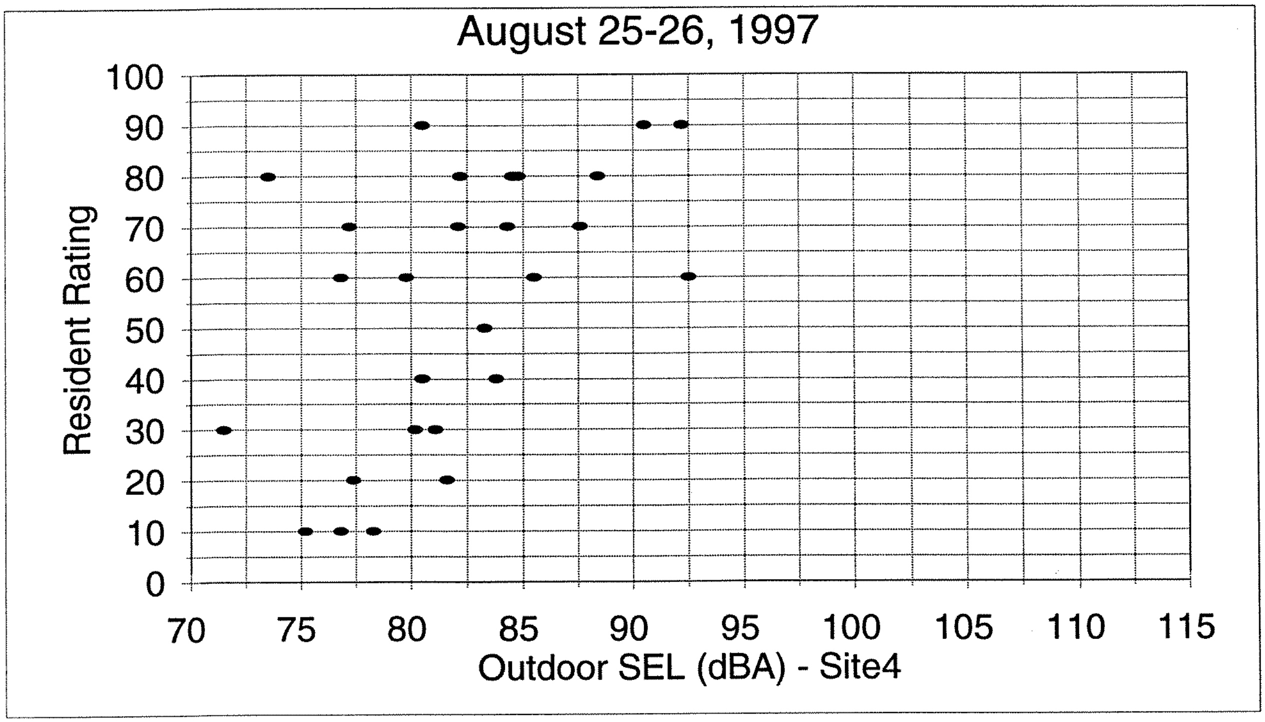

Figure 13. Resident Rating versus Outdoor A-weighted SEL - Two Days

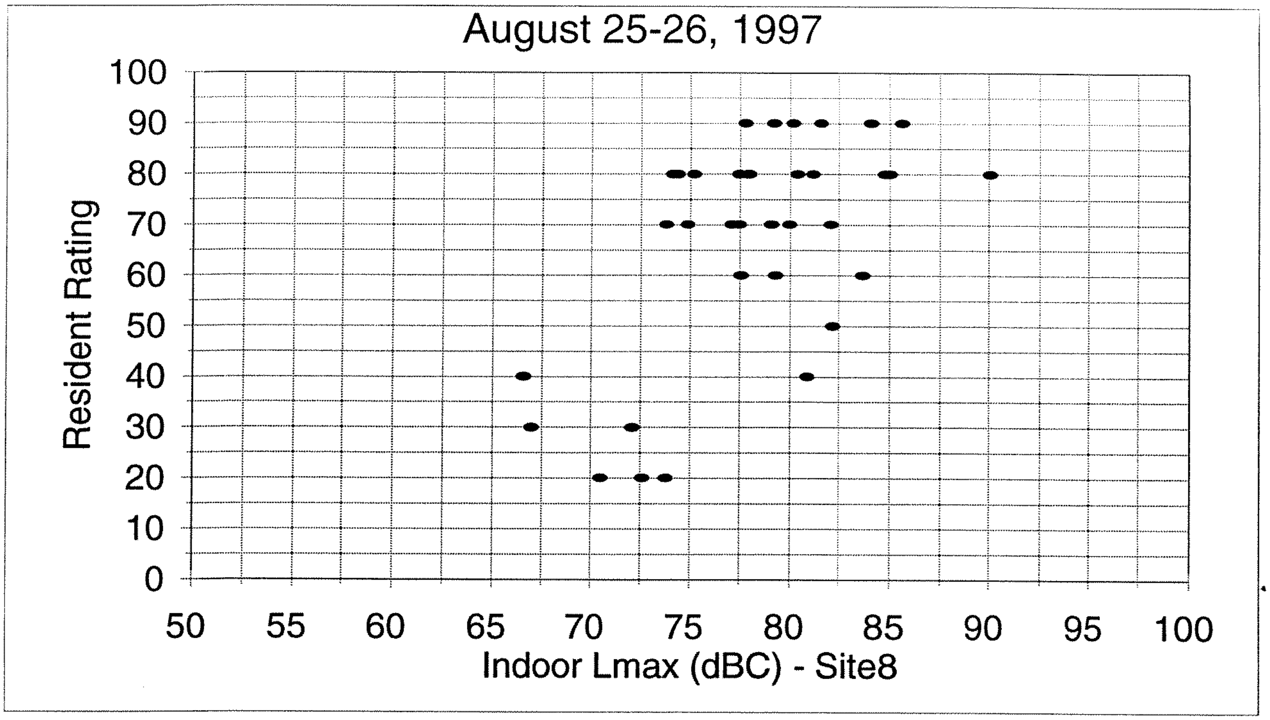

Figure 14. Resident Rating versus Indoor C-weighted Lmax - Two Days

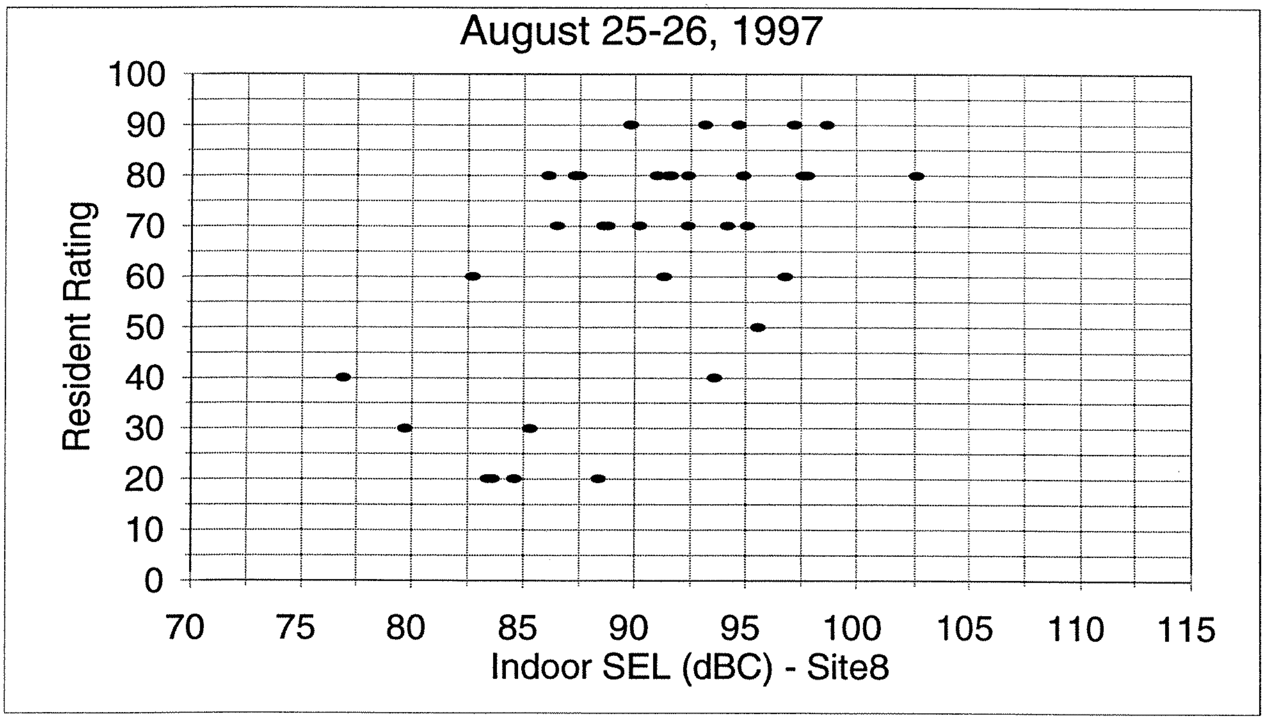

Figure 15. Resident Rating versus Indoor C-weighted SEL - Two Days

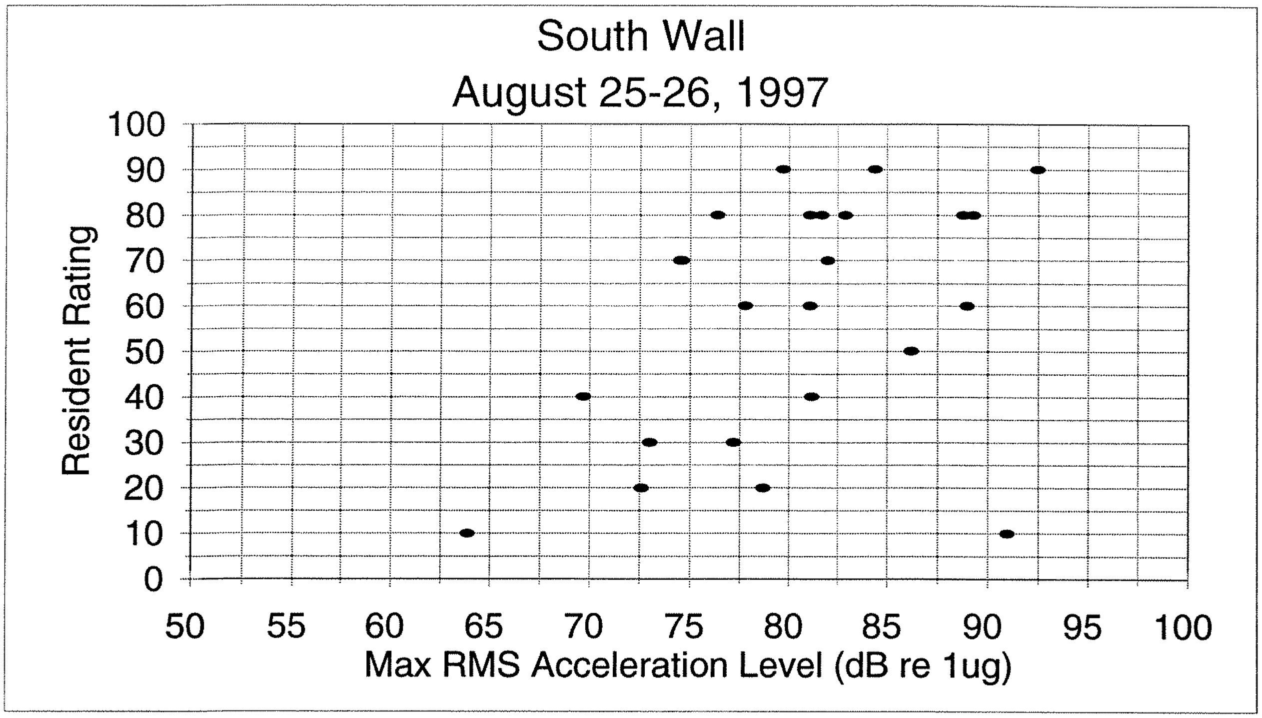

Figure 16. Resident Rating versus South Wall Maximum Acceleration Level - Two Days

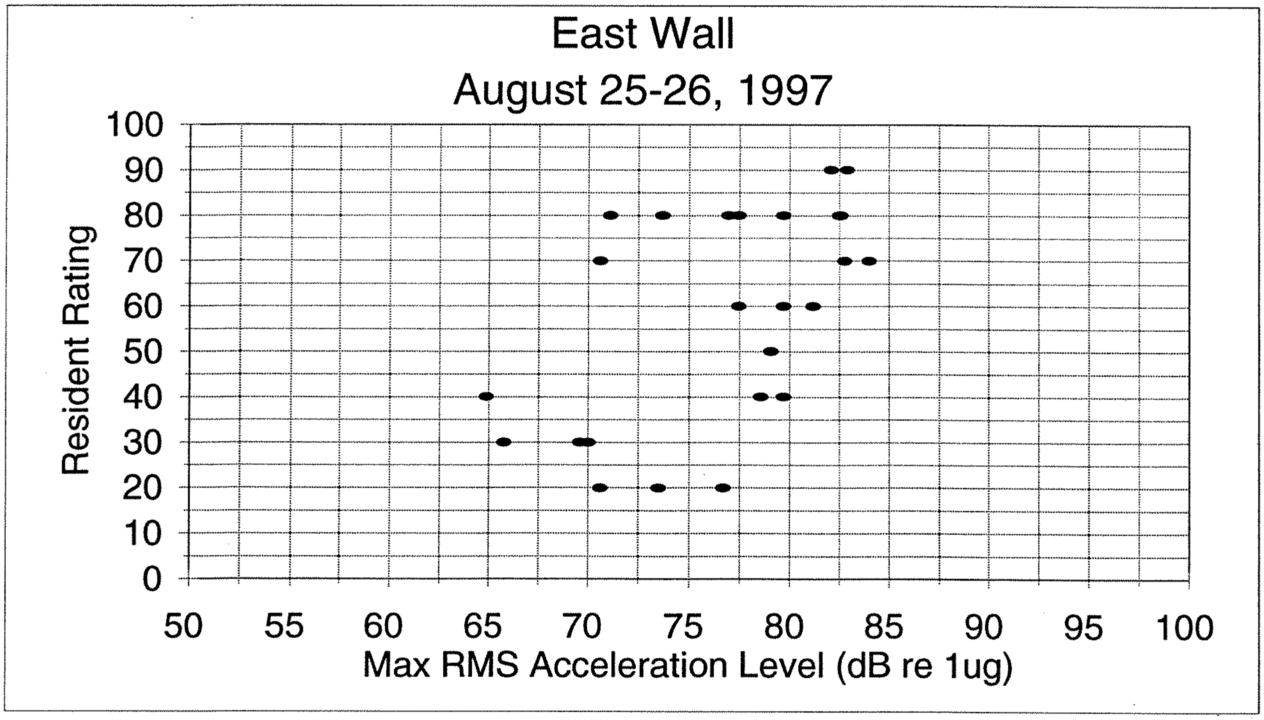

Figure 17. Resident Rating versus East Wall Maximum Acceleration Level - Two Days

4.1.2 Refined Analysis

Events were visually identified and metrics computed for another 4 days of data, a total of six days: August 21st, 22nd, 25th, 26th, 27th, and 28th, 1997. From the six day period, it was confirmed that the A-weighted levels did not correlate with the ratings as well as did the C-weighted levels, see Figures 18 and 19. Logically, for correlation of a metric with the ratings, low values of the metric should correspond to low ratings, and high values to high ratings. Though high values of both A-weighted and C-weighted Lmax in Figures 18 and 19 tend to correspond with high ratings, only the C-weighted values demonstrate a consistent pattern from high values / high ratings to low values / low ratings. Quantitative analysis using logistic regression confirms this observation.

Logist Regression

Logistic regression is a statistical analysis method that provides quantitative evaluation of data of the type presented in Figures 18 and 19. Basically, logistic regression provides the best curve that relates the independent variable or dose (sound level, in this case) to the probability of a specific outcome or response. Curves so derived are often called "dose-response" curves. For appropriate use, the dependent variable or response is