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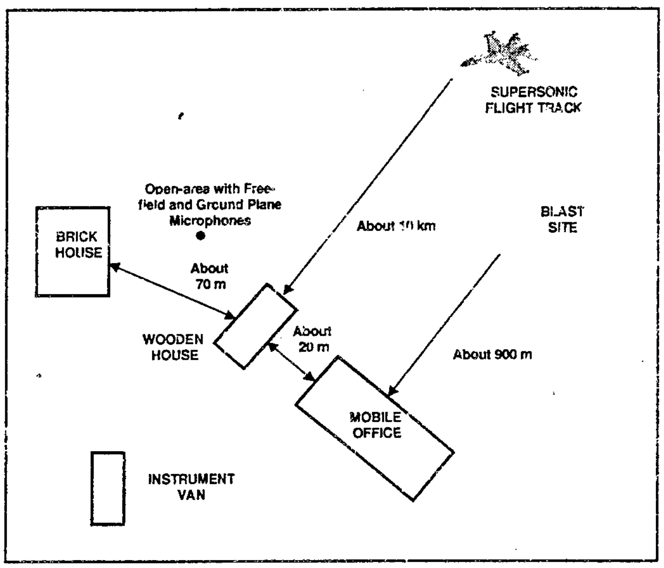
A Comparative Study of Indoor Human Response to Blast Noise and Sonic Booms

by
Paul D. Schomer, John W. Sias, and Domenic Maglieri

For the past two decades in the United States, blast sounds and sonic booms both have been assessed using C-weighted day-night average sound level. Based almost exclusively on blast sound research, a new method which replaces the C-weighted day-night average sound level recently has been recommended, reviewed, and incorporated into a new American National Standard. As in the previous method, the new method includes and assesses sonic boom sounds in a like manner to blast sounds. However, while available evidence suggested that in an indoor setting sonic boom could be treated in a similar fashion to blast sounds, experimental evidence was lacking.



To provide the lacking comparison data, this study tested the responses of subjects to sonic booms to determine if they were consistent with the previous blast response data presented in Schomer (1994), since these data formed the basis for the new method A key factor in the design of this study was the presentation of real blasts and booms to subjects situated in real structures in the field.

The study was performed as a paired-comparison test using the same control sound as was used in all the previous blast research that formed the basis for the new assessment method. In this new study, 232 subjects judged 20 booms and 30 blast sounds. The new data resulting from this study show good general agreement with the previous data reported in Schomer (1994). However, indications are that, for the same C-weighted sound exposure level, a boom is slightly more annoying than a blast.

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13. ABSTRACT (Maximum 200 words)

For the past two decades in the United States, blast sounds and sonic booms both have been assessed using C-weighted day-night average sound level. Based almost exclusively on blast sound research, a new method which replaces the C-weighted day-night average sound level recently has been recommended, reviewed, and incorporated into a new American National Standard. As in the previous method, the new method includes and assesses sonic boom sounds in a like manner to blast sounds. However, while available evidence suggested that in an indoor setting sonic boom could be treated in a similar fashion to blast sounds, experimental evidence was lacking.

To provide the lacking comparison data, this study tested the responses of subjects to sonic booms to determine if they were consistent with the previous blast response data presented by Schomer in 1994, since these data formed the basis for the new method. A key factor in the design of this study was the presentation of real blasts and booms to subjects situated in real structures in the field. The new data resulting from this study show good general agreement with the previous data.

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Foreword

This research was performed for the Strategic Environmental Research and Development Program (SERDP) with funding from Project 97-523, "Controlling, Assessing, Managing, and Monitoring Noise Impacts." SERDP is a joint program of the U.S. Departments of Defense and Energy, and the U.S. Environmental Protection Agency, and is managed by the Department of Defense. Carl Adema was the SERDP technical manager for this effort.

The Planning and Mission Impact Division (LL-P) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL) was responsible for undertaking and completing this project. Dr. Paul D. Schomer was the principal investigator. D. Maglieri is with Eagle Aeronautics, Inc., Newport News, VA. Harold Balbach is Acting Chief, CECER-LL-P; Dr. William D. Severinghaus is Operations Chief, CECER-LL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

This study was made possible by the great support provided by the civilian support staff and the officers and enlisted personnel at NAS Fallon, NV. These individuals provided on-site logistics, supersonic flying, setting of C-4 blast charges, RADAR for aircraft guidance, and meteorological forecasting and analysis.

COL James A. Walter is Commander, USACERL, and Dr. Michael J. O'Connor is Director.

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1 Introduction

Predicting human response to high-energy impulsive sounds such as the sounds generated by sonic booms or explosives is a difficult problem. Much research on sonic booms was undertaken in Europe and the United States during the 1960s and 1970s in connection with the British/French Concorde and the U.S. Supersonic Transport programs. More research in the United States during the late 1980s and 1990s studied the possibility of a second generation supersonic transport and, in particular, a U.S. High-Speed Civil Transport. Warren and Web (1965) described Exercise Westminster, which was a demonstration of sonic bangs, together with some explosive bangs and flyovers by a jet aircraft. Johnson and Robinson (1967) also described this experiment, in which 61 subjects used the method of direct magnitude estimation to judge the relative annoyance of the sonic bangs, explosions, and jet aircraft noise. Artificial white noises were included to test the subjects' performance for individual consistency and to compare their results with the established relationship between subjective magnitude and objective level. Von Gierke and Nixon (1972) provided a review of human response to sonic booms, both individually and in the community, primarily in terms of possible physiological and psychological responses as found in experimental field and laboratory studies and community survey programs. Leatherwood and Sullivan (1993) used a sonic boom simulator to quantify subjective loudness and annoyance response to simulated indoor and outdoor sonic booms. Results were used to assess loudness and annoyance as sonic boom criterion measures and to evaluate several metrics as estimators of loudness and annoyance.

Background

Recently, there has been a fair amount of research on blast sounds in the United States (Schomer, Buchta, and Hirsch 1991; Schomer et al. 1994; Schomer and Wagner 1995), Germany (Buchta 1989), and Australia (Cook et al. 1994). Schomer performed "field" laboratory studies of blast noise while Buchta and Cook conducted attitudinal surveys in their respective countries.

Schomer (1994) proposed a new method for the assessment of high-energy impulsive sound based primarily on blast noise research. This new method was based on a large body of research results which shows that: (1) a 1 dB increase in C-weighted sound exposure level (CSEL) of a blast sound corresponds to about a 2 dB increase in the A-weighted sound exposure level (ASEL) of an equivalently annoying control sound, and (2) groups of test subjects are equally annoyed by a blast sound at a CSEL of 103 dB and a vehicle passby at an ASEL of 103 dB. The National Research Council (NRC) has recently reported on the assessment of high-energy impulsive sound and has included the method proposed by Schomer (1994) as one of two recommended methods (NRC 1996). The Schomer method is recommended when the distribution of C-weighted sound exposure levels for the blast or boom events is known and the standard deviation of the levels is large. This new method has been incorporated into an American National Standard (ANSI 1996).

The new method is implemented by summing "adjusted" sound exposures (termed "annoyance units" in the NRC study). With the new method, "adjusted" sound exposure levels, L_{AUE}, are calculated from the C-weighted sound exposure levels, L_{CE}, of high-energy impulse sounds by:

$$L_{AUE} = 2\,L_{CE} - 103 \text{ dB} \qquad \text{[Eq 1]}$$

These "adjusted" sound exposures are summed to form the "adjusted" day-night (total) sound exposure which can then be converted to "adjusted" day-night average sound level by dividing by 86,400 (the number of seconds in a day), calculating the logarithm of the result, multiplying by 10, and adding a scale factor.

The other NRC method is recommended when there is no information on the range or variance of the impulsive sound levels or it is known that the variance is small. This method continues the use of C-weighted day-night average sound level (CDNL) but makes substantial increases in the percent highly annoyed versus CDNL as compared with the original NRC (1981) recommendations. Unlike the Schomer method, this second NRC method cannot be used when assessing combined noise environments. CDNL is an equal-energy method. Equation 1, with its coefficient of 2 relating adjusted sound exposure to CSEL does not support the equal-energy method. For Equation 1 to support the equal-energy method, this coefficient of 2 would have to equal one.

In the United States, blast sounds and sonic booms have been assessed in an identical manner for the past 20 years using the CDNL (ANSI 1986). Again, in ANSI (1996)* and in both methods of NRC (1996), both blast sounds and sonic booms are treated in a like manner. While these two sources are grouped for assessment purposes, strong evidence for this grouping has been lacking. Before this study, a single experiment of significant size had never used these two sources together.

Objective

The purpose of the research was to test if the responses of subjects to sonic booms were consistent with the blast response data used in Schomer (1994) to formulate Equation 1.

Approach

This study used the paired-comparison test methodology used for earlier blast noise research (Schomer 1991; Schomer et al. 1994; Schomer and Wagner 1995). A key factor in the design of this study was the presentation of real blasts and booms to subjects situated indoors in real structures in the field. The blast sounds in this study serve as a control to ensure that this group of subjects was similar to previous groups in their assessment of blast sound. The control sound used in the previous blast sound was used herein for both the blast and the boom sounds.

Mode of Technology Transfer

These data will be used will be used to reinforce National Research Council recommendations and corresponding American National Standards. These data will be used to help reformulate appropriate International Organization for Standardization Standards. These Standards will be used worldwide by the Department of Defense (DOD) for purposes of noise impact assessment and mitigation and compatible land use planning.

* ANSI 1996 supercedes ANSI 1986.

2 General Study Concepts

The Study Site

This study tested human response to sonic booms and blast sounds as observed indoors in one unified experiment, with the blast sounds included as a control. The study was performed during August 1995 at Naval Air Station (NAS) Fallon, NV. The study site was in the Nevada desert almost centrally within a 15,000 sq km supersonic flying area. Three differing test structures were located at the test site. One structure was a rehabilitated heavy-brick house with a large flat timber-beam, wooden-decked roof covered with about 35 cm of small gravel stones (Plate 1*). The main room in this house was about a 5.5-m by 7-m living room. The second structure was a rather small, single-room, 3-m by 6-m wood frame building (Plate 2). The third structure was a large mobile office trailer divided into two 3.5-m by 8-m living rooms (Plate 3). Each test room was furnished as if it were a normal living room, including couches and chairs, carpets or rugs, coffee and end tables, window treatments, etc. The booms and blasts came from about the same direction and each room had windows that faced the blast site and the direction of arrival of the sonic booms. All windows were closed. Each room was cooled using a quiet evaporative air conditioner ducted through muffler sections. The ambient A-weighted sound level in unoccupied rooms was about 40 dB. Two walls of the brick house received the blasts and booms (each at an incidence angle of about 45 degrees), the smaller wall of the wood house directly (face-on) received the blasts and booms, and the long wall of the mobile office structure directly received the blasts and booms. Figure 1 shows the test area, including the study site where the structures and subjects were located, the blast site, and the general aircraft supersonic flight tracks. Figure 2 is a pictorial plan view of the study site, and Plate 4 shows the study site structures and acoustical measurement van.

* Plates and figures are shown at the end of chapters in which they are referenced.

Study Site Instrumentation

Two microphones were situated at the ear height of seated subjects and near to the subject positions in each test room. These microphones were 1-in. (25 mm) Brüel & Kjær (B&K) condenser type microphones with associated B&K preamplifiers and a line driver developed by U.S. Army Construction Engineering Research Laboratory (USACERL). One outdoor microphone was located about 10 cm (the windscreen radius) from the blast/boom-facing wall of each structure (Plate 5). Each of these microphones was located on a flat open part of the wall (Plate 6). In addition, there was one microphone located at a height of 1.2 m in an open field away from any reflecting surfaces (Plate 7). These four microphones were (B&K) Type 4921 outdoor microphone systems but were specially modified to have a low-frequency cutoff of about 2 Hz. In addition, there were two very low-frequency sealed B&K Type 4145 microphones (nominally 0.1 Hz cutoff). One microphone was situated near the front wall of the mobile office trailer (Plate 6), and the other was set up as a ground plane microphone (Plate 8).

All microphones were wired to the USACERL instrument van. In the van, all the test signals were amplified using a Tectronix AM502 differential amplifier to reduce extraneous electrical noise. The data were reduced in real time to obtain the peak level and CSEL for each test stimulus measured by each microphone. The data were reduced using the USACERL Model 380 true-integrating noise monitor and sound exposure level meter. For backup and any subsequent analysis, all data were recorded on Panasonic Model 3500 DAT recorders.

Study Test Sounds

Sonic booms were produced by Navy F-5 fighter aircraft flying at about Mach 1.2, typically at 21,000 to 32,000 ft (6,400 to 9,760 m) above ground level. The aircraft established the specified mach/altitude conditions 20 km from the test site and maintained these conditions to within about 7 km of the test site. The central flight track was aimed directly at the study site. Other flight tracks laterally offset from the central flight track were used to generate lower sonic boom levels; the larger the offset, the smaller the boom level. Offsets up to 10 km were used.

The blasts were produced by C-4 explosives set off on posts at a height of about 0.9 m. The blast site was about 900 m from the test houses. To achieve various blast levels and signatures, three sizes of blast charges were used: (1) the large blast, which was 2.26 kg of C-4 explosives, (2) the small blast, which was 1/4 the size of the large blast or 0.55 kg, and (3) the double blast which was two

1.13-kg charges. The double blasts were set off simultaneously but were separated by about 30 m to achieve a 100-ms delay at the test houses. This double blast was created to have a blast sound which somewhat mimicked a sonic boom.

The original study plan was to produce two sizes of booms, a "large" boom generating a flat-weighted peak level of about 130 dB and a "small" boom generating a flat-weighted peak level of about 125 dB. The combination of high surface temperatures, large negative temperature gradients, winds from the test site towards the aircraft (headwinds), and the limited operational capabilities of the F-5 aircraft resulted in many flights that were very nearly at Mach cutoff, where the booms do not reach the ground due to atmospheric refraction. To try to account for these atmospheric effects, the aircraft altitude and flight track offset was continually adjusted during the study. However, it simply was not possible to control the booms to the original planned levels. Rather, the outdoor flat-weighted peak sound pressure levels of the booms measured at the face of a building generally ranged from about 120 to 135 dB. Moreover, planned "small" booms might actually be large, and planned "large" booms might actually be small. A few boom peak sound pressure levels were higher than 135 dB, and many were lower than 120 dB. The corresponding boom C-weighted sound exposure levels (CSEL) were about 20 to 25 dB below the flat-weighted peak sound pressure levels. The outdoor measured boom CSELs ranged from below 100 dB to above 115 dB. (This same range of levels and degree of scatter was found by Wilshire [1992] for sonic boom sounds generated by this type of aircraft under similar conditions.)

Like the booms, the plan was to have different sizes of blast sounds. It was planned to have a "large" blast with a flat-weighted peak level of about 130 dB, a "small" blast with a flat-weighted peak level of about 125 dB, and a double blast with a flat-weighted peak level of about 127 dB. In contrast to the boom sounds, the planned levels for blast sounds were achieved with a fairly small standard deviation, typically about 2 dB. For single blasts the CSEL was about 20 dB below the peak, flat-weighted sound pressure level and, for the double blasts, this difference was about 17 dB. The outdoor-measured blast CSELs typically ranged from about 104 to 112 dB, which was half the range of the boom data.

The plan was to have only two boom levels, two single blast levels, and one double blast level. The plan was not to span all possible blast and boom levels, but rather, to use the higher end of typical high-energy impulse sound levels experienced in a community. It was also necessary to limit the levels on the high end to levels consistent with previous blast noise research, since the purpose of this study was to compare sonic boom responses to the responses to blast noise found in previous research.