usually "dichotomized" or divided into "yes" and "no". For this analysis, the ratings are divided into greater than 40 as "yes" and less than or equal to 40 as "no". This division reflects the notion that, around an airport, some degree of noise should be expected and acceptable. Hence, for this resident, the dichotomization at 40 implies that exposure to events rated in the upper half of the scale is the circumstance of greater concern than exposure to events rated 40 or less.

Once the dependent variable is dichotomized, logistic regression produces the curves in Figures 20 and 21, with 90% confidence limits for those curves. Each curve is the best fit to the data for predicting the actual distribution of responses that resulted from the doses. That is, of all possible "s" curves that start on the left, at low sound levels, at 0% response, and end on the right at 100% response, the one derived best predicts the actual data set.

Interpreting these curves is straight-forward. For example, the curve in Figure 20 shows that for outdoor C-weighted Lmax of 75 dBC, for this particular resident there is a 25% chance that the event will be rated at greater than 40.

The steeper the dose-response curve and the narrower the confidence limits, the more likely is the curve to accurately represent the underlying data, and the more reliable is the relationship between the dose and the response. A very flat or almost horizontal curve means there is little or no relationship between dose and response, as, for example, when 20% of the responses are no, regardless of dose. A very steep or almost vertical curve means there is a very clear and almost "threshold" relationship between dose and response. Comparing the curves of Figures 20 and 21 demonstrates that the C-weighted maximums better predict the responses than do the A-weighted maximums.

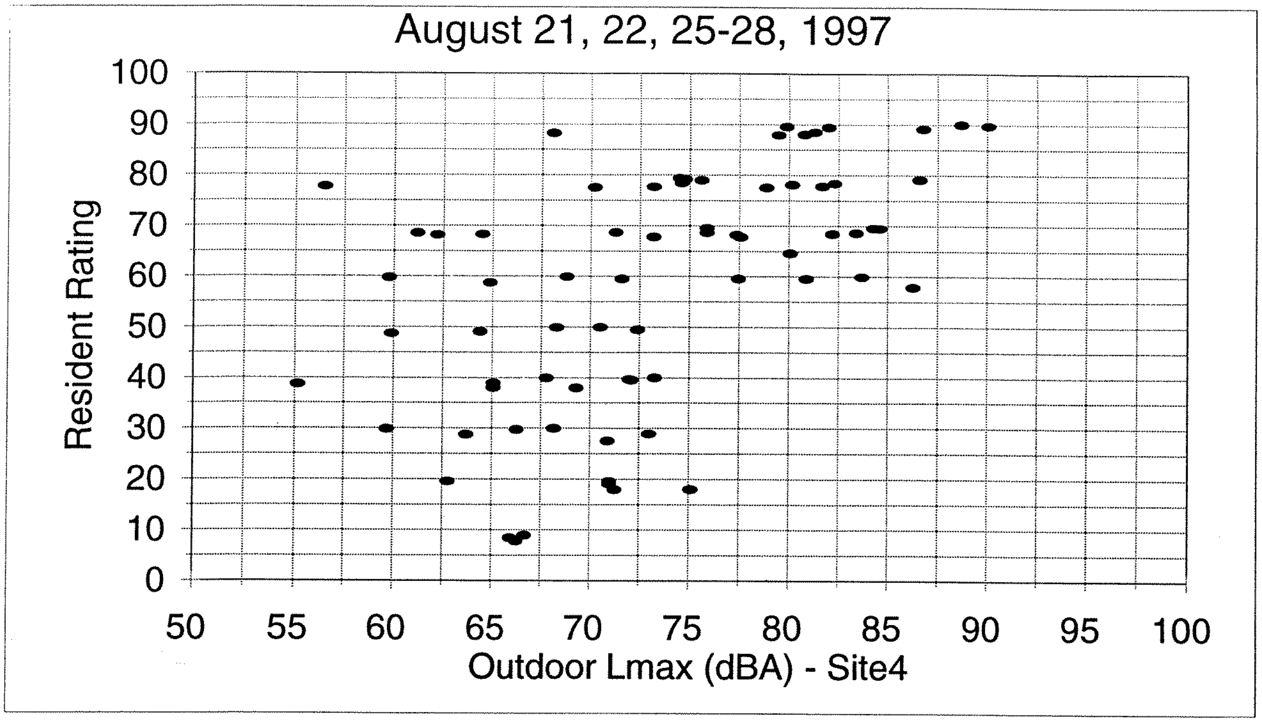

Figure 18. Resident Rating versus Outdoor A-weighted Lmax - Six Days

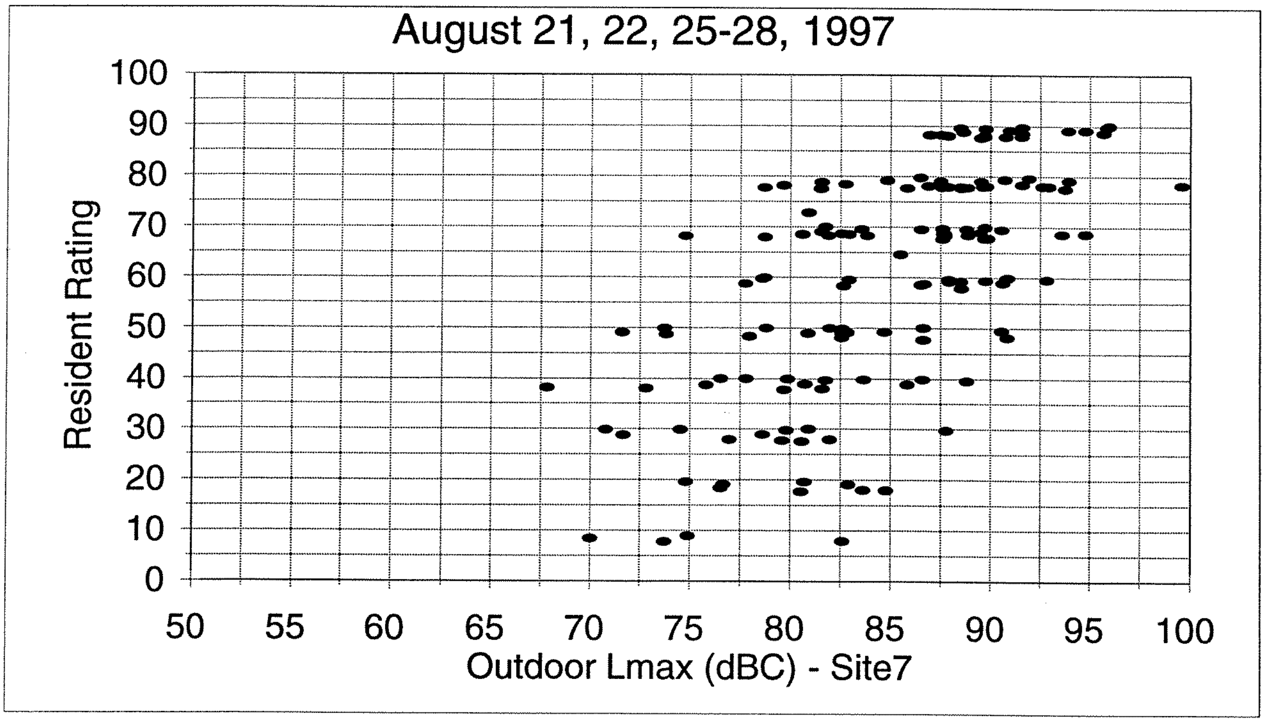

Figure 19. Resident Rating versus Outdoor C-Weighted Lmax - Six Days

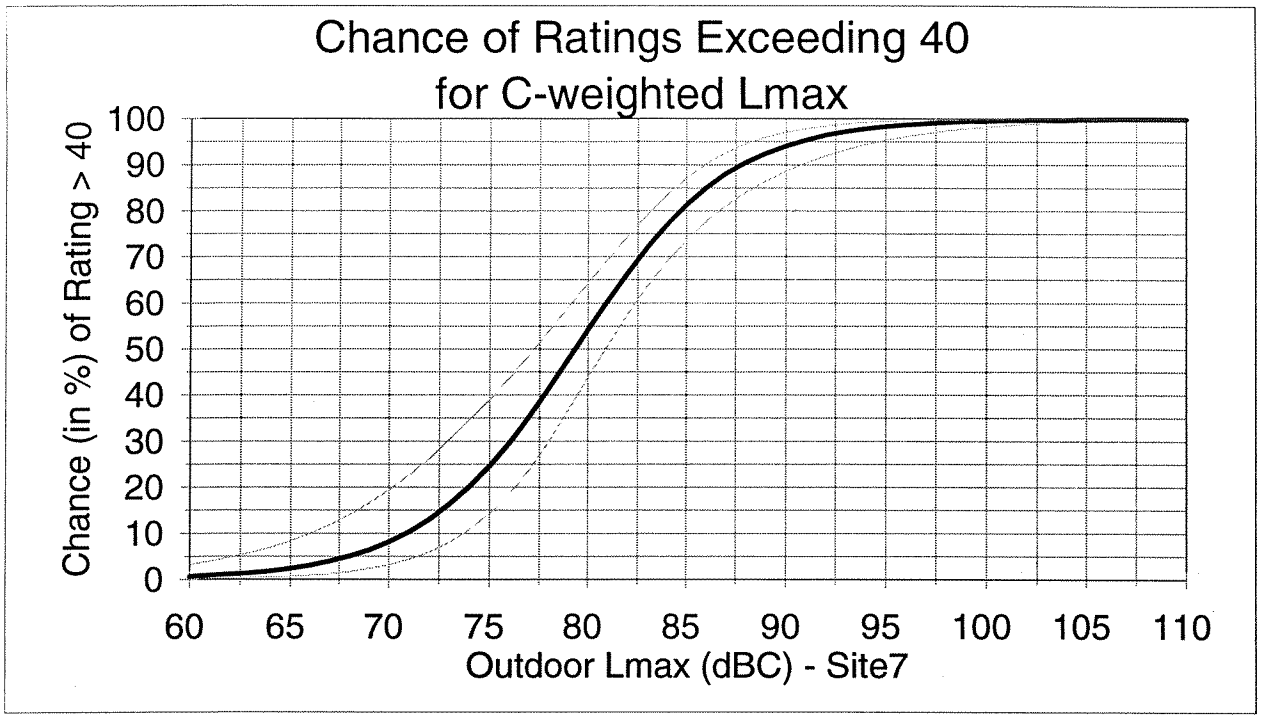

Figure 20. Dose Response Relationship for C-Weighted Lmax and Ratings > 40

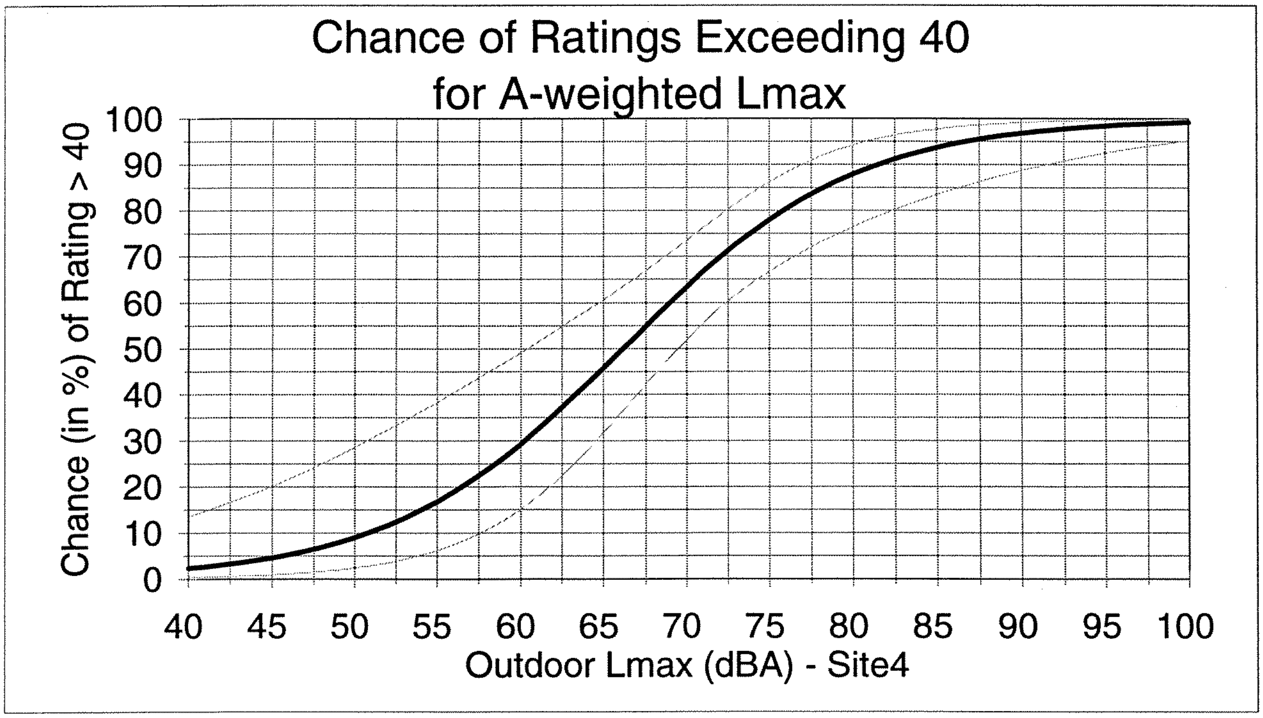

Figure 21. Dose Response Relationship for A-Weighted Lmax and Ratings > 40

4.2 Vibration Level Measurements

4.2.1 Correlation with Sound Level Maximums

Using this same six-day period of correlated measurements and ratings, the vibration level measurements are plotted versus the corresponding outside C- and A- weighted Lmax levels, Figures 22 and 23. As seen on the plots, there exists a close linear relationship between the vibration levels measured and the sound level measured outside; i.e. the higher the sound level, the higher the vibration level. Though both the C- and the A-weighted levels are correlated with the vibration levels, the C-weighted levels correlate somewhat better. Using standard least-squares analysis, the sample correlation coefficients for all plotted points are 0.63 and 0.62 for Figures 22 and 23, respectively. However, if the four furthest outliers in each figure are omitted, the correlation coefficients become 0.91 and 0.84 for the C- and A- weighted data, respectively.