Study Methodology

The test was performed using the paired-comparison study methodology over a 2-wk period. During this time, nine separate groups of subjects participated in the study. Each group consisted of about 26 subjects who judged about 20 boom and 30 blast sounds. Overall, there were a total of 232 subjects.

Subjects arranged in each of the three test structures listened to pairs of sounds. One sound in each pair was a blast or boom test sound. The other sound (control sound) in each pair was a time-shaped, 0.5-s burst of 200 to 1500 Hz, band-limited white noise presented to the subjects through loudspeakers in each living room. An example of the white-noise control sound is shown in Figure 3. The blast or boom test sound was randomly presented first or second in each pair of sounds. The subjects' main task was to decide which was the more annoying sound in each pair, the first sound or the second sound.

The two sounds in each pair were presented within about 30 s of each other. Boom sounds (with corresponding white-noise control sounds) were separated by about 6 min, the time required for the F-5 aircraft to complete an oval flight path and return to generate another sonic boom. One or two blast sounds (with corresponding white-noise control sounds) were presented at random times between each two boom sounds. Because the purpose of this study was to compare the new sonic boom data with the previous blast data that formed the basis for the new method (Schomer 1994), the control sounds and test methodology were very similar to those used in previous blast noise research (Schomer, Buchta, and Hirsch 1991; Schomer et al. 1994; Schomer and Wagner 1995).

In any test, there were five control sound ASELs for each of the five planned impulse sounds (large and small boom, large and small blast, and double blast). The control sound levels were separated by 5 dB, and their levels were chosen so that the middle control sound level would be near the middle of the analysis range as described in the section on **Data Analysis**. The control sound-test sound pairs were presented in a completely random order to the subjects. Table 1 gives the order of test sound presentation, and lists the five test sounds along with the corresponding, relative control sound levels. Table 2 gives the control sound "base" level used in conjunction with Table 1 to calculate the absolute control sound level for each event, structure, and test session.

Table 1. The order of sound pairs presented during each test.

First Half			Second Half		
Event	First Sound	Second Sound	Event	First Sound	Second Sound
1	Large Boom	+10	26	Large Boom	-10
2	0	Small C4	27	0	Double C4
3	-5	Large Boom	28	Small C4	+5
4	-10	Large C4	29	0	Small Boom
5	Small C4	-10	30	+5	Large C4
6	+10	Small Boom	31	+5	Large Boom
7	Large C4	-5	32	Large C4	0
8	+10	Double C4	33	+5	Double C4
9	Large Boom	0	34	Small Boom	-5
10	Small C4	-5	35	Double C4	-10
11	Small Boom	-10	36	Large C4	+10
12	Small C4	+10	37	Small Boom	+5
13	Double C4	-5	38	-5	Double C4
14	+5	Small Boom	39	+10	Small C4
15	+10	Large C4	40	-10	Small Boom
16	-10	Double C4	41	-5	Small C4
17	-5	Small Boom	42	0	Large Boom
18	Double C4	+5	43	Double C4	+10
19	0	Large C4	44	-5	Large C4
20	Large Boom	+5	45	Small Boom	+10
21	Large C4	+5	46	-10	Small C4
22	Small Boom	0	47	Large C4	-10
23	+5	Small C4	48	Large Boom	-5
24	Double C4	0	49	Small C4	0
25	-10	Large Boom	50	+10	Large Boom

For each event pair, the control sound ASEL is given by the base level in Table 2 for that room and test number plus the offset indicated. For example, in all tests the base level in the mobile office for the large booms was 95 dB. Therefore, for sound pair 1, the control sound was presented second and had an ASEL of 105 dB in the two mobile office rooms and in the wooden house. In the brick house, the control sound levels were always 5 dB lower than in the other locations.

Table 2. Control sound ASEL in dB (base levels) in the mobile office rooms and the wooden house by source and test number.

Test Set	Large Boom	Small Boom	Large C4	Double C4	Small C4
1	95	85	95	95	85
2	95	85	95	95	85
3	95	85	90	90	85
4	95	85	90	90	85
5	95	85	90	90	85
6	95	85	90	90	80
7	95	85	90	90	80
8	95	85	90	90	80
9	95	85	90	90	80

Control sound base levels were always set 5 dB lower in the brick house because of its enhanced attenuation from outdoors to indoors. These base levels are used in conjunction with Table 1 to find the actual control level for any test sound, test session, and event. Note that the base levels for the blast sounds were gradually reduced by 5 dB as the data showed that subjects were responding less to the blast sounds than expected by about 5 dB.

Subjects

Subjects were recruited from the Fallon area by a manpower service, and included a cross section of the community; young and old, men and women. Subjects were paid about $50 for participating in the study. As in nearly all former studies, USACERL has performed using this paired comparison methodology, subjects were not screened for hearing acuity (Schomer 1987, 1989; Schomer, Buchta, and Hirsch 1991; Schomer et al. 1994; Schomer and Wagner 1995). Rather, the elderly and others with moderate hearing losses were included as a part of the community cross section. (By design, the paired comparison methodology reduces the dependence on hearing acuity.) Subjects were screened to the extent that they had to be able to converse in English over the telephone and were required to speak, read, and write in English. In this study, 4 of the 232 subjects self-reported some hearing problem. One of these four subjects was in the 25- to 35-yr age range, one was in the 35- to 50-yr range, and two were over 50. Table 3 gives a breakdown of the subjects by age and gender.

Test Procedure

One test was conducted per day and required approximately 2.5 hr to complete. Each day's new group of about 26 subjects was brought by bus to the site where the test was explained. The subjects were randomly divided into groups. Five subjects were situated in the wooden house, and six or seven subjects were situated in the brick house and in each of the mobile office rooms. Plate 9 shows a group of subjects in one of the mobile office rooms.

Each group of subjects had a supervisor. The subjects sat on chairs and couches toward the rear of each room; seat locations were as distant as possible from the wall facing the firing sites and direction of arrival for the sonic booms (i.e., the wall containing the front windows). The test supervisor sat with each test group for a variety of quality control purposes such as answering questions, ensuring that subjects were using the correct answer sheet line number, etc.

Table 3. Breakdown of subjects by age group and gender.

Age Group	Male	Female	TOTAL
16 to 25	56	50	106
25 to 35	13	18	31
36 to 50	15	34	59
Over 50	17	29	46
TOTAL	101	131	232

First, to train the subjects, a pretest used two white-noise samples as the pair of sounds. Typically, three pairs of sounds were presented. If necessary, more pretest pairs were run until everyone fully understood the instructions. Preprinted test forms were used (Plate 10). For each pair of sounds, the subjects were told to mark which of the two sounds in the pair was more bothersome or annoying; the sound they would rather not hear again given the choice.

The subjects were also told to mark how difficult it was to make this decision on a scale of 1 to 5 with the endpoints anchored by the adjectival descriptions "very easy" and "very hard." It is important to note that test participants were required to decide which sound of a pair was more annoying or bothersome for every pair of sounds. They could not say that the two sounds were of equal annoyance, but they could indicate that it was "very hard" to decide. The primary purpose for including this degree-of-difficulty scale was to give the subjects an outlet to ensure that they made a choice as to which sound was more annoying in a pair. This scale was not included for direct-analysis purposes and, as in previous studies, has not been used further. (In earlier studies, it was found that this degree-of-difficulty scale did not provide any information not contained in responses to the direct choice question: "Which sound is more annoying?")

Judgments of the annoyance of each pair of sounds were accomplished in four segments. First, a red light would light and subjects would concentrate on the first sound. Second, a yellow light would light and the participants would listen to the second sound. Third, a green light would light and the subjects would have approximately 5 s to mark the form. Finally all lights would be turned off and the subjects would wait until the red light was turned on again to signal the start of the next pair of sounds. The red and yellow lights lasted for approximately 5 to 10 s with somewhat longer times for the sonic boom sounds.

Signal lights and generation of control sounds were computer controlled. The operator of the computer used a portable radio to contact the blast site and the aircraft and ensure the arrival of each sound at its proper time.

Data Analysis

The test sound CSEL and the control sound A-weighted sound exposure level (ASEL) were the metrics used. The control sound was adjusted so that, at low sound levels, nearly all of the subjects would find the test sound more annoying and, at high control sound levels, nearly all of the subjects would find the control sound more annoying. In between these levels was the point where 50 percent of the subjects found the test sound to be more annoying, and 50 percent found the control sound to be more annoying. This point, also called the equivalency point, is where the annoyance generated by the test sound (blast or boom) was equivalent to the annoyance generated by the control sound.

To perform the data analysis, the blast and boom signals were divided into 4-dB-wide bins. The bin center was used to designate the blast or boom level. The data in any bin contained many control levels, so it was possible to plot the percent finding the test signal more annoying as a function of the control signal level. For each such bin, each type of sound and each room, the data were plotted and analyzed.

The result of such analysis should have the form of a transition function. However, it is not feasible to test with extremely high- or low-level control sounds. For example, indoors, control ASELs at or below 40 dB were virtually inaudible and not measurable (at a field test site), and control ASELs at or above 120 dB are well above recommended levels for hearing conservation. Therefore, in this analysis, a transition curve was fitted to the data. However, this curve was constrained to be very near to 100 percent for control ASELs at or below 40 dB. Also, this curve was constrained to be very near 0 percent for control ASELs at or above 120 dB. As explained later, this analysis was also performed using the outdoor-measure CSELs of the impulse sounds. For this latter analysis, the transition curves were constrained to be very near 100 percent for control sound ASELs at or below 50 dB and very near 0 percent for control sound ASELs at or above 130 dB.

One of the following three transition functions was used to produce a plot for each test sound and corresponding set of control sounds. Selection of the best-fit function was made on the basis of which yielded the smallest errors. The curve having the largest F-statistic (i.e., minimum mean square residuals) was selected. Once the plots were generated, the sound exposure level of the test sound source and the corresponding ASEL of the control sound for each equivalency point were determined by computer solution of the curve fitted to the data.

Each of the three potential transition functions has four independent parameters, a, b, c, and d. Each curve relates the percent of the judgments finding the test sound to be more annoying, %, to the ASEL of the control sound, L_{AE}, in decibels.

The Sigmoid function has the form:

$$\% = a + b/\{1 + \exp[-(L_{AE} - c)/d]\}, \qquad [Eq\ 2]$$

the Logistic Dose Response function has the form:

$$\% = a + b/[1 + (L_{AE}/c)d], \qquad [Eq\ 3]$$

and the Cumulative Distribution function has the form:

$$\% = a + (b/2)\{1 + \mathrm{erf}[(L_{AE} - c)/(21/2d)]\} \qquad [Eq\ 4]$$

where erf is the Error function.

Each of these functions was fit to the data, and the best fit was selected using a commercial PC curve-fitting software package called "Tablecurve." This package also plotted the 95%-confidence limits to the transition function. The 50 percent equivalency point was found for each such curve.

Figure 4 shows a typical transition curve. This particular transition curve shows the percentage of respondents from the brick house that found a boom sound more annoying than a control sound as a function of the control sound ASEL. The boom sound data used in this figure are outdoor data and are for the bin with CSELs between 108 and 112 dB. The bin center is 110 dB. The equivalency point is calculated using the computer software and has a control sound level of 88.3 dB. In this transition curve fitting process, the data points are weighted by the number of subjects included in the calculation of that percentage.

Each pair of points in Tables 4 or 5 is derived from a transition curve figure like Figure 4. For example, the value listed for the "Brick House Boom" in the "110 dB" column of Table 5 is 88.3 dB; the value derived from Figure 5. Overall, each table summarizes the results from 232 subjects, each of whom responded to 20 boom and 30 blast sounds. Appendix A contains the transition curves for each entry in Table 4, and Appendix B contains the transition curves for each entry in Table 5. The tables include the F-statistic and the corresponding standard error for each transition curve, type of curve fit, 95%-confidence limits, and the t-value and standard error for each of the four independent parameters.

Bins not represented in Tables 4 or 5 did not have sufficient data to create a good transition curve. The criterion used to label a bin as bad was that the percentages calculated from the measured data did not encompass the 50 percent point. That is, all of the calculated percentages were either above or below 50 percent. In this case the error range on the 50 percent point was very large—typically greater than 30 dB. In one case, a bin was deleted even though the data encompassed the 50 percent point. In this case (Figure 5), the lower two points represented only 4 and 14 subject judgments, respectively. Therefore, the data for this transition curve virtually did not include the 50 percent point. As shown, the resulting 95%-confidence interval is very large.

Table 4. Equivalently annoying white-noise control sound ASEL (in decibels) for the blast or boom CSEL bin center indicated—indoors.

Bin Center CSEL (dB)	86	90	94	98	102	106
Brick House Blast		79.9 +1, -2	79.5 +2, -2			
Brick House Boom	74.0 +2, -2	83.0 +4, -4	88.1 +3, -2			
Mobil Office Blast			73.9 +1, -1	88.8 +3, -2		
Mobile Office Boom			84.1 +6, -7	88.7 +3, -3		
Wooden House Blast				70.6 +1,-1		86.1 +7, -7
Wooden House Boom						85.3 +5, -10

Each pair of points on this table comes from a transition curve like Figure 5. Bins not represented on this table did not have sufficient data to create a good transition curve. Each bin was 4-dB wide. Bin centers were chosen to maximize the number of good data bins. Overall, this table summarizes the results from 232 subjects, each of whom responded to 20 boom and 30 blast sounds.

Table 5. Equivalently annoying white noise control sound ASEL in decibels for the blast or boom CSEL bin center indicated—outdoors.

Bin Center CSEL (dB)	102	106	110	114
Brick House Blast		69.3 +1, -1	79.6 +2, -2	
Brick House Boom	75.7 +3, -4	81.6 +6, -9	88.3 +2, -2	94.9 +12,-7
Mobile Office Blast		74.7 +2, -2	81.9 +2, -2	
Mobile Office Boom	79.3 +7, -11	84.4 +4, -6	90.0 +1, -1	94.7 +5, -3
Wooden House Blast			82.5 +3, -4	
Wooden House Boom			83.6 +4, -5	

The CSEL are measured outdoors and the control sound ASEL are measured indoors. Each pair of points on this table comes from a transition curve like Figure 4. Bins not represented on this table did not have sufficient data to create a good transition curve. Each bin was 4-dB wide. Bin centers were chosen to maximize the number of good data bins. Overall, this table summarizes the results from 232 subjects, each of whom responded to 20 boom and 30 blast sounds.

The bin centers and bin widths were chosen to maximize the number of good data bins and are indicated in the table headings. The selected bin width was 4 dB. We also examined 3-dB-wide bins but found that, with less subject judgments per bin, the error bounds were frequently unacceptably large. Because of these larger error bounds, there were no more acceptable bins using a 3-dB bin width than there were when using a 4 dB bin width. The bin centers were staggered by 2 dB in an attempt to obtain more good bins, but the data as presented herein provided the maximum number of good bins.

Tables 4 and 5 also list the 95%-confidence intervals for each data point. Some intervals are very small (+1, -1 dB) and others are quite large. On average, the blast sound data confidence intervals are ±2 dB and the boom sound data confidence intervals are ±5 dB for both tables. Table 5 shows that all of the outdoor measured blast sound data fit in just two bins (the 106 and 110 dB CSEL bins), just as originally planned. In contrast, the boom sound data span four bins because of the large variability of the boom levels. Moreover, because of this variability, "large" booms did not necessarily occur with correspondingly large control sounds, and vice-versa. Because of this variability in the conduct of the test, the larger sonic boom sound data confidence intervals are not surprising.