4.2.2 Comparison of Vibration Measurements with Published Information

Guidelines for judging human perception of vibration levels have been published in several forums.[5] Hubbard provides sound level thresholds at which the induced vibrations in windows, walls and floors may become perceptible. He also identifies thresholds of tactile perception - that is, vibration levels that are likely to be perceptible to finger tip touch. Figure 24 presents the maximum ***outdoor*** spectrum for event 1, rated as 80, see Figure 4, but also includes the Hubbard window, wall and floor thresholds of perceptible vibration. For this event, the outdoor sound pressure levels clearly exceed the window threshold and somewhat exceed the threshold of perceptible wall vibration.

Hubbard provides information about tactile perceptibility as a function of the frequency of vibration. Overall vibration levels were measured for this study, but judging from the spectra of Figures 4, 5, 6 and 24, it is likely that much of the induced vibration energy lies between 20 and 100 Hz. For this frequency range, Hubbard data (Figure 10 of the Hubbard article) show the threshold of tactile perception to be between acceleration levels of 75 and 80 dB. Figure 25 repeats the South

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[5] Hubbard, Harvey H., "Noise Induced House Vibrations and Human Perception," **Noise Control Engineering Journal,** 19, (2), pp 49-55, Sep-Oct 1982.

American National Standards Institute, "Guide to the Evaluation of Human Exposure to Vibration in Buildings," ANSI S3.29-1983.

Wall acceleration levels *versus* C-weighted maximum sound levels and identifies this threshold. According to the Hubbard data, this figure shows that for the measured events, induced vibration levels become perceptible to the touch when outdoor C-weighted maximum levels are higher than 75 to 80 dBC.

The ANSI standard S3.29-1983 identifies base response curves that correspond to the approximate threshold of vibration perception of the most sensitive humans. These thresholds are frequency dependent, are different for vertical and horizontal directions, and are intended to address the annoyance effects produced when a building responds to a vibration source. Figure 26 repeats the data of Figure 25, but shows the range of these ANSI thresholds for horizontal vibrations between 20 and 80 Hz.

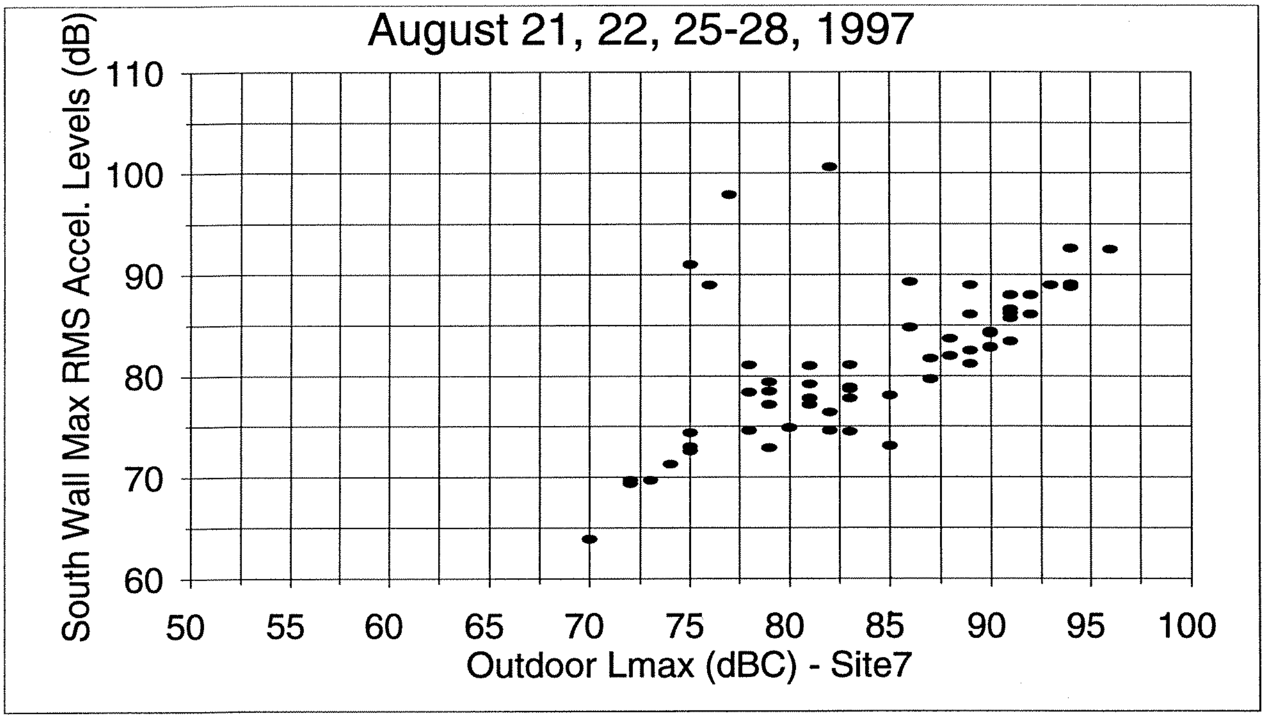

Figure 22. South Wall Maximum Acceleration Levels versus Outdoor C-weighted Lmax

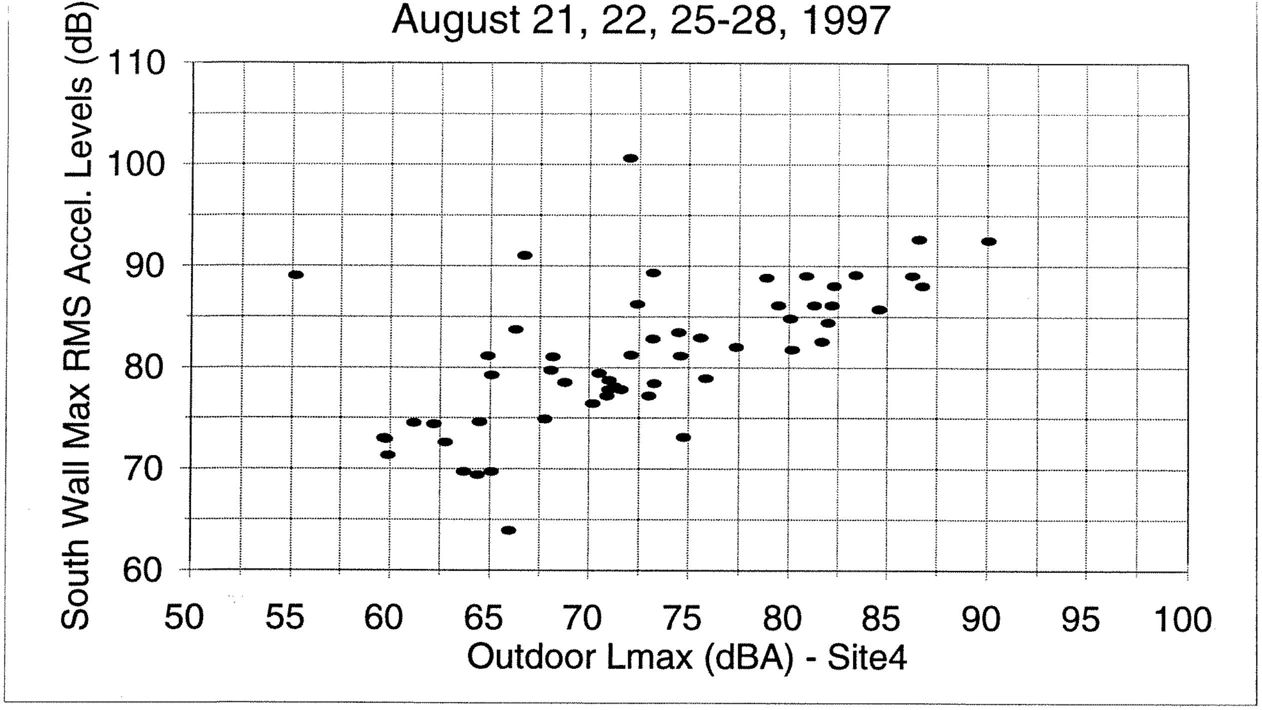

Figure 23. South Wall Maximum Acceleration Levels versus Outdoor A-weighted Lmax

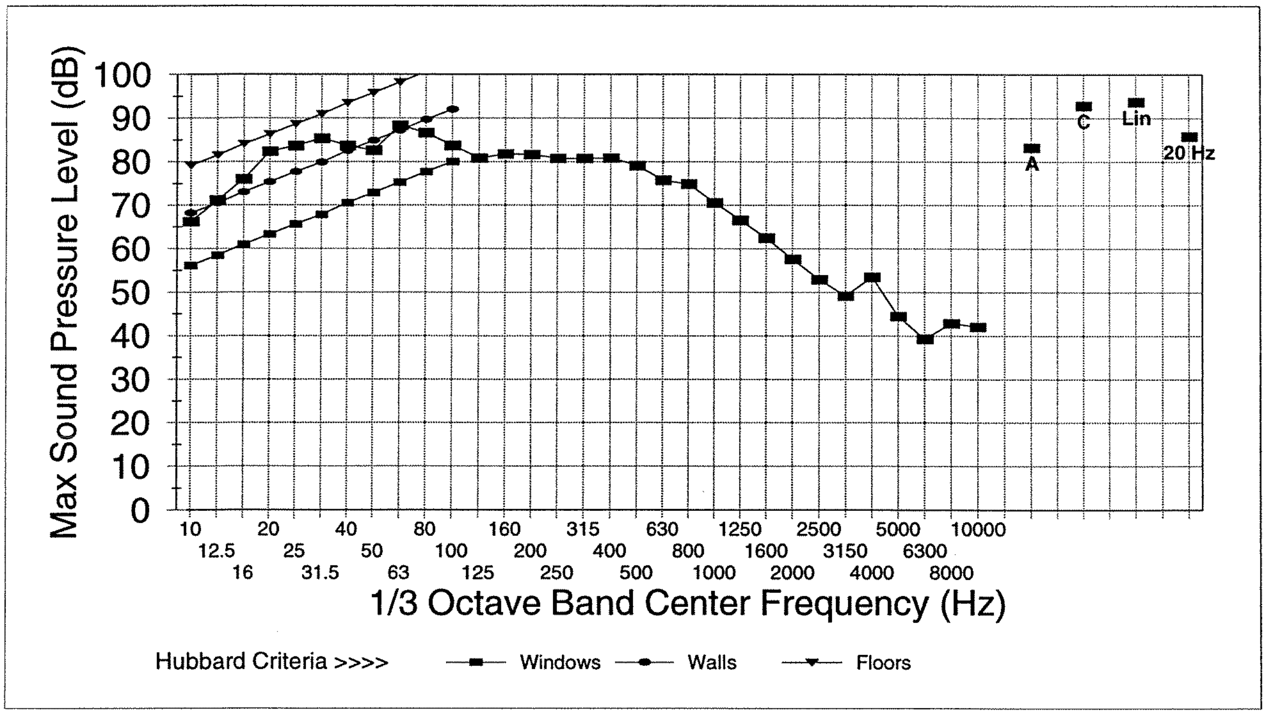

Figure 24. Spectra for Recorded Event 1 (Outside) - Resident Rating of 80

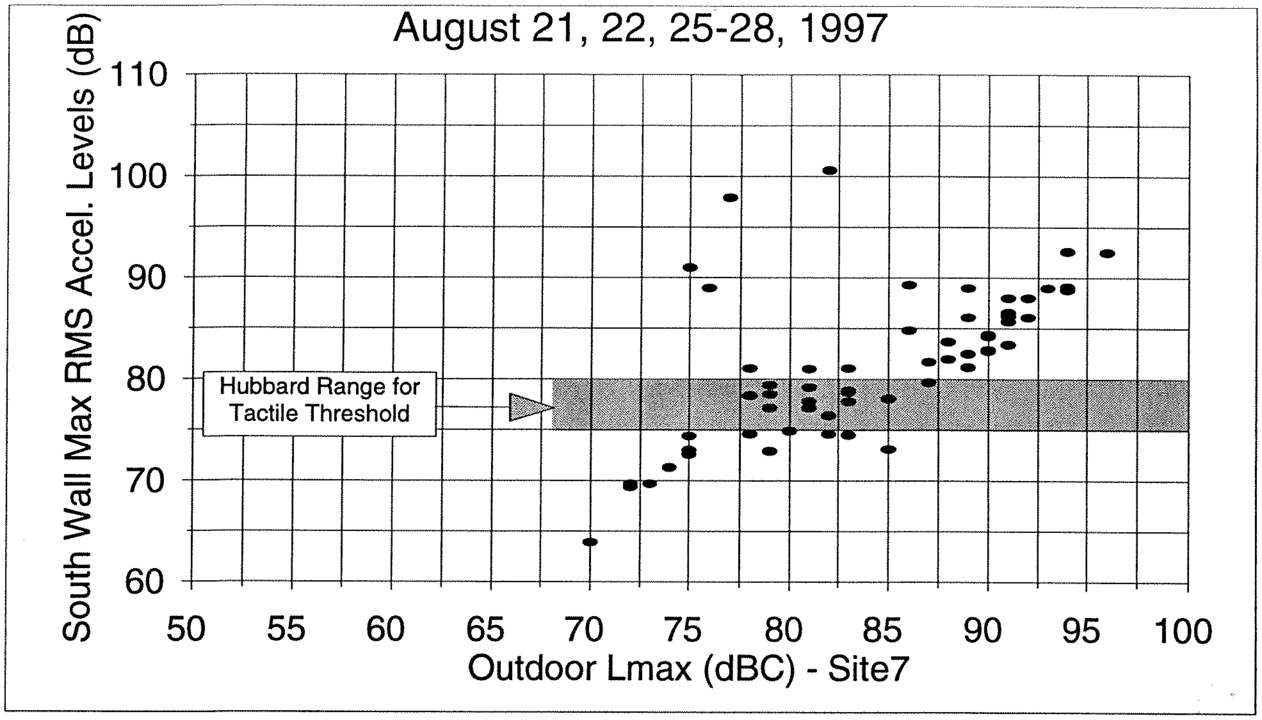

Figure 25. South Wall Maximum Acceleration Levels Compared with Hubbard Tactile Threshold

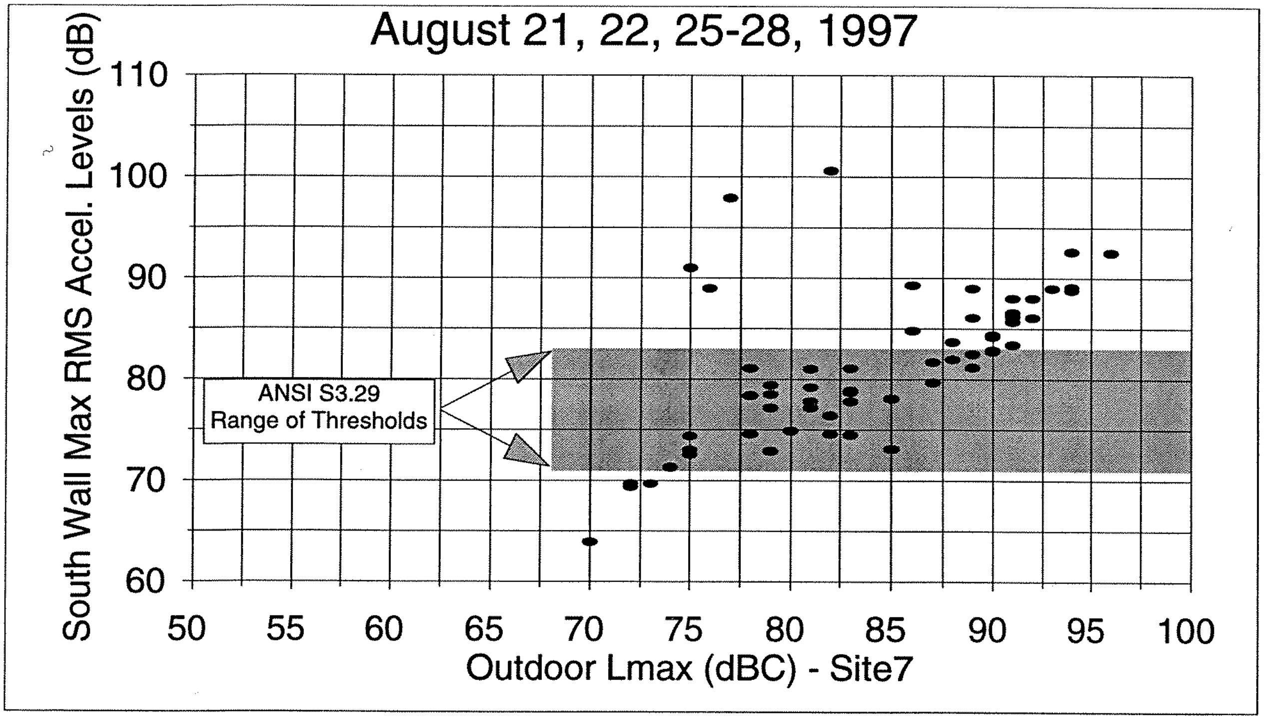

Figure 26. South Wall Maximum Acceleration Levels Compared with ANSI Thresholds

4.3 C-weighted Sound Level Propagation Rate

If the C-weighted maximum level is the best readily measured metric of takeoff noise, how do sound levels, as measured in this metric, vary with distance? The C-weighted Lmax data from the two further out measurements sites were obtained for the same six day period of events. Figure 27 shows the C-weighted Lmax values measured for some 84 events as a function of site location. Note that the distance scale is logarithmic.

The heavier line connects the mean value at each location, and the lighter lines show the theoretical "spherical spreading" drop off of sound level with distance. Because the logarithmic scale is used, the theoretical propagation rate plots as straight lines. The theoretical drop-off rate is 6 dB for every doubling of distance. The average drop-off rate for the 84 events measured simultaneously at Sites 7 and 3 is 5.6 dB per doubling of distance, or very close to the theoretical propagation rate.

As shown on this plot, regardless of the data scatter, it is clear that the further from Runway 28, the lower the average C-weighted maximum sound level. This drop-off is presented in Figure 28. This figure shows the percentage of measurements above a certain C-weighted maximum sound level for each measurement site. The percentages of each measurement sight clearly separate from the others in the range of C-weighted Lmax levels of 75 dBC to 95 dBC. The closest location had the higher percentages and the furthest had the lower percentages, showing that the closer in to Runway 28, the more occurrences there were over a given C-weighted Lmax range.

Finally, the measured levels of Figure 27 may be used in combination with the "dose response" curve of Figure 20 to estimate how the person providing the ratings would judge the same events, but heard at the three different sites. In other words, if a person with the sensitivity that is characterized by the curve of Figure 20 lived at each of the three different sites, how might he / she rate the takeoff sounds experienced at each of the sites? Figures 29, 30 and 31 provide an answer. These figures show, for the events measured simultaneously at each site, what percent would likely be rated as more objectionable than a rating of 40 for each 5 dB range of C-weighted maximum level. Table 2 summarizes the data of these figures. As shown, the total percent of events likely to be rated greater than 40 decreases with distance from 77% of all events at Site 7, to just under half at Site 3.