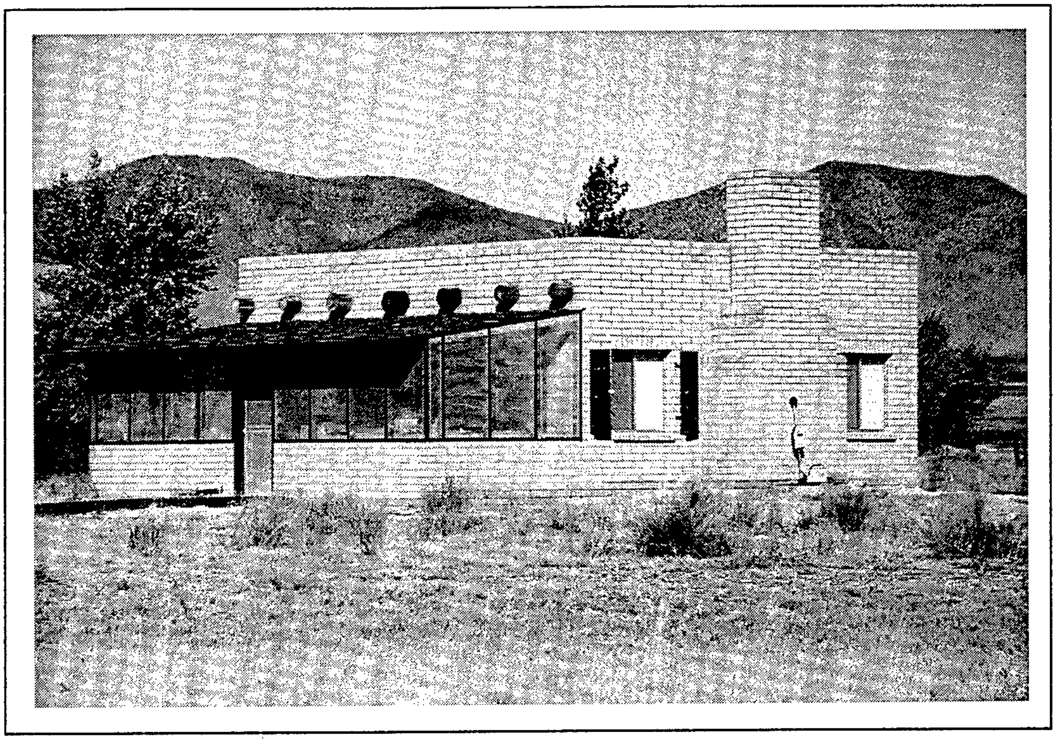


Plate 1. The brick house.

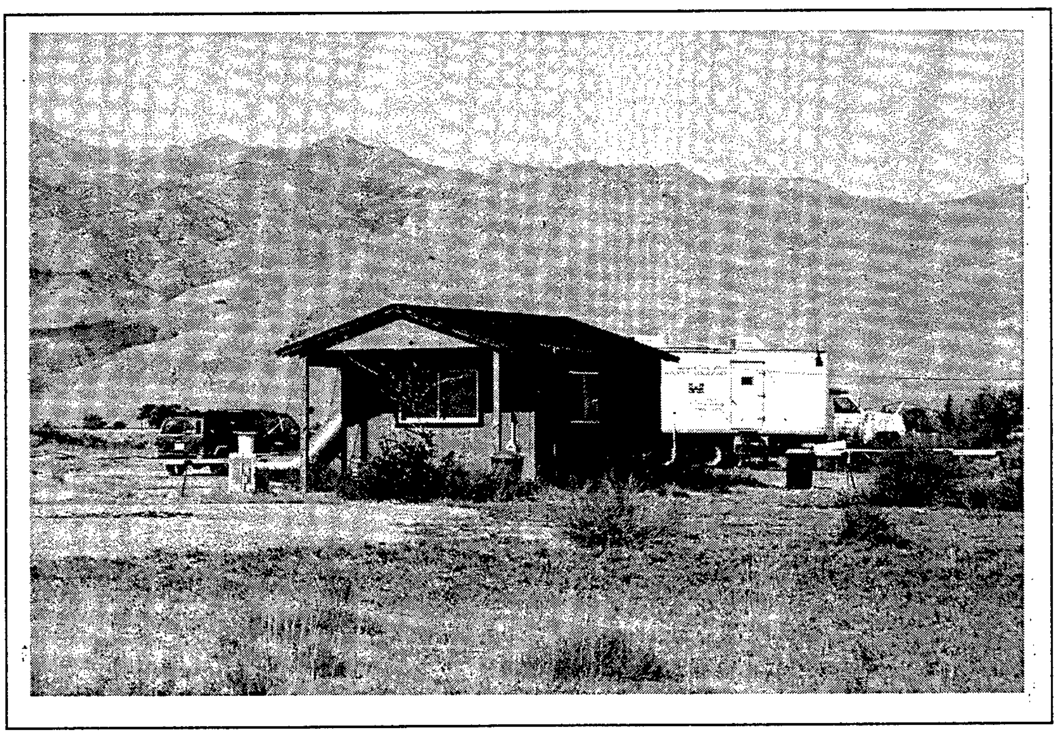


Plate 2. The wooden house.

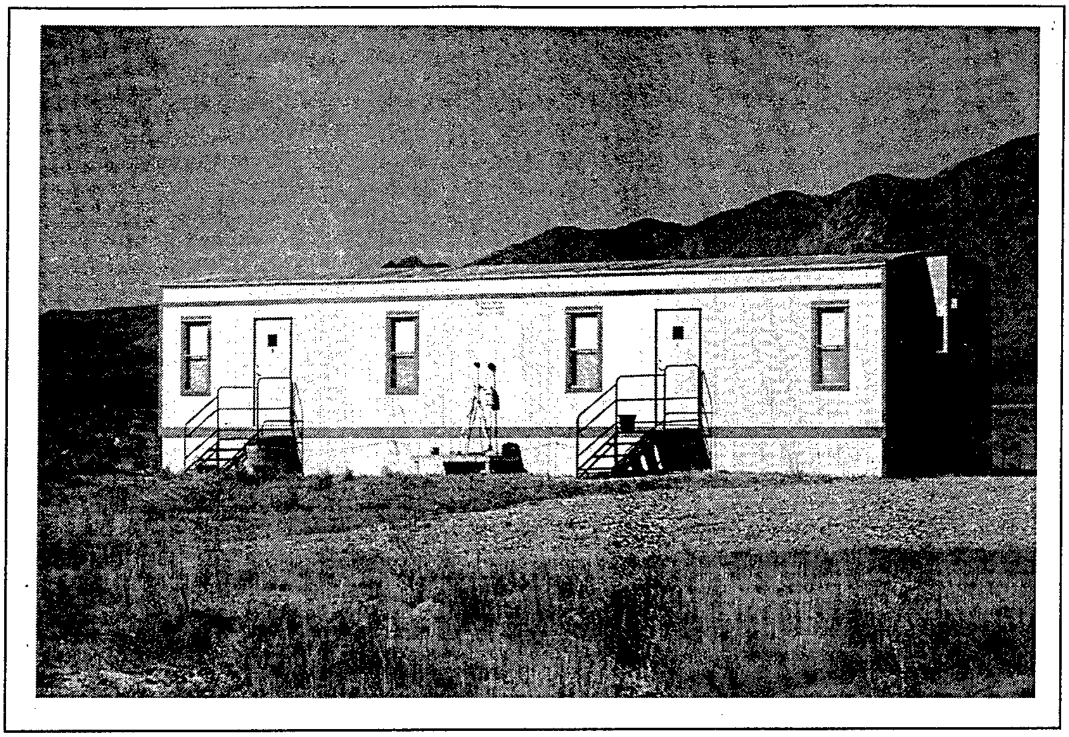


Plate 3. The office trailer.

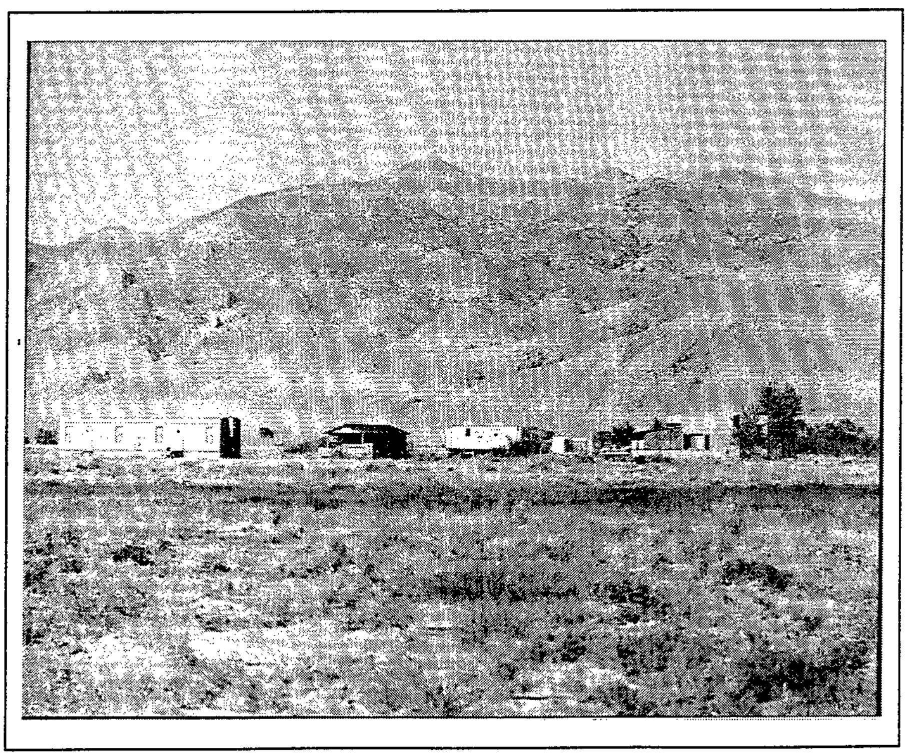


Plate 4. The three structures and the measurement van at the study site.

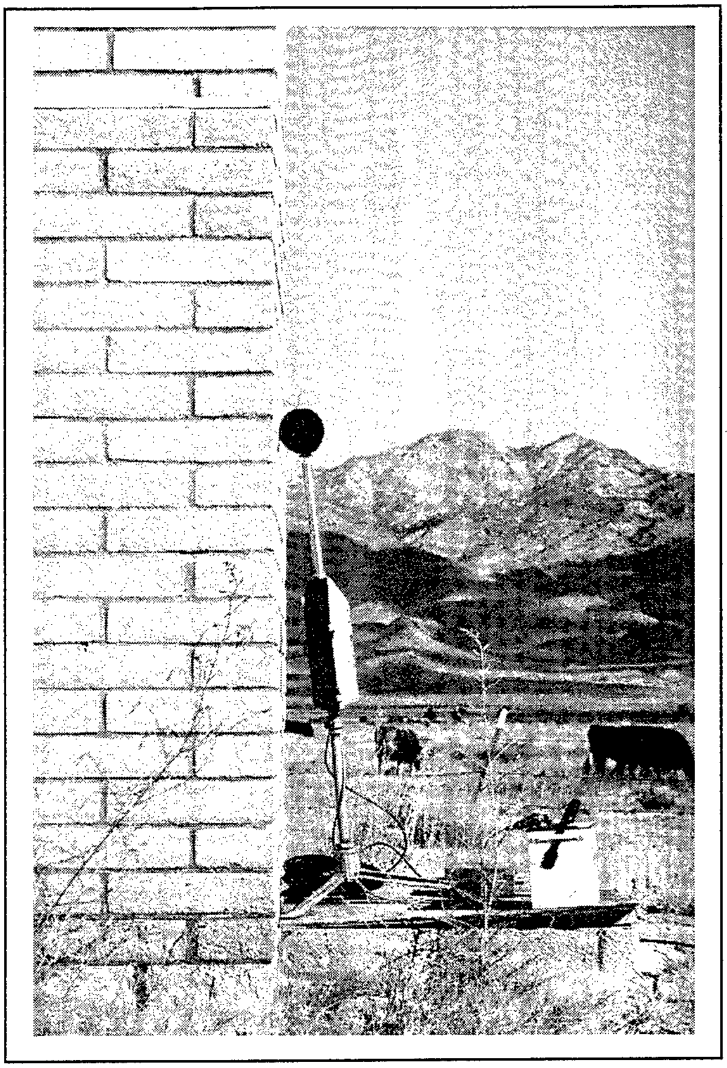


Plate 5. A B&K Model 4921 outdoor microphone situated close to the chimney wall of the brick house.

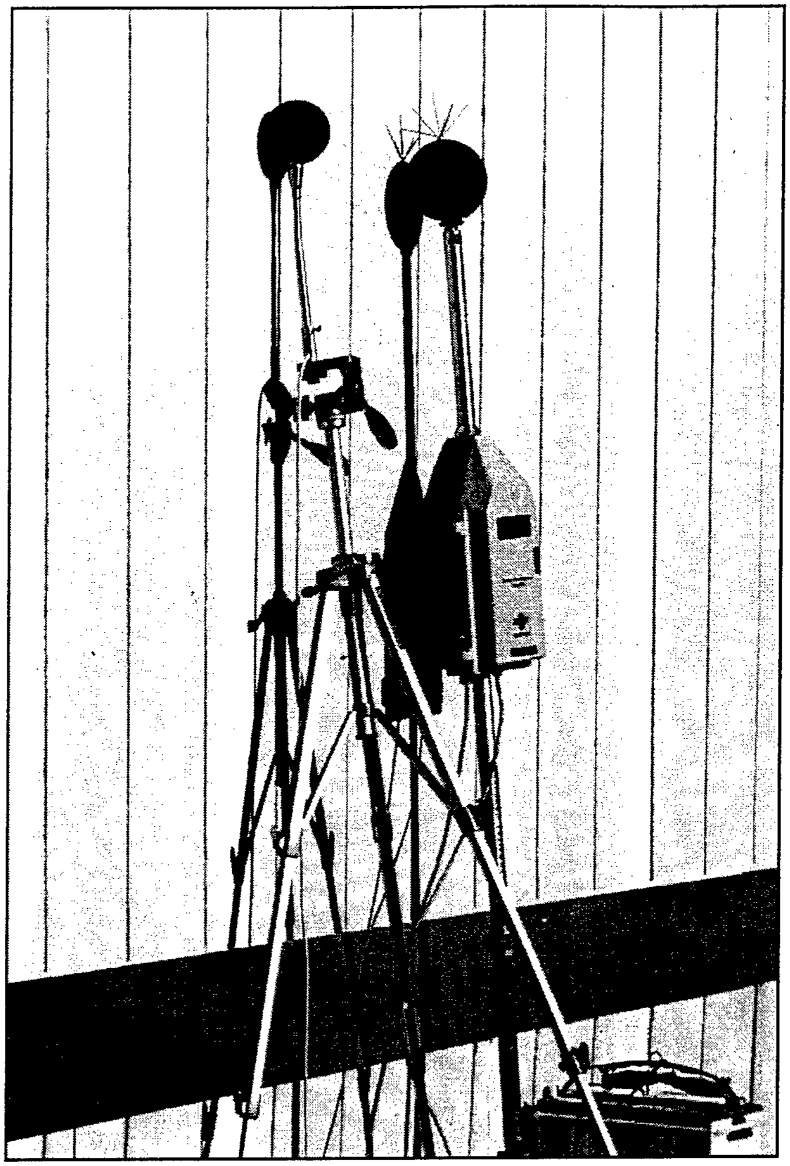


Plate 6. Two microphones (left, a special low-frequency 0.1 Hz microphone; right, the B&K model 4921 outdoor system) in front of a large open area on the front wall of the trailer.