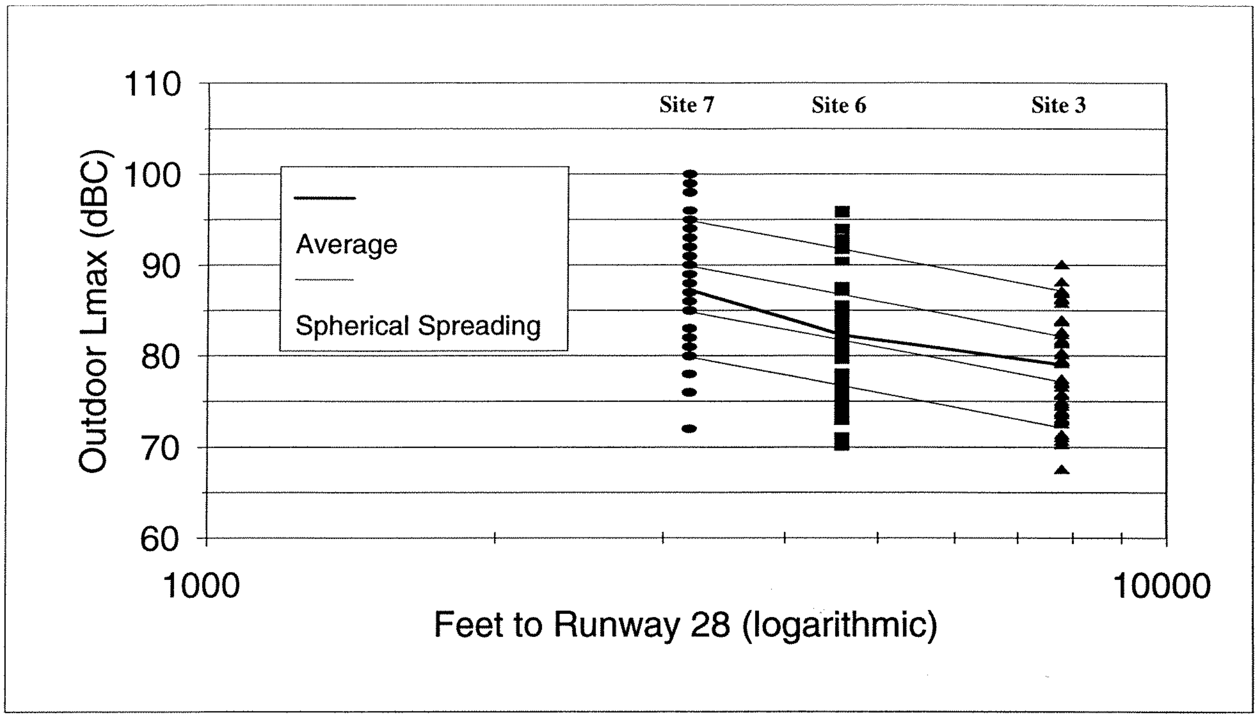

Figure 27. Outdoor C-weighted Lmax at each of the Three Measurement Sites

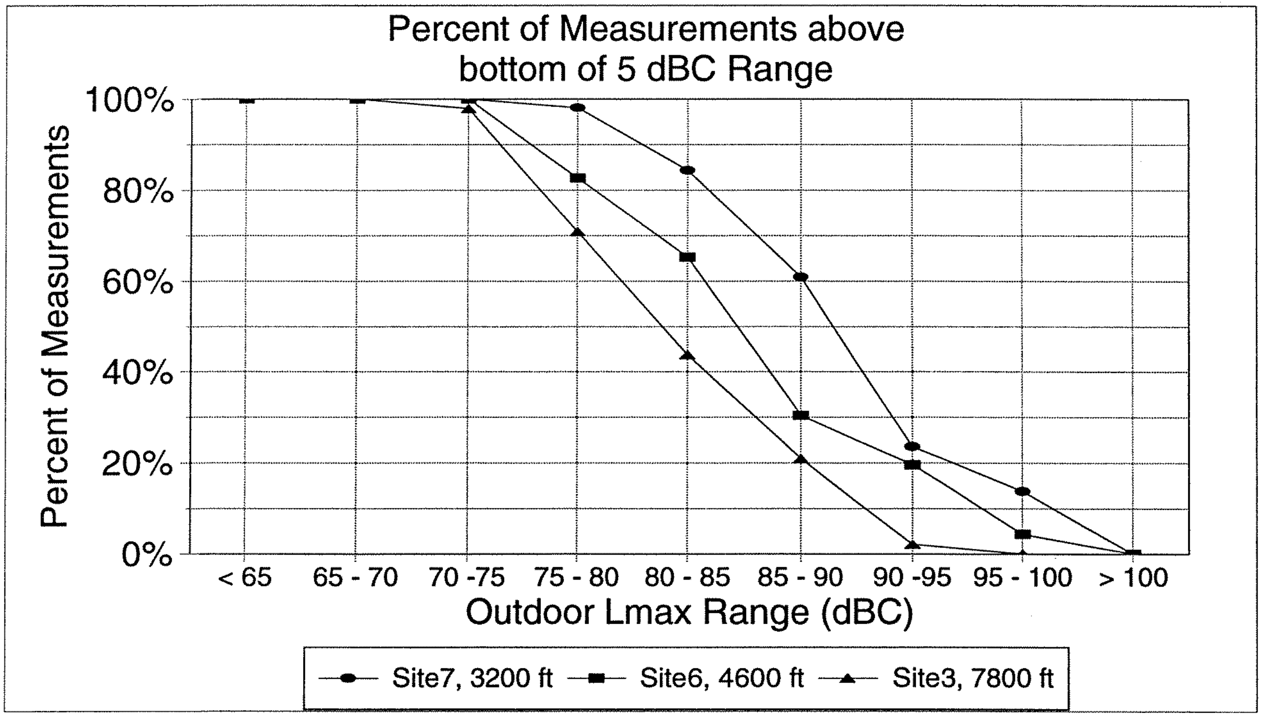

Figure 28. Percent of Measurements at each Site above a C-weighted Lmax

Table 2. Percent of Takeoff Noise Events Rated > 40 at Each Site

Range of Measured Lmax (C)	Location, See Figure 1		
	Site 7	Site 6	Site 3
65 - 70	0.00	0.00	0.09
70 - 75	0.32	2.85	4.44
75 - 80	5.42	6.87	10.70
80 - 85	15.98	23.62	15.56
85 - 90	32.67	9.53	16.44
90 - 95	9.42	14.62	2.00
95 - 100	13.60	4.31	0.00
> 100	0.00	0.00	0.00
Total	77.42	61.80	49.23

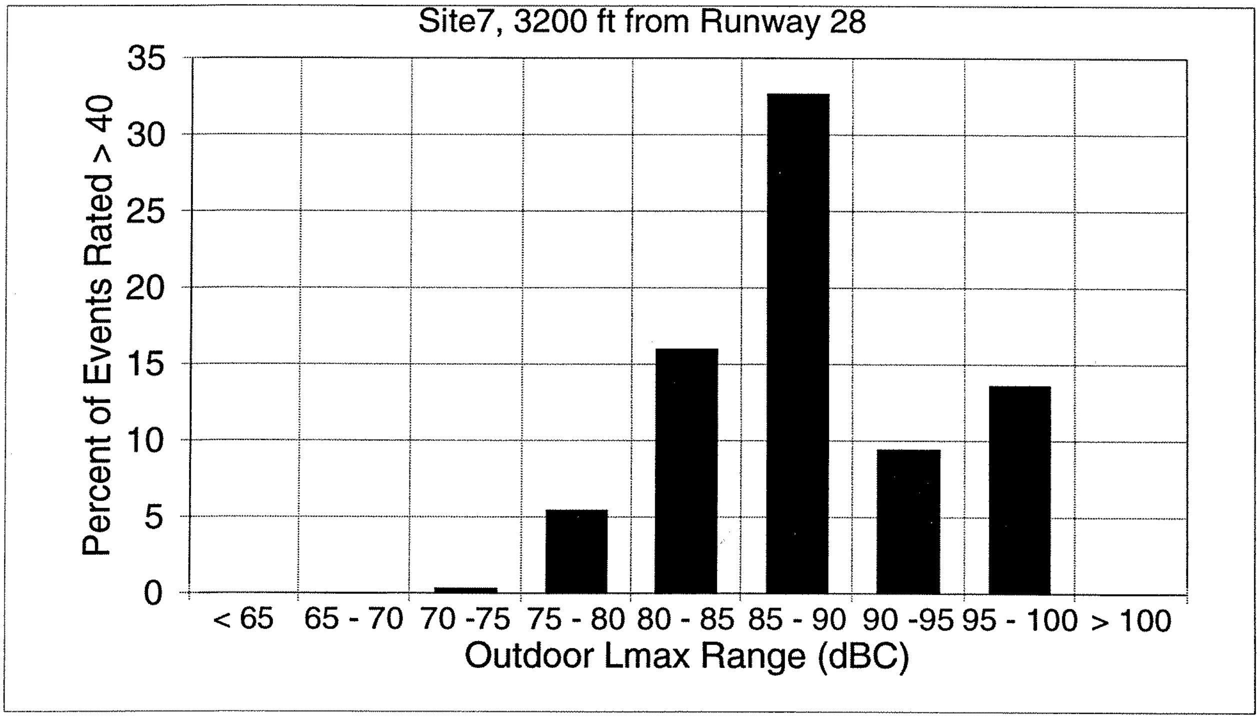

Figure 29. Percent of Resident Ratings > 40 versus C-weighted Lmax - Close-in Site