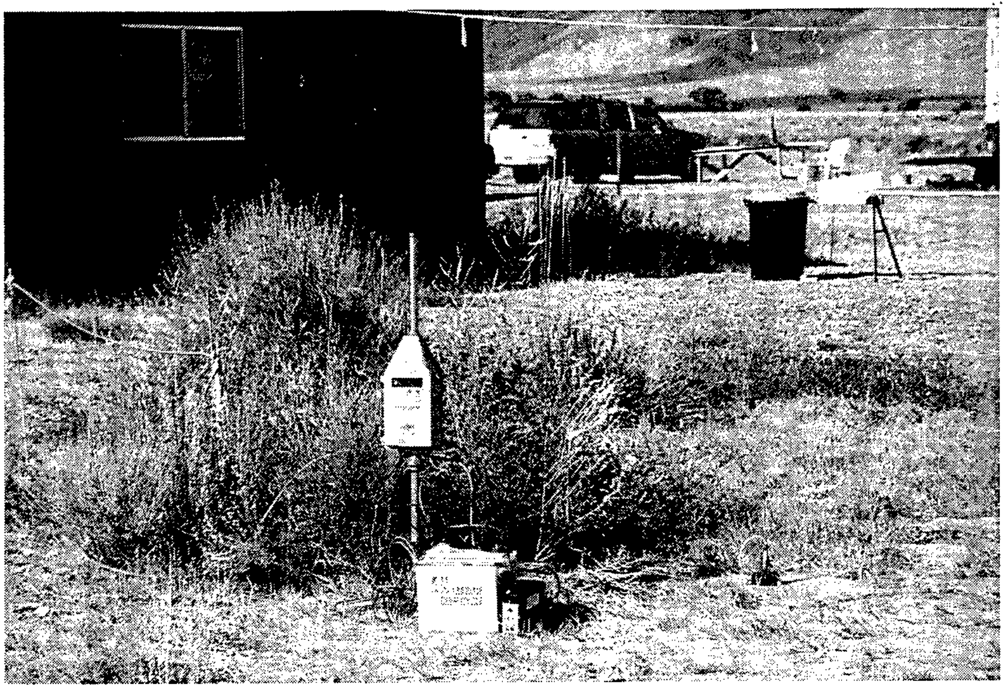


Plate 7. A B&K Model 4921 outdoor microphone system used as a "free-field" microphone.

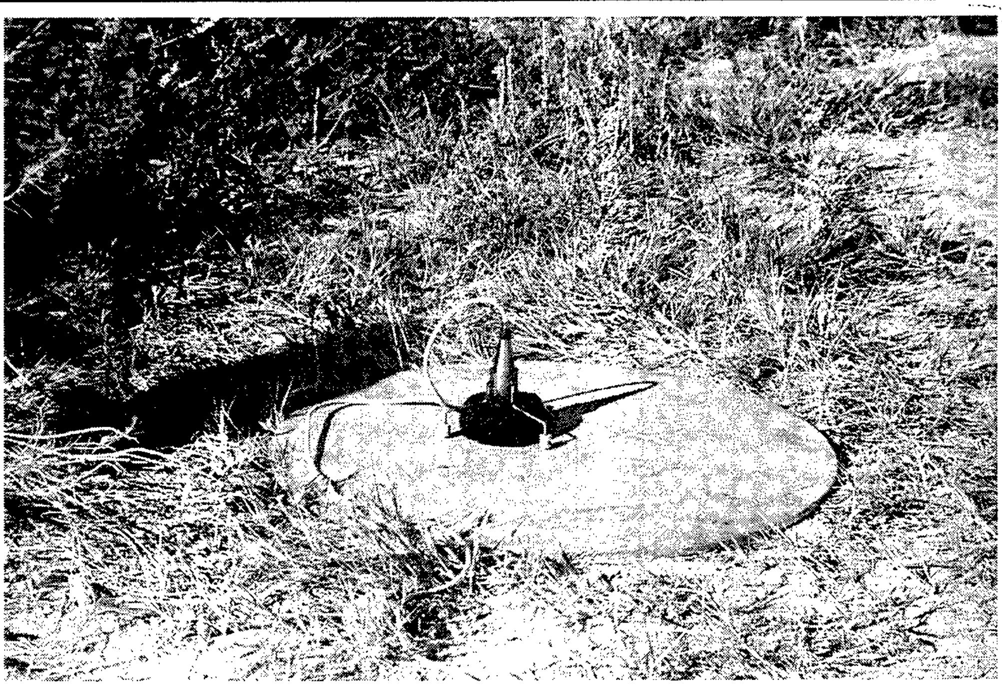


Plate 8. The ground plane microphone.

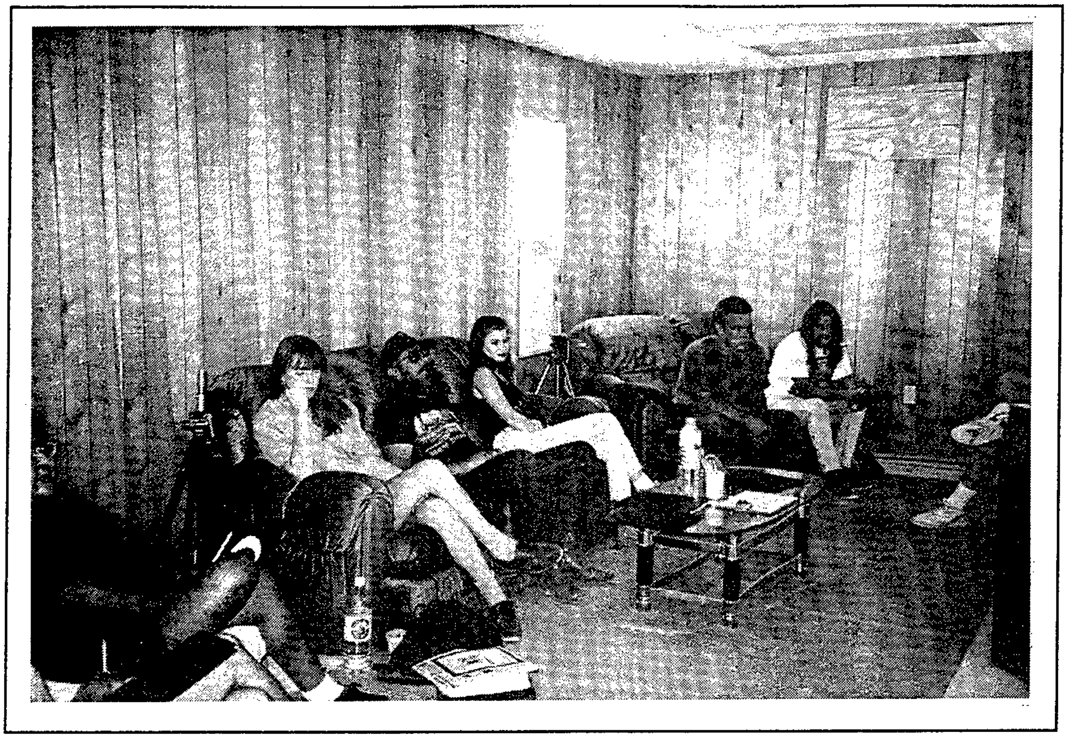
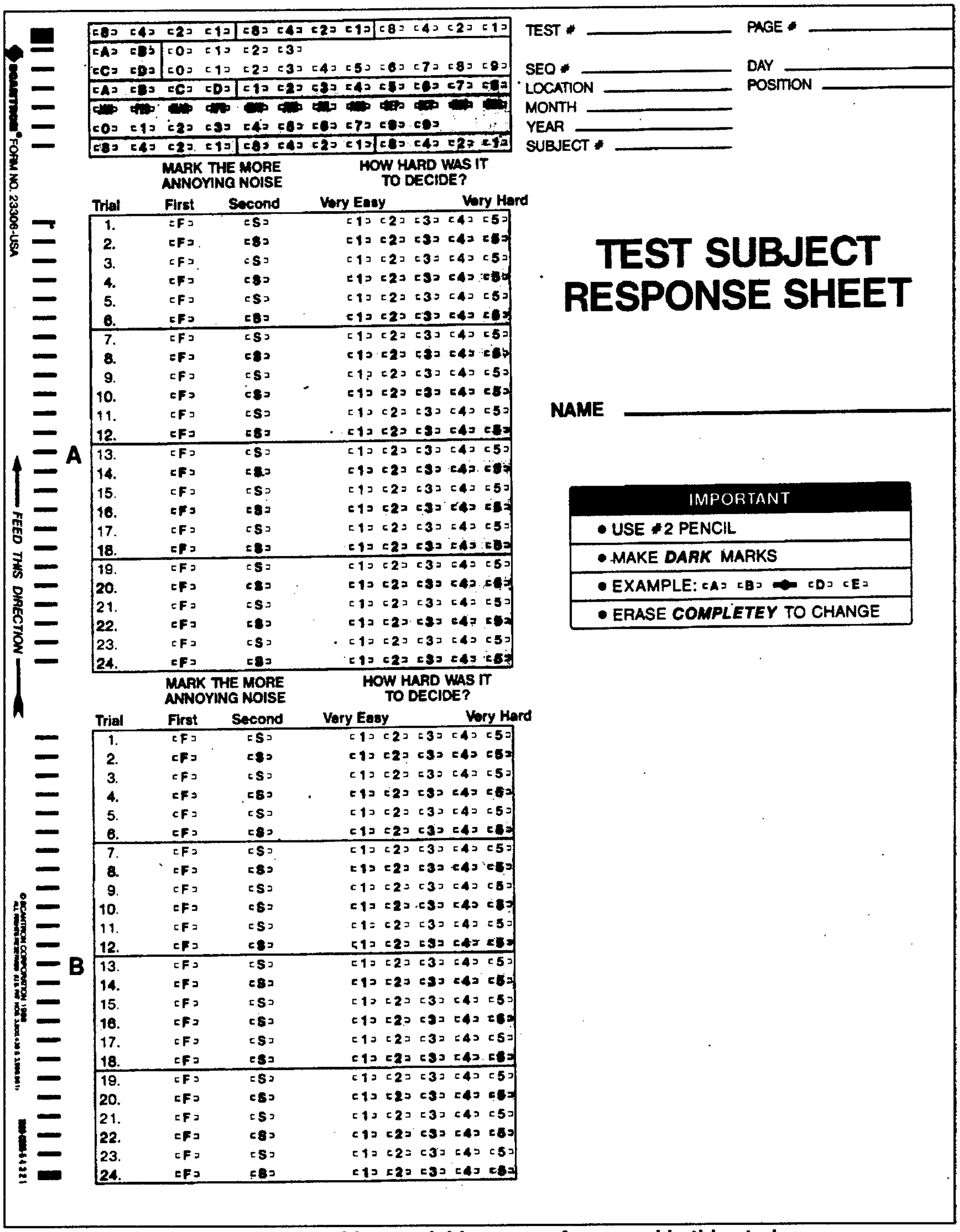


Plate 9. Subjects in one of the two trailer test rooms.


TEST SUBJECT RESPONSE SHEET

TEST # ____ PAGE # ____

SEQ # ____ DAY ____

LOCATION ____ POSITION ____

MONTH ____

YEAR ____

SUBJECT # ____

NAME ____

IMPORTANT

- USE #2 PENCIL
- MAKE **DARK** MARKS
- EXAMPLE: A B ■ D E
- ERASE ***COMPLETEY*** TO CHANGE

SCANTRON® FORM NO. 23306-USA

FEED THIS DIRECTION

A

MARK THE MORE ANNOYING NOISE / HOW HARD WAS IT TO DECIDE?

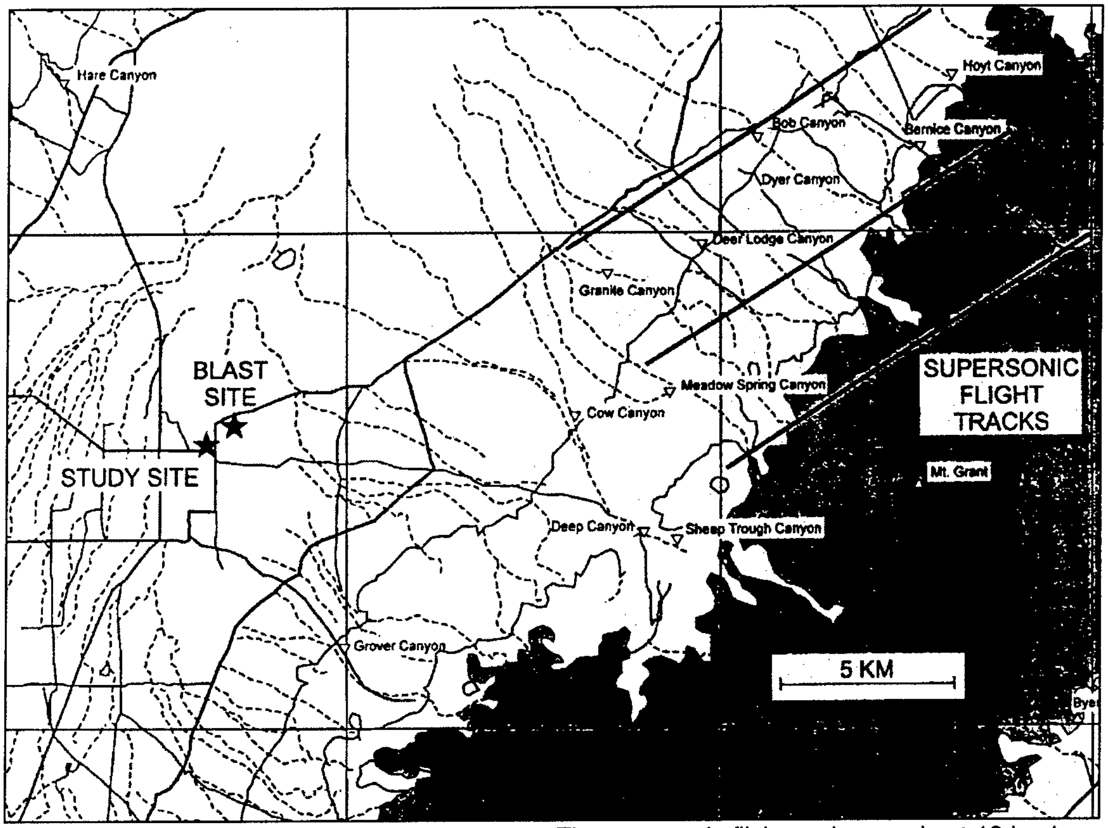
Trial	First	Second	Very Easy				Very Hard
1.	F	S	1	2	3	4	5
2.	F	S	1	2	3	4	5
3.	F	S	1	2	3	4	5
4.	F	S	1	2	3	4	5
5.	F	S	1	2	3	4	5
6.	F	S	1	2	3	4	5
7.	F	S	1	2	3	4	5
8.	F	S	1	2	3	4	5
9.	F	S	1	2	3	4	5
10.	F	S	1	2	3	4	5
11.	F	S	1	2	3	4	5
12.	F	S	1	2	3	4	5
13.	F	S	1	2	3	4	5
14.	F	S	1	2	3	4	5
15.	F	S	1	2	3	4	5
16.	F	S	1	2	3	4	5
17.	F	S	1	2	3	4	5
18.	F	S	1	2	3	4	5
19.	F	S	1	2	3	4	5
20.	F	S	1	2	3	4	5
21.	F	S	1	2	3	4	5
22.	F	S	1	2	3	4	5
23.	F	S	1	2	3	4	5
24.	F	S	1	2	3	4	5

B

MARK THE MORE ANNOYING NOISE / HOW HARD WAS IT TO DECIDE?