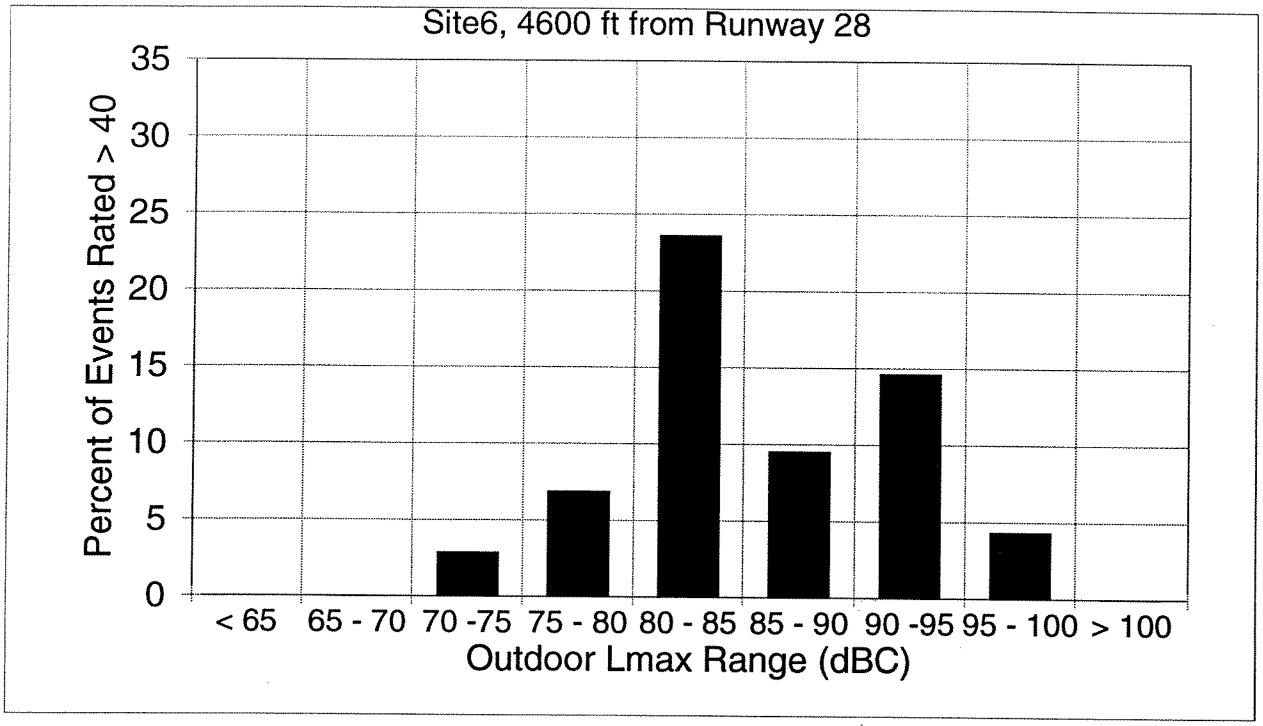

Figure 30. Percent of Resident Ratings > 40 versus C-weighted Lmax - Middle Site

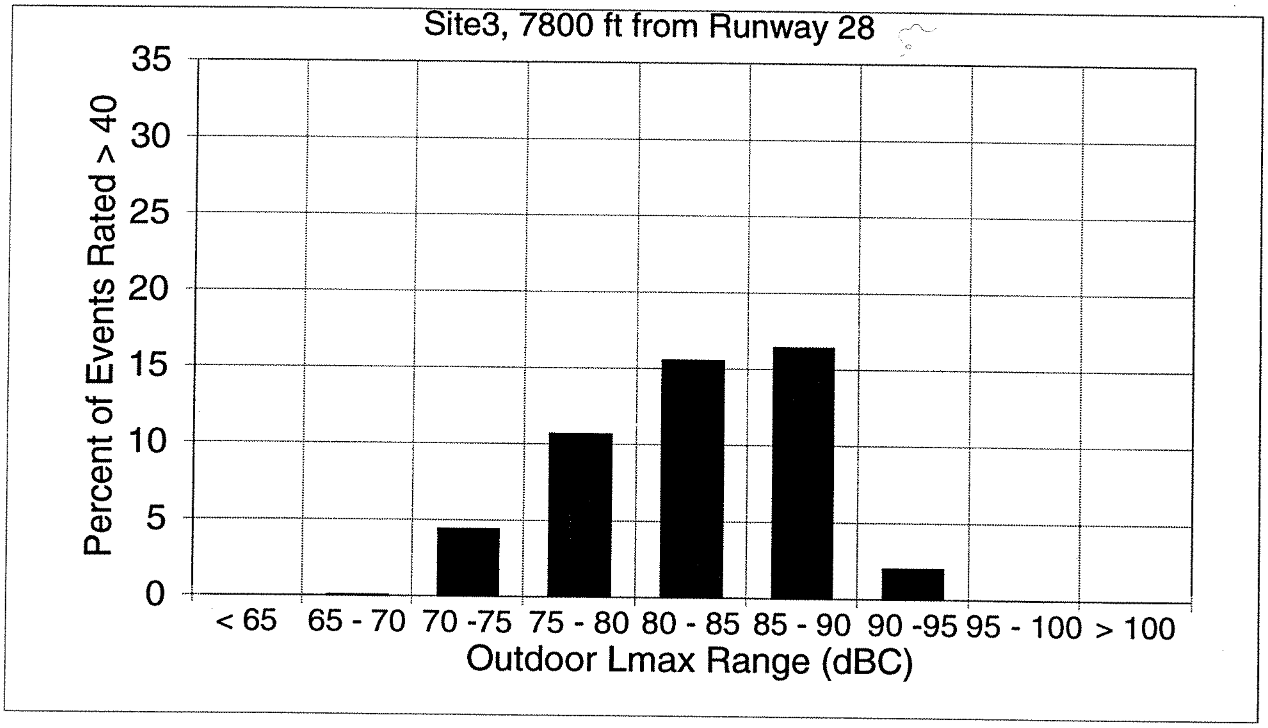

Figure 31. Percent of Resident Ratings > 40 versus C-weighted Lmax - Furthest Site

APPENDIX A. INSTRUCTIONS FOR RATING AIRCRAFT EVENTS

Purpose: Thank you for participating in this study. The goal is to learn more about people's reactions to aircraft noise as experienced inside their own homes, especially in neighborhoods like yours near airport runways. Later comparison of our measurements with your reactions will provide valuable insight into what aspects of the noise are most objectionable to residents *as experienced inside their own homes*.

General Instructions: You will be listening for individual aircraft noise events and rating each one on the form provided on the reverse side of these instructions. We do not expect you to do this all day long. Pick a 15 to 20 minute listening period during the day when there is a concentration of aircraft activity. This will give us the most information and require the least amount of your time. If your schedule permits, pick a different listening period each day ... perhaps the morning one day, the evening the next, the afternoon next, and so on. This will provide us with a complete range of weather conditions and runway use characteristics over the 4-week data collection period. If aircraft are barely audible (from both takeoffs and landings) when you begin a listening period, simply pick a different period later in the day if possible. It is not mandatory that you complete one session *every* day.

We have placed instrumentation in your living room to monitor sound and vibration, so this is the room in which we would like you to listen. Please make yourself comfortable, but for consistency between listening sessions, we ask that you turn off radios, televisions or other noise-making devices during the session. During peak periods of aircraft activity, we suspect this listening task will require your undivided attention. Interruptions, such as telephone calls, etc. are bound to occur and we expect you will need to suspend your listening task when these occur.

You have been provided with 2 clipboards and sets of forms. Each person fills out their own form during the session.

Each morning place any completed forms in one of the self-addressed envelopes we have provided, and simply leave it for our equipment servicing technician.

When you hear an aircraft: Please note the time from the wristwatch attached to the clipboard when you are confident you hear the sound of a new aircraft (time to the nearest 10 or 15 seconds is quite adequate). Write that time on the form. The watch has been synchronized with clocks in our noise measuring equipment so we can correctly match our measurements to your responses. Continue to listen to the aircraft as the sound level increases, then decreases, and finally fades away.

When the aircraft noise event is over: In the box to the right of the time, enter the numerical rating that best describes how you felt about the *entire* noise event from beginning to end. The numerical scale is meant to provide you with a range of responses from least objectionable to most objectionable to rank your impression. You are free to decide for yourself what aspects of the noise and/or vibration most influence your feelings. Furthermore, the relative importance of these aspects may change from one noise event to the next. That is your prerogative. Two sample entries are shown on the first two lines of the form.

If a new noise event starts before the previous one is over: Continue to rate the first event until you can no longer hear it. Then concentrate on the new event. If the new event has progressed to far before you can concentrate on it, simply ignore it and wait for the next.

If you have questions: Please call us at our toll-free number 1-800-859-1401 during business hours (8:30 am to 5:30 pm). Ask for David Senzig, Dick Horonjeff or Elena Langlois. Thank you.