Trial	First	Second	Very Easy				Very Hard
1.	F	S	1	2	3	4	5
2.	F	S	1	2	3	4	5
3.	F	S	1	2	3	4	5
4.	F	S	1	2	3	4	5
5.	F	S	1	2	3	4	5
6.	F	S	1	2	3	4	5
7.	F	S	1	2	3	4	5
8.	F	S	1	2	3	4	5
9.	F	S	1	2	3	4	5
10.	F	S	1	2	3	4	5
11.	F	S	1	2	3	4	5
12.	F	S	1	2	3	4	5
13.	F	S	1	2	3	4	5
14.	F	S	1	2	3	4	5
15.	F	S	1	2	3	4	5
16.	F	S	1	2	3	4	5
17.	F	S	1	2	3	4	5
18.	F	S	1	2	3	4	5
19.	F	S	1	2	3	4	5
20.	F	S	1	2	3	4	5
21.	F	S	1	2	3	4	5
22.	F	S	1	2	3	4	5
23.	F	S	1	2	3	4	5
24.	F	S	1	2	3	4	5

Plate 10. The machine-readable answer form used in this study.



The blast site is about 900 m from the structures. The supersonic flight tracks are about 13 km long and end about 7 km from the study site. The central flight track was aimed directly at the study site. Other flight tracks laterally offset from the central flight track were used to generate lower sonic boom levels; the larger the offset, the smaller the boom level. Offsets up to 10 km were used. To generate the booms at the study site, the aircraft flew towards the site.

Figure 1. The study area.

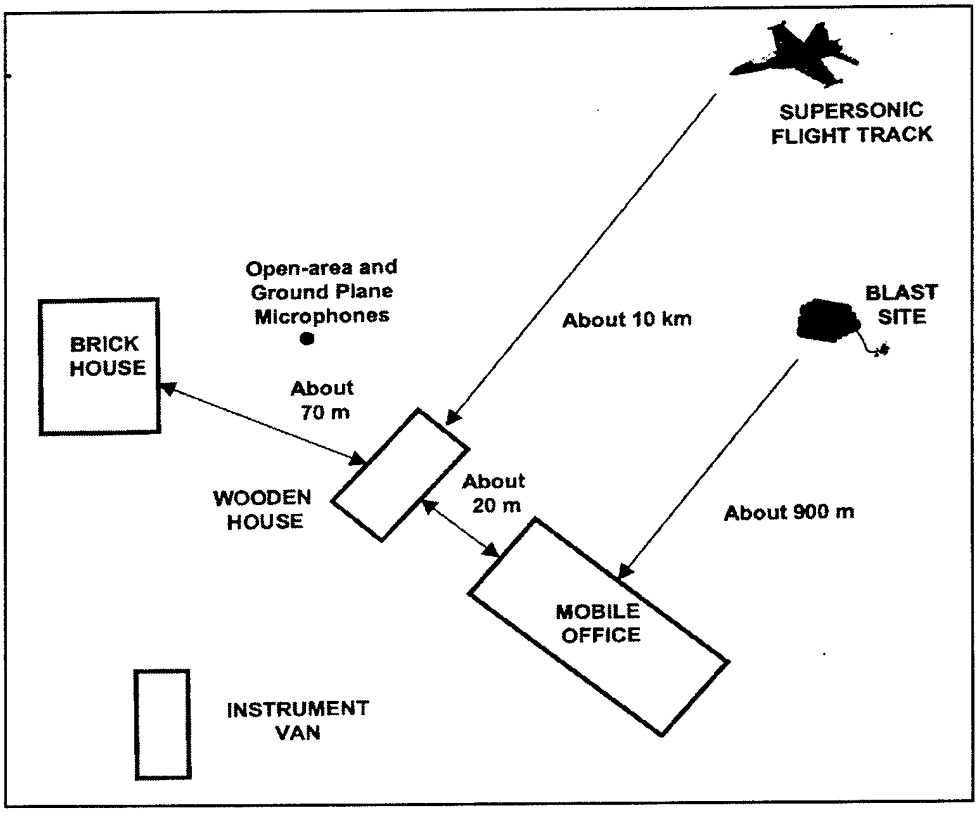


Figure 2. The layout of the immediate test site.

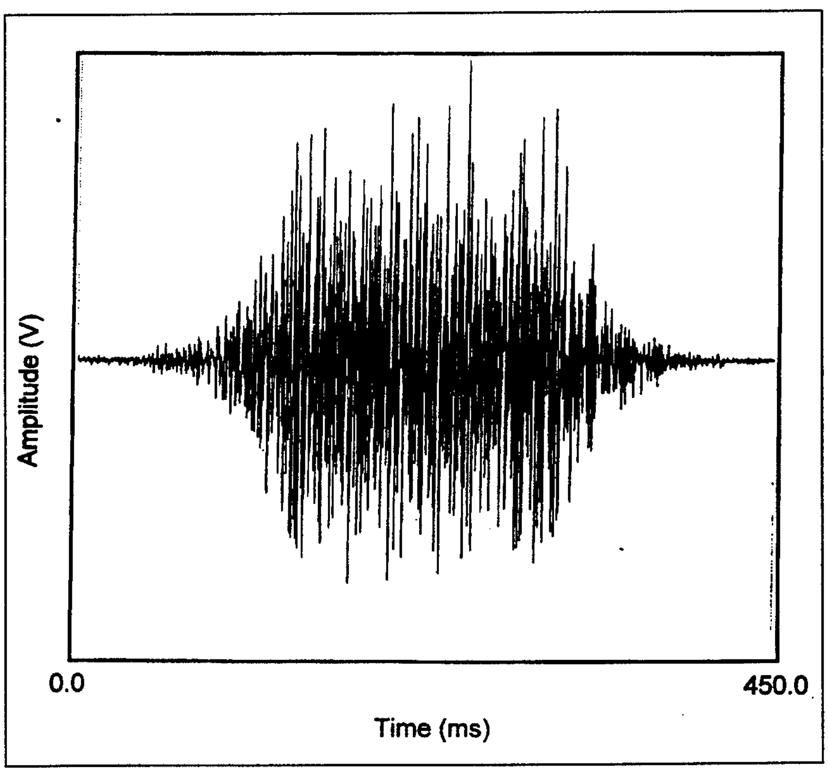
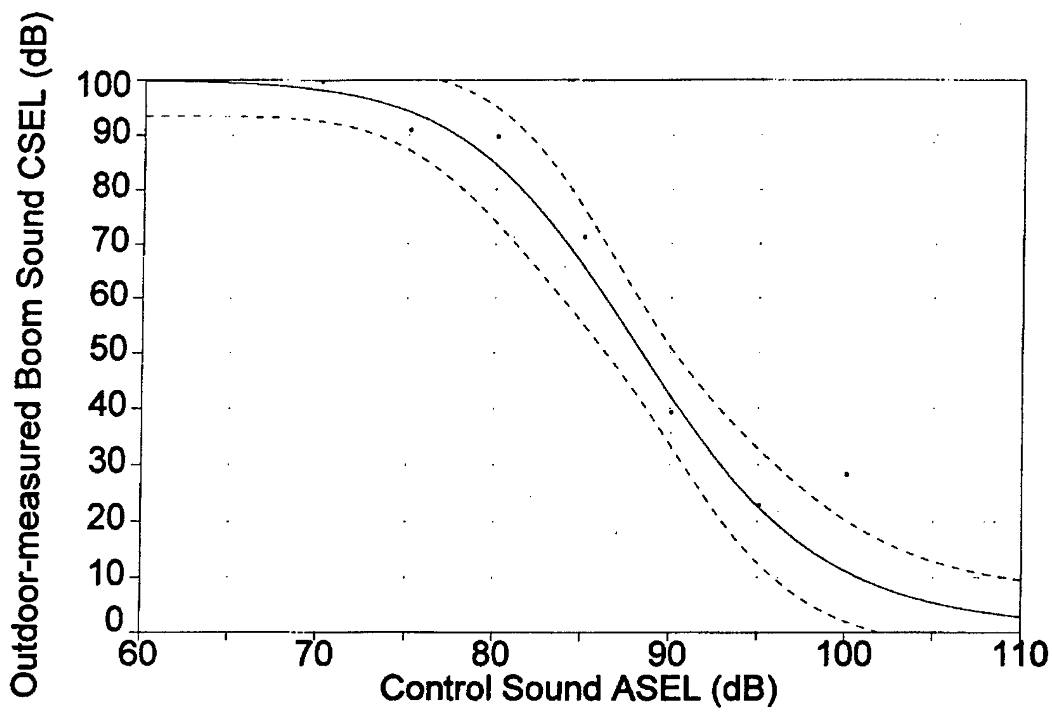
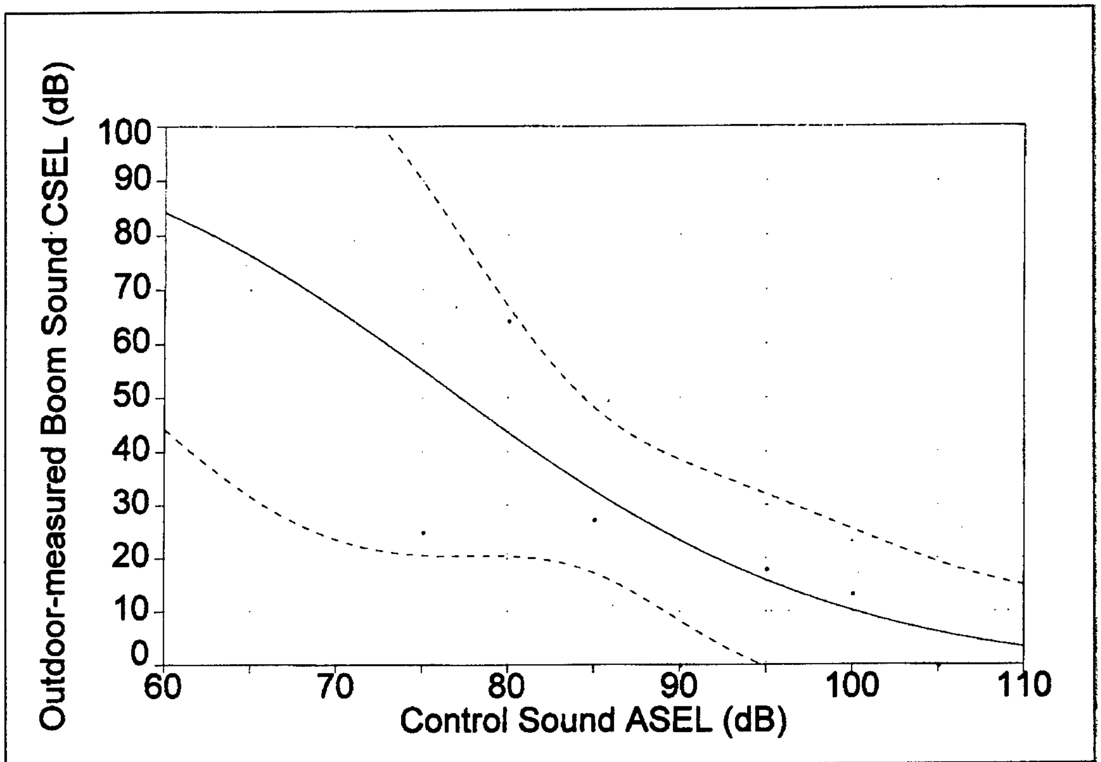


Figure 3. An example of the 200 to 1500 Hz band-limited white-noise control signal.



One of these curves was produced for each entry in Tables 4 and 5. A commercial curve-fitting program was used to fit a transition curve to the data. These transition curves determine the equivalency point where the annoyance generated by the two sounds, the blast or boom sound and the control sound, are equivalent. This figure shows the percentage of respondents from the brick house that found a boom sound more annoying than a control sound as a function of the control sound ASEL. The boom sound data used in this figure are outdoor data and are for the bin with CSELs between 108 and 112 dB. The bin center is 110 dB. The equivalency point is calculated using the curve-fitting program and has a control sound level of 88.3 dB. This is the value listed for the Brick House Boom in the 110 dB column in Table 5.

Figure 4. A typical transition curve along with the 95%-confidence interval.



This example is for indoor-measured booms in the wooden house. The two lower ASEL points represent only 4 and 14 subject responses, so there was very little data for response percentages above 50 %. The resulting 95 % confidence intervals are considered to be too large and so this bin was excluded from the analysis.

Figure 5. An example of rejected bin data.

3 Analysis and Discussion

Preliminary Blast/Boom Analysis

In the preliminary analysis, equivalency points were determined separately for large blast, small blast, and double blast sounds for each house. The sonic boom data were immediately grouped together since, as noted earlier, frequently a large boom was generated when a small boom was planned and *vice-versa*; they could not be grouped separately. The large blasts and the double blasts produce about the same CSEL since they were generated by the same size charge in weight. Therefore, one can compare the responses of the subjects to the double blasts as compared with their responses to the large blasts. Table 6 lists this comparison by room. For the same CSEL and test room, virtually no difference exists between subject responses to the large or to the double blast sound. A t-test on the means for the two sources represented in Table 6 shows that they are not significantly different. The subjects responded to the double 2.25-kg blast sound in essentially the same manner as they did to the single blast sounds of comparable energy. For this reason (as in previous studies), all of the blast sound data were grouped together in the following analysis.

Table 6. Differences between subject responses to large blast and double blast sounds.

Location	Blast CSEL (dB)	Large Blast Control Sound ASEL (dB)	Double Blast Control Sound ASEL (dB)	Difference in Control Sound ASEL (dB)
Brick House	92	78	79	1
Mobile Office Rooms	96	80	82	2
Wooden House	100	78	77	-1
Mean		78.67	79.33	0.667
STD Deviation		1.16	2.52	1.36

The 95-% confidence interval for difference of means is -3.1 to +4.5 dB.

General Blast/Boom Analysis

The general analysis was performed by plotting the pairs of equivalency points developed from each data bin represented in Tables 4 and 5. Since the purpose of this study was to compare the new sonic boom data with all of the previous blast data, the starting point for the analysis was the totality of previous blast noise results performed using this paired-comparison methodology. This totality includes the data from Munster and Grafenwöhr Training Area (GTA), Germany and Aberdeen Proving Ground (APG), MD, USA (Schomer 1994). Figure 6 reproduces all of these previous blast noise results and includes a regression line fitted to these previous data (R^2=0.80; see C1). This figure compares the indoor-measured blast sound CSELs with equivalently annoying white-noise control sound ASELs. The new data from the NAS Fallon tests (contained in Table 4) also are plotted in Figure 6, which shows that the new, measured-indoor results from the Fallon tests are generally similar to the previous blast noise data. There is quite a bit of scatter to the data, especially for the Wooden House.

These new Fallon test data, like the previous blast noise results, are indoor-measured CSELs. But it is not clear that CSEL should be measured indoors near to the subjects. All environmental noise is normally measured or predicted outdoors. Further, in the case of high-energy impulsive sounds, the C-weighting was not chosen for its ability to correlate directly with human response. Rather, the C-weighting was chosen primarily to provide a standardized measure that incorporated the low-frequency sound pressures associated with high-energy impulsive sounds, since these low-frequency energies contribute most to building vibrations and rattles (NRC 1996). This occurrence is best represented by the outdoor-measured CSEL, not the CSEL measured near the subjects ears. Therefore, it is appropriate to examine these same relations using outdoor-measured CSELs. To do this, the previous blast data from Figure 6 were converted to portray the results with outdoor-measured CSEL. These converted data are displayed in Figure 7.

Outdoor-measured CSEL are shown in Figure 7 as a function of indoor-measured, equivalently annoying white-noise control sound ASEL. (The indoor-measured control sound levels were used because there were no corresponding outdoor-measured levels for sounds created by indoor loudspeakers.) For the new data from the Fallon tests, all of the subject data were reanalyzed using actual outdoor CSEL measurements. These data also were combined into bins. Table 5 contains the results of this analysis. For the previous blast noise data (Schomer 1994), the outdoor-measured CSELs were approximated as the indoor-measured CSEL plus a constant. For APG, the original outdoor- and indoor-measured data were used to find a constant difference of 14.5 dB. This difference had a standard deviation of less than 1 dB. For Munster, the original data were used to find a constant difference of 12 dB, again with a standard deviation of less than 1 dB, and for the previous GTA data (where the original data are no longer readily available), an average value of 13 dB was used.