APPENDIX B. NOISE MEASUREMENT DATA

EVENT	DATE	MAXTIME	RATING	S7_SEL	S7_Lmax	S8_SEL	S8_Lmax	S4_SEL	S4_Lmax	S1_Lmax	S2_Lmax
1	08/21/97	07:15:25	70	97.3	84.0	89.3	75.8				
2	08/21/97	07:20:15	70	108.3	95.0	99.2	86.1				
3	08/21/97	07:21:00	60	102.1	90.0	91.6	77.8				
4	08/21/97	07:23:57	90	107.3	94.0	98.5	84.1				
5	08/21/97	07:25:48	90	101.6	89.0	93.7	80.4				
6	08/21/97	07:33:43	80	107.2	93.0	98.0	84.3				
7	08/21/97	07:38:38	90	103.2	90.0	94.6	81.1				
8	08/21/97	08:21:45	60	101.4	88.0	92.8	79.7				
9	08/21/97	12:09:51	80	103.5	93.0	94.3	83.6				84.8
10	08/21/97	12:12:06	40	96.5	84.0	88.9	76.0				
11	08/21/97	12:15:10	60	99.9	87.0	91.4	77.3				
12	08/21/97	12:16:43	70	101.8	88.0	93.7	80.6				
13	08/21/97	12:35:42	80	104.2	92.0	95.2	83.9				
14	08/21/97	13:10:16	40	89.6	77.0	87.6	74.1			97.9	76.7
15	08/21/97	14:36:12	70	105.0	94.0	94.4	81.8	93.2	83.4	89.1	86.5
16	08/21/97	14:40:44	80	99.5	90.0	89.1	76.5				
17	08/21/97	14:45:42	70	102.7	90.0	94.3	82.2	85.6	73.2	82.8	76.5
18	08/21/97	15:35:02	70	102.7	90.0	92.6	79.7		77.6		84.1
19	08/21/97	16:12:19	60	103.9	91.0	93.3	79.3			86.6	80.9
20	08/21/97	16:17:54	60	103.7	91.0	92.4	79.7		83.7		84.7
21	08/21/97	16:22:28	70	102.6	90.0	92.5	79.7				
22	08/21/97	16:27:27	50		87.0	91.8	77.7				
23	08/21/97	16:40:15	30	100.6	88.0	92.5	79.6	79.3	66.3	83.7	75.5
24	08/21/97	18:38:56	50	96.8	83.0	95.1	83.4				
25	08/21/97	19:17:32	90	101.9	91.0	93.7	84.4		86.8	88.0	86.4
26	08/21/97	19:20:30	90	104.5	91.0	96.9	81.7				
27	08/21/97	19:36:52	80	102.7	91.0	97.3	84.2	89.1	74.5	83.4	79.6
28	08/21/97	21:09:47	70	100.3	88.0	86.0	73.7				
29	08/21/97	12:15:12	80	95.0	82.0	86.1	72.8				
30	08/21/97	21:19:35	70	95.8	82.0	86.4	72.1				
31	08/21/97	21:25:21	80	103.0	89.0	92.4	78.3				84.6
32	08/21/97	21:30:41	80	100.1	88.0	91.5	79.1				
33	08/21/97	22:07:31	90	104.9	92.0	94.4	81.3	93.1	81.3	86.1	84.7
34	08/22/97	00:16:08	90	103.4	90.0	93.9	80.0			84.2	80.8
35	08/22/97	07:10:07	90	107.7	95.0	101.0	86.8				
36	08/22/97	07:22:30	90	101.5	88.0	95.9	81.8				
37	08/22/97	07:24:21	80	102.6	89.0	96.7	82.4				
38	08/22/97	08:21:58	50	83.5	72.0			76.6	64.4	69.4	66.9
39	08/22/97	08:31:16	70	102.7	90.0	96.7	83.1				
40	08/22/97	08:46:01	50	96.2	83.0	91.3	78.6				
41	08/22/97	08:49:53	50	98.9	87.0	96.1	83.5				
42	08/22/97	08:59:30	50	102.6	91.0	95.1	82.5				80.2
43	08/22/97	09:27:34	60	100.0	89.0			96.2	86.3	89.0	82.8
44	08/22/97	13:37:18	70	103.3	91.0	92.7	80.9		84.6	85.7	83.1
45	08/22/97	14:12:46	70	93.9	81.0	97.8	86.2				
46	08/22/97	19:03:58	80	102.7	92.0	96.2	84.5		82.3	88.0	85.2
47	08/22/97	20:04:05	70	95.5	82.0						
48	08/22/97	20:49:29	50	83.7	74.0			76.4	68.3		
49	08/22/97	21:09:49	30	88.8	80.0						
50	08/22/97	21:30:24	60	101.9	91.0	93.5	82.3				
51	08/22/97	21:39:43	40	99.9	87.0	91.9	80.1				
52	08/22/97	22:06:06	80	107.3	94.0	95.3	81.7	97.9	86.6	92.6	85.5
53	08/22/97	23:10:20	90	109.2	96.0	97.0	83.6	99.9	88.7		86.6
54	08/25/97	05:53:27	60	106.6	93.0	96.8	83.7	92.5	80.9	89.0	81.2
55	08/25/97	06:13:15	80	105.8	94.0	97.6	85.0		78.9	88.8	82.6
56	08/25/97	06:20:46	90	108.0	96.0	98.7	85.6				
57	08/25/97	07:08:58	80	111.1	100.0	102.6	90.1				
58	08/25/97	07:59:44	80	104.1	90.0	97.8	84.8				82.5
59	08/25/97	08:41:34	80	102.7	88.0	94.9	81.2				
60	08/25/97	09:00:35	80	96.0	82.0	91.6	77.5	82.2	70.2	76.4	
61	08/25/97	09:40:31	70	102.3	88.0	94.2	80.0				84.0
62	08/25/97	11:09:33	90	101.8	90.0	93.2	80.2	90.5	80.8		82.1
63	08/25/97	11:21:08	80	93.1	80.0	87.5	74.1				
64	08/25/97	11:43:02	70	101.1	88.0	95.1	82.1	84.3	71.3		
65	08/25/97	11:48:02	70	100.9	88.0	92.4	79.1	87.6	77.4	82.0	82.8
66	08/25/97	12:09:41	80	94.6	83.0			84.6	74.6	81.1	73.7
67	08/25/97	15:09:45	20	88.6	75.0	83.4	70.5	77.4	62.8	72.6	76.7
68	08/25/97	18:02:03	30	91.7	81.0			81.1	70.9	77.2	70.0
69	08/25/97	18:08:34	30	90.2	79.0	79.7	67.0	80.2	73.0	77.2	69.6
70	08/25/97	18:11:09	20	93.6	83.0	83.6	73.8	81.6	71.0	78.7	70.6

EVENT	DATE	MAXTIME	RATING	S7_SEL	S7_Lmax	S8_SEL	S8_Lmax	S4_SEL	S4_Lmax	S1_Lmax	S2_Lmax
71	08/25/97	18:22:49	20	89.6	77.0	88.4					
72	08/25/97	18:24:40	20	94.5	84.0	84.6	72.6		75.1		73.5
73	08/25/97	18:27:44	10	88.9	75.0			78.3	66.7	91.0	
74	08/25/97	18:30:55	10	85.0	74.0			76.8	66.3		
75	08/25/97	18:56:10	40	95.3	82.0				69.3		79.7
76	08/25/97	19:48:22	60	91.7	83.0	82.7	77.6	79.8	71.6	77.8	79.7
77	08/25/97	20:53:47	50	104.0	91.0	95.6	82.2	83.3	72.4	86.2	79.1
78	08/25/97	20:57:07	40	84.6	73.0	76.9	66.6	80.5	65.1	69.7	64.9
79	08/25/97	21:12:14	90	107.5	96.0	94.7	81.6		90.1	92.5	
80	08/25/97	21:34:01	90	103.1	90.0	93.2	79.2	92.2	82.0	84.4	
81	08/25/97	21:35:06	30	93.7	80.0	85.3	72.1				
82	08/25/97	21:49:28	80	102.2	90.0	92.4	80.4	84.8	75.6	82.9	77.5
83	08/26/97	05:56:47	70	97.0	82.0	88.6	73.8	82.1	64.5	74.6	
84	08/26/97	06:20:13	70	95.7	83.0	86.5	74.9	77.2	61.2	74.5	70.6
85	08/26/97	07:14:04	90	102.3	89.0	97.2	84.1		79.9		82.9
86	08/26/97	08:00:35	80	90.6	79.0	87.3	75.2	73.5	56.5		71.1
87	08/26/97	08:12:40	60	88.7	78.0	91.3	79.3	76.8	64.9	81.1	
88	08/26/97	10:59:15	80	97.4	87.0	86.1	74.4	88.4	80.2	81.7	79.7
89	08/26/97	12:05:27	70	97.6	87.0	88.8	77.1		75.9		
90	08/26/97	12:33:06	80	99.8	87.0	91.0	77.9				
91	08/26/97	12:36:15	70	100.8	89.0	90.2	77.5		84.3		
92	08/26/97	13:32:13	80	100.1	86.0	91.5	78.0	84.5	73.2	89.3	77.0
93	08/26/97	13:48:37	90	97.7	87.0	89.8	77.8	80.5	68.1	79.7	
94	08/26/97	14:02:19	10	81.5	70.0			75.2	66.0	63.9	
95	08/26/97	14:39:35	40	101.6	89.0	93.6	80.9	83.8	72.1	81.2	78.6
96	08/26/97	18:20:55	60	95.8	88.0			85.5	77.5		77.5
97	08/26/97	19:10:08	30	86.6	75.0			71.5	59.7	73.0	65.8
98	08/26/97	20:23:43	30	89.9	77.0						
99	08/27/97	05:08:45	70	96.8	89.0	79.1	69.4	91.8	82.2	86.1	78.1
100	08/27/97	05:59:54	65	95.6	86.0	82.1	71.4	89.3	80.1	84.8	76.6
101	08/27/97	06:39:53	70	92.6	84.0	80.3	71.2				
102	08/27/97	07:41:31	90	97.3	88.0	92.7	84.8				
103	08/27/97	08:12:30	70	93.0	83.0	83.6	71.1		75.9	78.9	
104	08/27/97	08:46:15	50	91.6	83.0	88.8	80.7				
105	08/27/97	08:59:13	50	90.4	82.0						
106	08/27/97	09:07:16	40	90.0	81.0	82.8	75.2	74.3	65.1	79.2	79.2
107	08/27/97	09:21:09	30	83.5	72.0		60.4	74.6	63.7	69.7	67.0
108	08/27/97	11:12:37	20	93.5	81.0	79.1	75.5	82.8	71.0	77.8	73.9
109	08/27/97	11:22:32	40	90.4	78.0	80.0	67.9	83.5	73.3	78.4	74.1
110	08/27/97	14:23:19	50	92.1	85.0						76.7
111	08/27/97	14:27:12	20	91.5	81.0	72.9	66.0				
112	08/27/97	14:28:30	20	88.9	77.0						74.9
113	08/27/97	15:09:17	40	89.4	76.0			67.2	55.2	89.0	
114	08/27/97	16:47:52	10	91.6	83.0	73.7	65.0				70.9
115	08/27/97	17:29:01	60	87.4	79.0			79.5	68.8	78.5	
116	08/27/97	18:28:21	70	87.0	75.0			76.7	62.2	74.4	
117	08/27/97	19:53:19	50	86.8	74.0			77.6	59.9	71.3	60.9
118	08/27/97	19:40:14	30	82.1	71.0						
119	08/27/97	19:56:08	40	79.4	68.0	76.0	68.7				
120	08/28/97	04:00:06	90	105.3	92.0			90.4	79.5	86.1	78.7
121	08/28/97	05:23:11	40	89.3	80.0					74.9	
122	08/28/97	06:37:27	80	102.8	89.0				81.7	82.5	80.3
123	08/28/97	06:54:39	60	95.9	83.0						
124	08/28/97	07:12:22	80	100.9	88.0	91.9	79.7				
125	08/28/97	07:19:29	90	103.5	92.0						
126	08/28/97	07:40:04	75	93.8	81.0						
127	08/28/97	07:48:51	60	103.2	89.0	78.8	69.2				64.8
128	08/28/97	07:49:52	50	96.1	83.0	75.8	65.3				77.5
129	08/28/97	08:39:52	60	99.5	87.0	91.3	77.3				
130	08/28/97	08:44:55	40	99.7	86.0	88.6	75.3				71.8
131	08/28/97	08:49:04	30	95.4	82.0						
132	08/28/97	16:17:35	80	93.9	85.0			86.7	74.8	73.1	73.0
133	08/28/97	16:29:28	40	91.9	82.0			83.0	72.0	100.6	78.2
134	08/28/97	17:10:28	50	88.2	78.0					74.6	
135	08/28/97	17:44:21	60	87.6	79.0			72.8	59.8	72.9	69.6
136	08/28/97	18:23:22	30	89.4	81.0			77.9	68.2	81.0	
137	08/28/97	19:14:26	20	97.9	85.0	87.3	73.6	82.0	71.3	78.1	75.4
138	08/28/97	21:32:43	50	94.5	81.0	84.2	71.4				70.4
139	08/28/97	22:09:23	70	89.8	79.0						70.5
140	08/28/97	23:21:18	40	93.5	80.0	84.0	70.7	82.2	67.8	74.9	67.8
141	08/28/97	23:39:41	50	88.9	79.0			81.5	70.5	79.4	72.6