As in Figure 6, Figure 7 includes the previous blast data and a regression line that has been fitted to these data (R^2 =0.79, see C2). Figure 7 also includes the outdoor-measured NAS Fallon data from Table 5. One can compare the fit of the Fallon data to the respective regression lines in Figures 6 and 7. From observation, it is clear that the new data in Figure 7 better fit the regression line than the data represented by Figure 6 fit. To quantitatively aid in this comparison, the 95%-prediction intervals for the previous blast data are shown in Figures 6 and 7. In Figure 6, three of the new data points (25 percent) lie outside the 95%-prediction interval for the previous blast data while, in Figure 7, none of the data points lie outside of the indicated prediction interval. For the new boom and blast data portrayed in Figures 6 and 7, one can construct the root-mean-square (RMS) difference in CSEL between the new measured data points and the regression line prediction of CSEL for the previous blast data (each for the same control sound ASEL). For the indoor-measured data (Figure 6), this RMS difference is 6.6 dB, and for the outdoor-measured data (Figure 7), this RMS difference is 3.2 dB. This analysis confirms that the new data in Figure 7 better fit the regression line than is the case for the data represented in Figure 6.

That the outdoor-measured data form a better prediction of response tends to reinforce the concept that C-weighting is a useful outdoor measure for assessing the indoor community response to high-energy impulsive sounds. It should only be used outdoors—not indoors. Since one reason for choosing C-weighting was to include those acoustical energies that induce building vibrations and rattles, it is inferred that the outdoor-measured CSEL works better than the indoor measurements because it is the outdoor measurements which correlate with induced building vibrations and rattles. The indoor C-weighted measurements predict neither building response nor human response. For these reasons, only the outdoor-measured data are used in the remainder of this report.

Comparison of New Blast and Boom Data With Previous Blast Data

The purpose of this study was to determine if the new responses of subjects to sonic booms were consistent with the previous blast response data. Two methods are used to form this test. First, Figure 7 shows that all of the sonic boom data gathered in this test lie well within the 95%-prediction interval for the previous blast data and are more or less evenly distributed around the regression line fit to the previous blast data. This result indicates that new sonic boom data are similar to the previous blast data. Second, Appendix C contains the results of regression analysis performed on the new sonic boom data and the previous blast data. The slopes and intercepts to the two regressions are virtually indistinguishable. Since results from the previous data are incorporated in an NRC study and are now being used in an ANSI Standard, the following analysis takes the slope and intercept of the regression line fit to the previous blast data as known constants. One can then test if the new data sonic boom regression line parameters are significantly different from the "known" slope and intercept. The 95%-confidence intervals for the slope and intercept for the regression line fit to the sonic boom data (Table C3) clearly are much larger than required to include the known slope and intercept of the previous blast data (Table C2). On the basis of this discussion, there is no reason to conclude that the sonic boom data are statistically distinguishable from the previous blast data.

This result shows that the new high-energy impulse noise assessment method (Schomer 1994), which is based on the previous blast data, can be used to predict people's response to sonic booms. In fact, for outdoor-measured data, the RMS difference of the new sonic boom data from the previous blast data regression line is 1.5 dB, which is much less than the variance (3.8 dB) of the previous blast data from its own regression line.

The same analysis as above can be performed with the new blast data and results compared with the previous blast data. First, Figure 7 shows that the new blast data lie within the 95%-prediction interval for the regression line fit to the previous blast data. However, the new blast data are not evenly distributed about the regression line fit to the previous data. Rather, all of the new blast data are situated above the regression line. Since there are five data points, this result is unlikely to happen by chance at the 5 percent level.

Table C4 contains statistical data for a regression line fit to the new blast data. The 95%-confidence interval for the slope to the new blast data regression line ranges from 0.0785 to 0.645. This slope clearly includes the slope to the previous blast data regression of 0.585. The 95%-confidence interval for the intercept to the new blast data regression line ranges from 58.3 dB to 102.4 dB. This 44 dB range in intercept just includes the intercept to the previous blast data regression line. Therefore, one cannot conclude that the slope or the intercept to the regression line fit to the new blast data are significantly different from the slope and intercept for the "standard."

Overall, with only five new blast data points and standard statistical tests, the new blast data cannot be said to be significantly different from the previous blast data. But the fact that all five points lie above the line is a strong indication that they are different. As a further comparison, the RMS difference of the new blast data from the previous blast data regression line is 4.9 dB, which one can compare with the variance (3.8 dB) of the previous blast data from its own regression line.

In general, the NAS Fallon data fit the existing wider body of blast data fairly well. The blast data from Fallon typically lie about 5 dB above (less annoying) the regression line fit to the previous blast sound data (Schomer 1994), but well within the range of previous blast data. The fit of the sonic boom data to the previous blast sounds regression line is excellent.

Comparison of New Blast and Boom Results

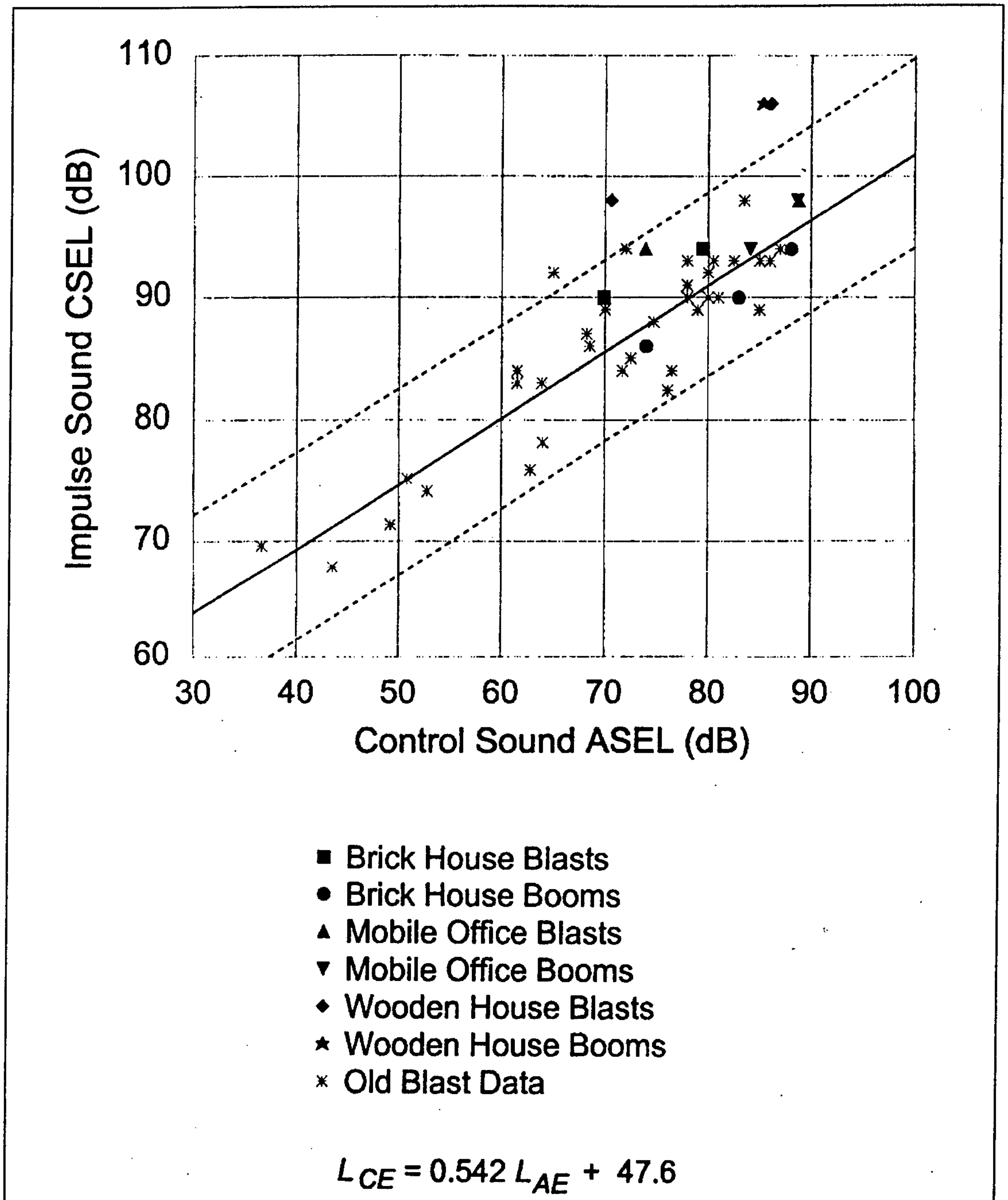
Figure 8 shows regression lines fit to just the new blast and boom data. One can compare just these regression line data to each other. For this comparison, the pooled standard error of the slope (0.07) and the pooled standard error of the intercept (5.7 dB) are estimated using the data in Appendix C. The difference in slopes is 0.28, and the difference in intercepts is 27.2 dB. With these differences, the t-values for slope and intercept differences would have to be 5.81 and 6.85, respectively, for a conclusion that they were not different. These t-values are too large to accept the null hypothesis. Therefore, this analysis shows that the slopes and intercepts to the new blast and new boom data are different.

Perhaps the most interesting point one can glean from Figure 8 and Appendix C is that the slopes to the new blast and boom data are both significantly different from 1, but neither slope is significantly different from 0.5. Hence, the slopes of the regression lines fit to these new data offer further support for the Schomer method and the coefficient of 2 in Equation 1. The fact that both slopes are significantly different from 1 casts doubt on the CDNL method given in NRC (1996). The CDNL method can be valid only if the slopes of the relations between the CSEL of blast or boom sounds and equivalently annoying control sounds are 1.

Discussion

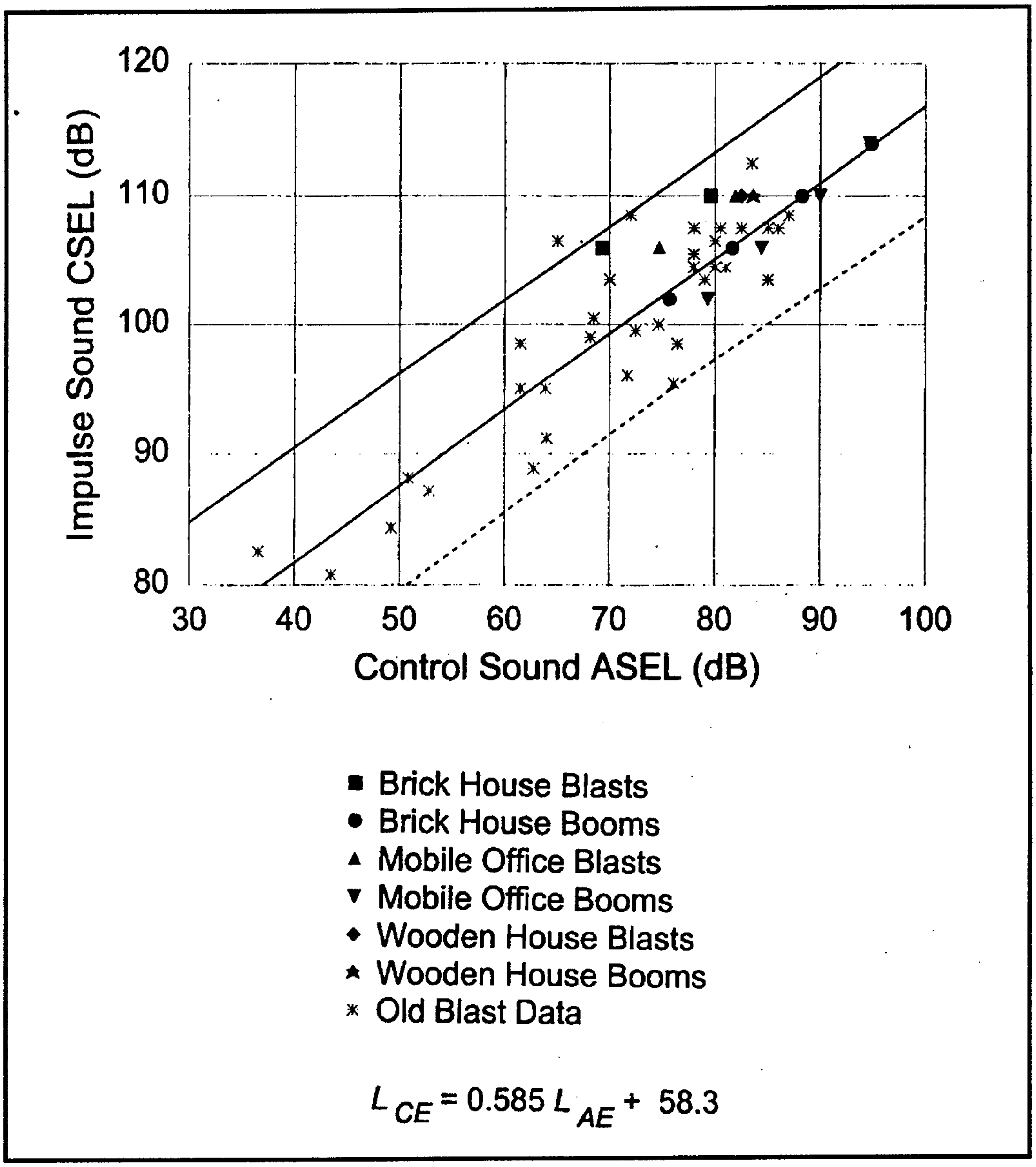
The purpose of this study was to determine if the new method to assess impulse noise (which was based primarily on blast noise research results) was equally applicable to sonic boom sounds. This test used the same methodology as the previous blast sound research and included similar blast sounds for control purposes. The results indicate that this group of subjects judged the blast sounds to be slightly less annoying (about 5 dB) than did previous subjects for the same CSEL. One could suggest many reasons for this 5-dB difference. First, one could suggest that this group of subjects was about 5 dB more tolerant of all impulse sounds and that the sonic booms should receive an additional 5 dB of penalty. Second, one could suggest that this group of subjects was about 5 dB more tolerant of blast sounds and that sonic boom sounds are correctly assessed. Third, one could suggest that this group of subjects is like all others in their response and the differences, as shown by the statistical tests, are virtually the result of random fluctuations. Fourth, one could suggest that this group of subjects was some few number of decibels (perhaps 2 to 3 dB) more tolerant of all impulse sounds. (With a 2 to 3 dB shift to all of the new data, these new data will then evenly straddle the regression line fit to the previous blast sound data). Each of the above is equally plausible, as are other alternatives. In any case, the conclusions that follow are: (1) subject responses to sonic boom sounds fit the wider body of previous blast sound results, and (2) the difference between response to blast and boom sounds is small (about 5 dB or less) with boom sounds being more annoying than blast sounds for the same CSEL.

By way of further comparison, the earlier discussion shows that the subjects responded to the double 2.25 kg blast sound in essentially the same manner as they did to the single blast sounds of comparable energy (Table 6). In comparison, subjects responded indoors with 5 dB more annoyance to booms than to blasts producing the same CSEL. Therefore, the double sound does not appear to be the factor that separates perception of sonic booms from blast sounds. Rather, the difference, if any, is some other attribute(s) of the sounds.



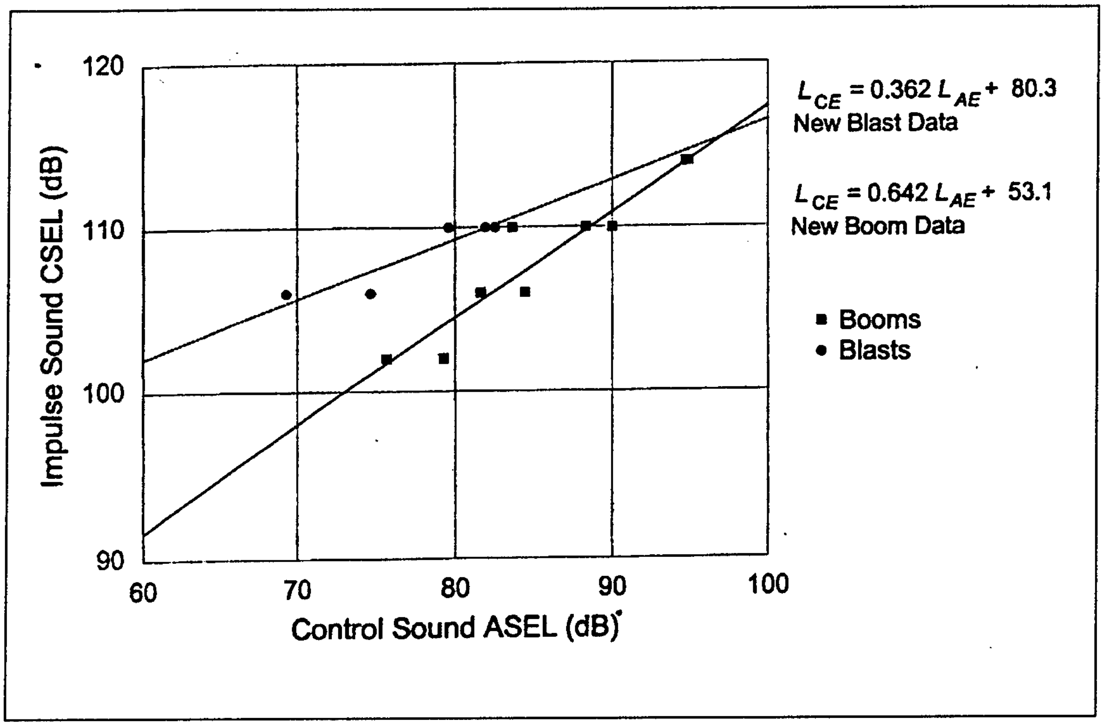
The recent NAS Fallon data are shown compared to previous (indoor) blast data and a regression line fit to those blast data. The dashed curves show the 95%-prediction intervals for the regression line fit to the previous blast data.

Figure 6. CSEL of blast or boom sounds versus ASEL of equivalently annoying control sound—blasts and booms measured indoors; control sound measured indoors.



The recent NAS Fallon data are shown compared to previous (outdoor) blast data and a regression line fit to those blast data. The dashed curves show the 95%-prediction intervals for the regression line fit to the previous blast data.

Figure 7. CSEL of blast or boom sounds versus ASEL of equivalently annoying control sound—blast and booms measured outdoors; control sound measured indoors.



Only the recent NAS Fallon data are shown. Regression lines are shown for each data set separately.

Figure 8. CSEL of blast or boom sounds versus ASEL of equivalently annoying control sound—blast and booms measured outdoors; control sound measured indoors.

4 Conclusions

A field study has been conducted to determine if subjects responded in like manner to both blast and sonic boom sounds and to determine if the responses of subjects to sonic booms were consistent with the previous blast response data used in Schomer (1994). A key factor in the design of this study was the presentation of many real blast and boom sounds to subjects situated indoors in real structures in the field

The results of these present studies show that only the outdoor-measured CSEL should be used to predict human and community response to high-energy impulsive sounds. The RMS differences between the measured CSEL data and a regression line fit to previous blast sound data is far less for outdoor-measured data than for indoor-measured data. Since one reason for choosing C-weighting was to include those acoustical energies which induce building vibrations and rattles, it is inferred that the outdoor-measured CSEL works better than the indoor measurements because it is the outdoor measurements that correlate with induced building vibrations and rattles. The indoor C-weighted measurements predict neither building response nor human response.

The general results show that human response to sonic booms and blast sounds is quite similar. There is some indication that response to booms is greater than response to blasts for the same CSEL. However, all of the house and mobile office data fit the wider body of blast data quite well, so regression curves fit to this wider body of data provide a good overall empirical high-energy impulsive noise assessment tool.

The results in this study support the general inclusion of sonic boom sounds into the framework developed primarily for blast sound. The sonic boom data from the field study at Fallon were quite similar to the large body of previous blast sound data.

The NRC recommended two possible methods for the assessment of high-energy impulsive sounds. The method mainly referred to in this report uses adjusted sound exposure as given by Equation 1. The other NRC method is based on

CDNL. The slopes found in this study to the new data for blast sounds and sonic boom sounds are very consistent with the coefficient in Equation 1 that relates adjusted sound exposure to CSEL. Therefore, the results of this study add further support to the NRC method that is based on Equation 1. The slopes to the data found in this study do not support the NRC method that is based on CDNL.

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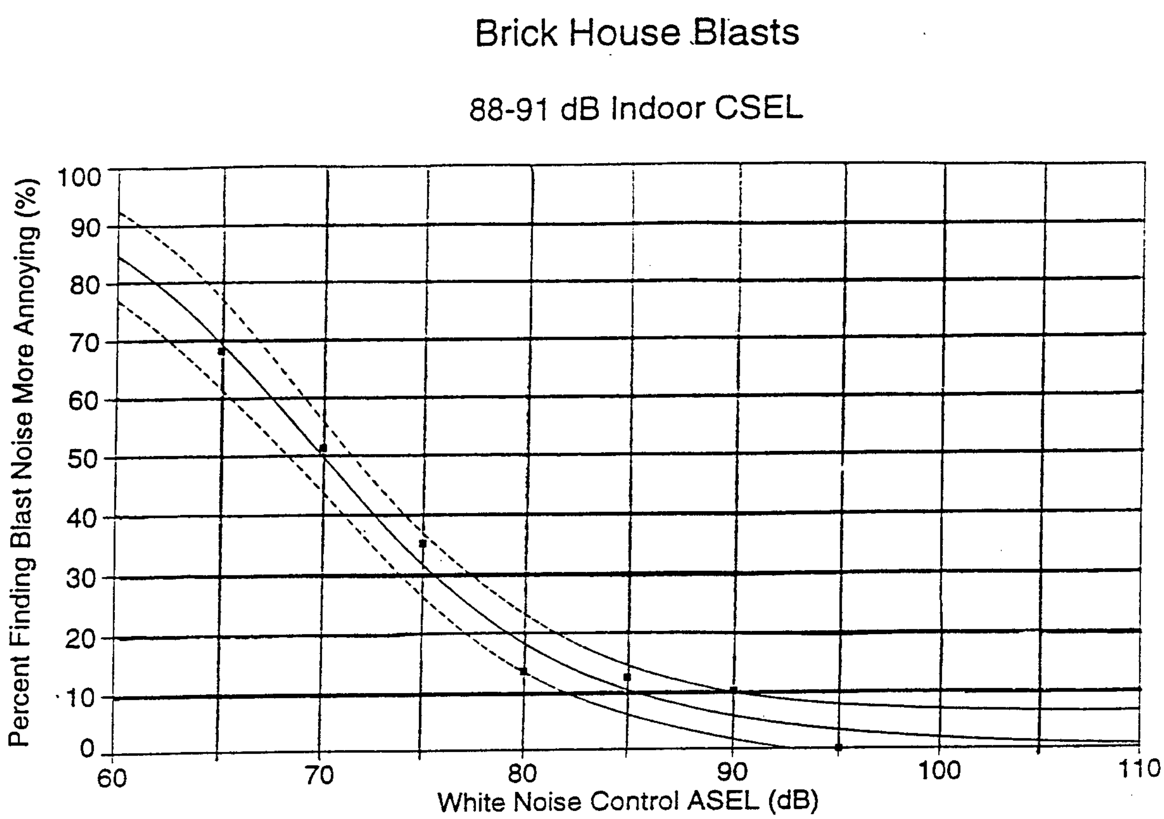
Appendix A: Transition Curves for Indoor-measured Blast and Sonic Boom Data at NAS Fallon



Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9954336868	0.9908673736	3.3478820170	363.32508959

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.003003256	2.449391155	0.001226124	-6.31666064	6.322667148
b	100.1006858	3.682639837	27.18177454	90.59912209	109.6022494
c	69.92899047	0.781680042	89.45986429	67.91218106	71.94579988
d	11.12631521	1.246607963	8.925272054	7.909947214	14.34268321

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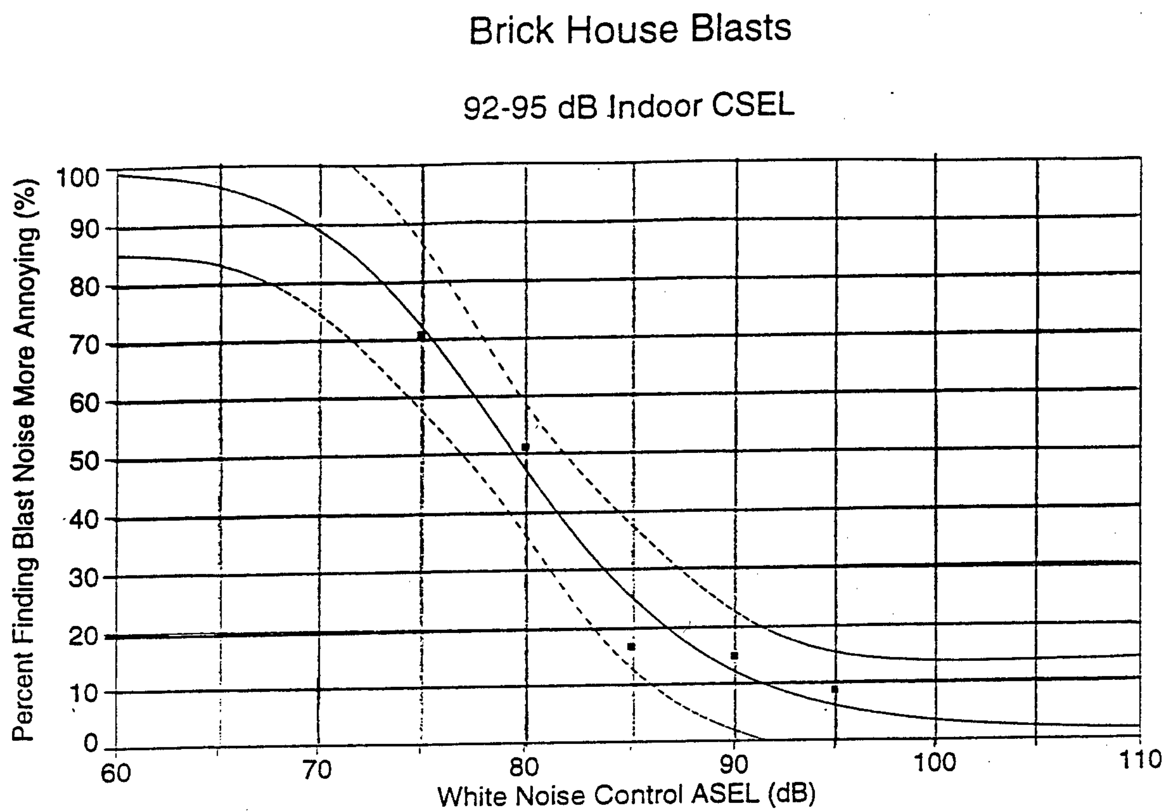

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r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9910367211	0.9731101632	5.2490114539	110.56631508

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	1.283760985	4.248707990	0.302153264	-12.1372191	14.70474107
b	98.57381034	6.492493096	15.18273626	78.06507668	119.0825440
c	79.40195955	0.991988581	80.04321929	76.26842836	82.53549074
d	16.58442067	3.278257048	5.058914061	6.228937865	26.93990348

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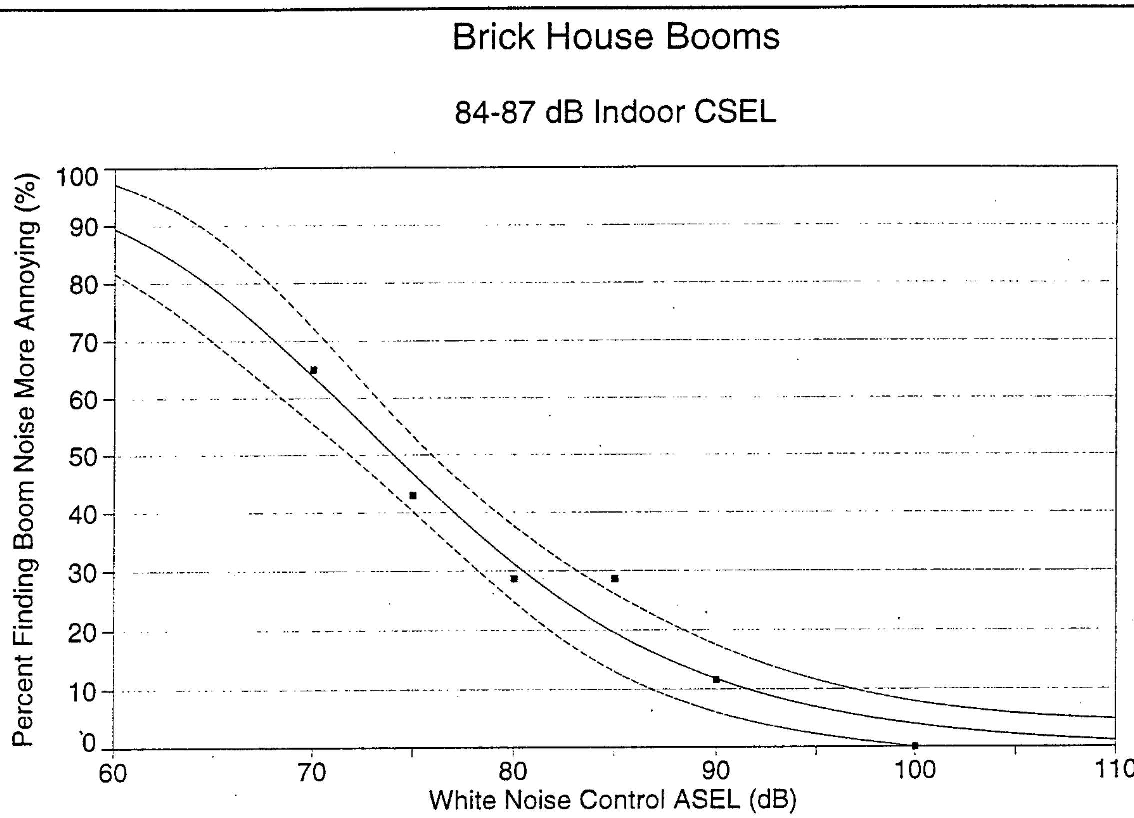

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0.9984060730	0.9962808370	2.5248452610	835.17506133

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.85090561	1.705658885	-0.49887209	-5.59236971	3.890558488
b	101.0900101	2.371019465	42.63567282	94.49894803	107.6810723
c	74.09925029	0.801824050	92.41335463	71.87030523	76.32819535
d	10.03759504	1.197555167	8.381739157	6.708579559	13.36661052

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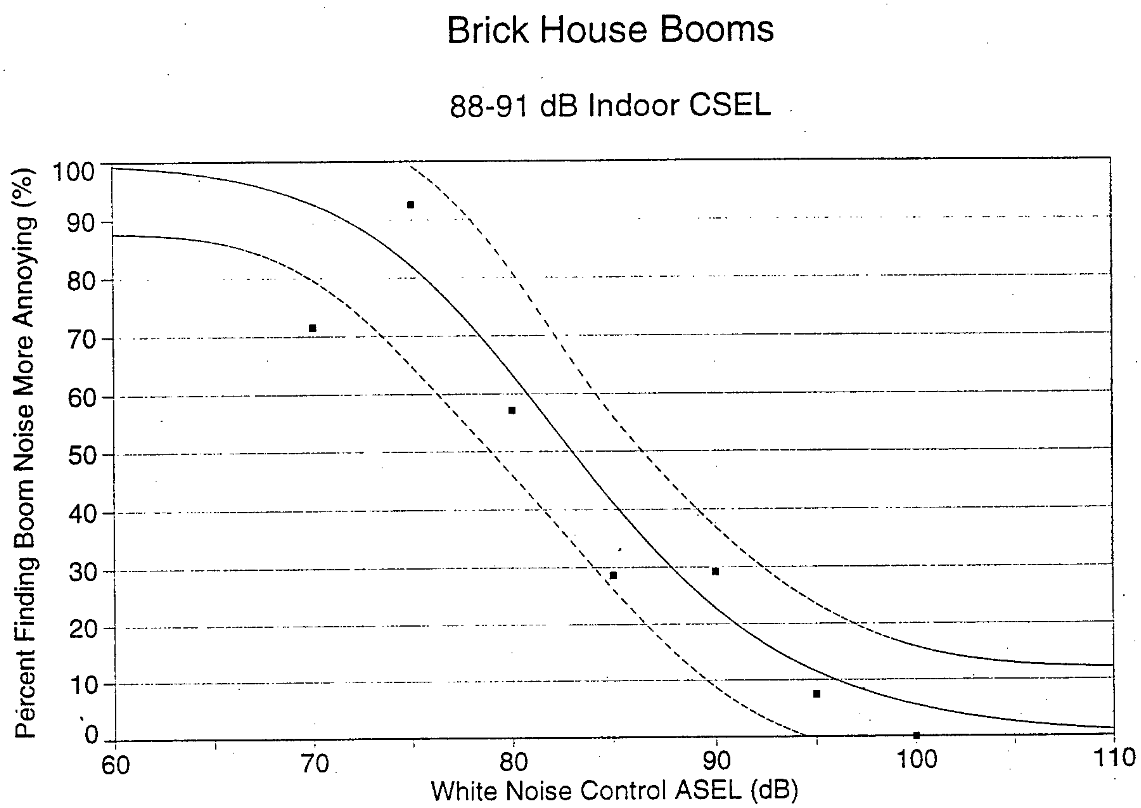

Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9815320302	0.9630640603	7.7963692699	88.579672297

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.49084233	5.019891389	-0.09777947	-13.4426431	12.46095848
b	100.4605651	7.110885114	14.12771596	82.11380015	118.8073301
c	83.05279371	1.672004210	49.67259844	78.73886262	87.36672479
d	14.90680367	3.638877568	4.096538945	5.518150853	24.29545650

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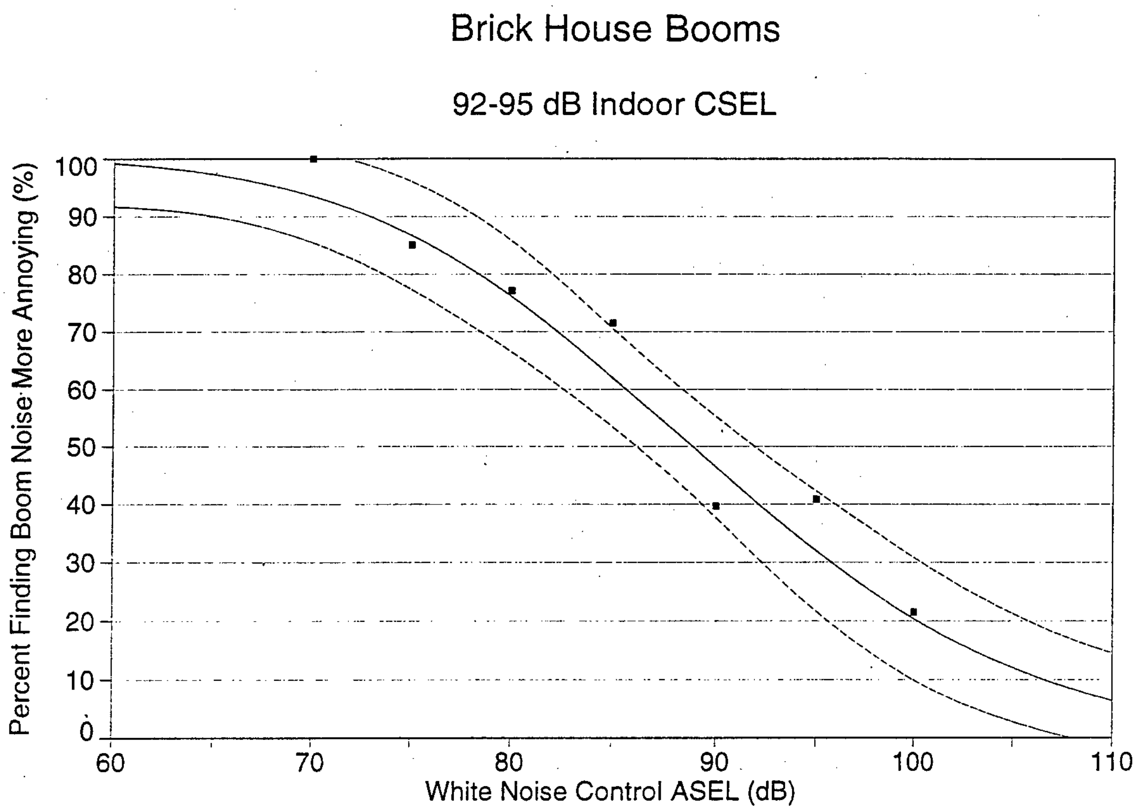

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r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9905807295	0.9811614589	5.2274294964	175.27555629

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-3.97179726	5.310724880	-0.74788232	-17.6739764	9.730381827
b	104.6360776	6.755386206	15.48928135	87.20653385	122.0656213
c	89.36777362	1.620208048	55.15820867	85.18748160	93.54806564
d	10.63731890	2.022053891	5.260650545	5.420226102	15.85441171

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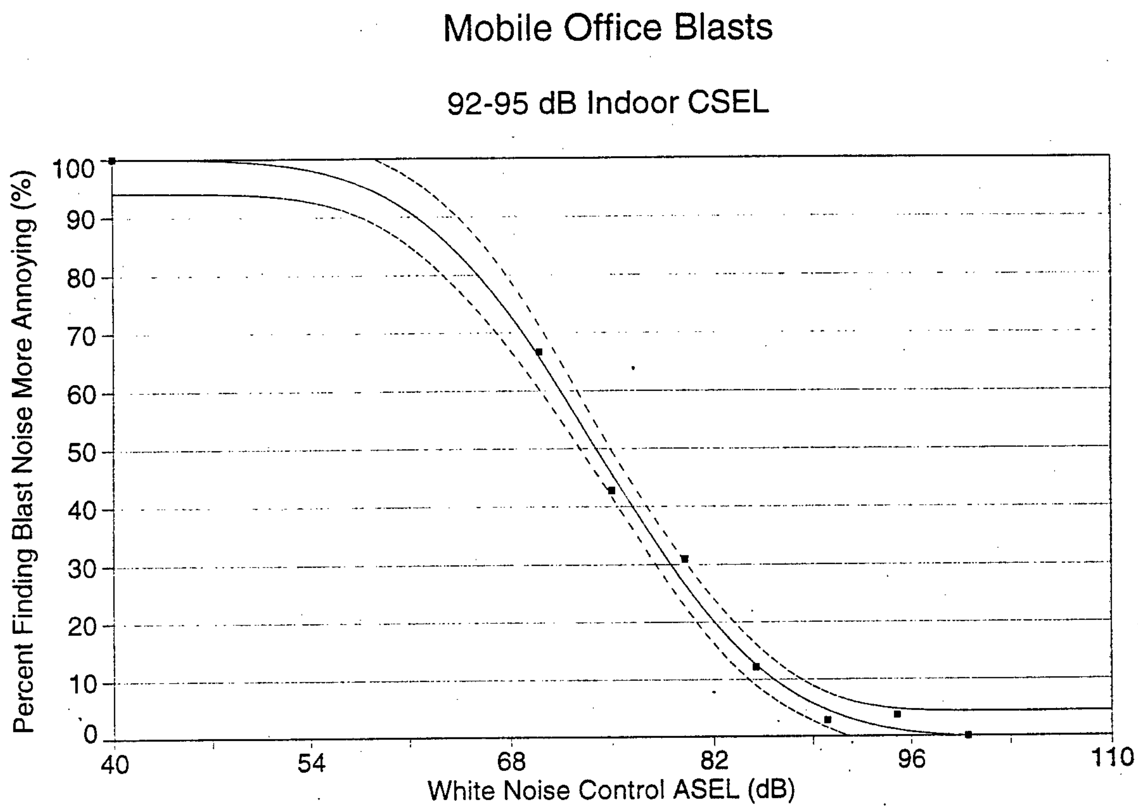

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0.9968941812	0.9937883624	2.5759751862	534.96047705

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.49958701	1.888695314	-0.26451435	-5.37260190	4.373427885
b	100.5328060	3.037274173	33.09968094	92.69634762	108.3692644
c	73.99712977	0.557545464	132.7194545	72.55860905	75.43565049
d	-9.73873598	0.802983367	-12.1281914	-11.8105100	-7.66696194

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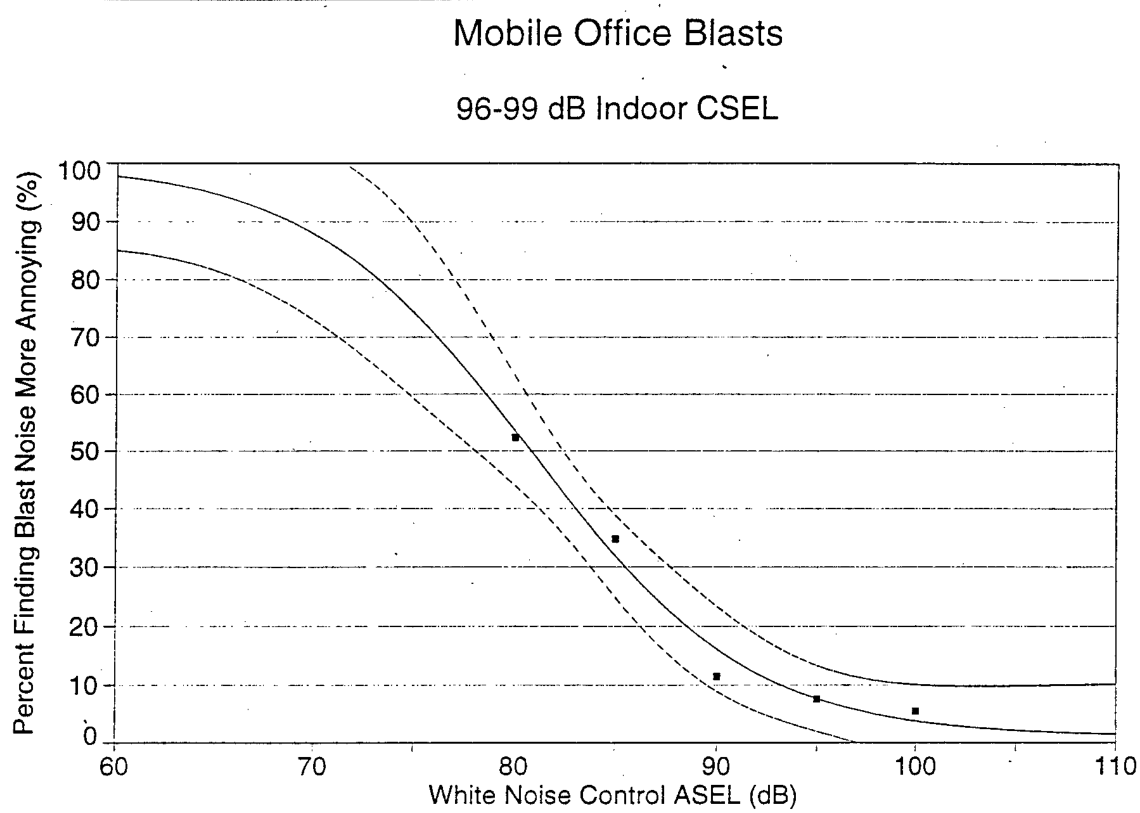

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0.9940346903	0.9821040710	3.4520399252	166.63589049

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.978660204	3.049108687	0.320965995	-8.65298006	10.61030047
b	98.89372181	5.380058171	18.38153393	81.89898983	115.8884538
c	80.69174712	0.791207828	101.9855267	78.19244979	83.19104444
d	-5.43841605	0.944985297	-5.75502715	-8.42347148	-2.45336062

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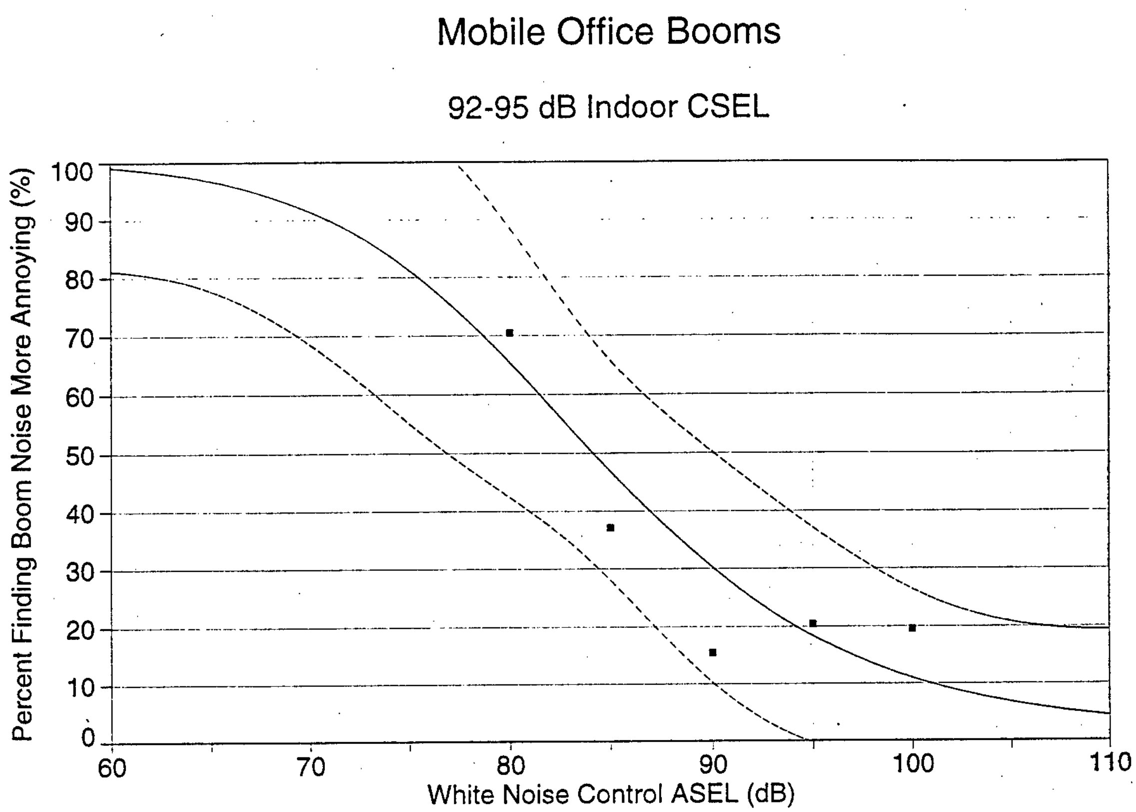

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r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9827616251	0.9482848753	7.9505411902	57.010108647

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	1.183364984	6.880598895	0.171985753	-20.5513320	22.91806197
b	99.28747730	9.231774693	10.75497189	70.12579695	128.4491576
c	83.92491659	2.148196299	39.06761995	77.13911257	90.71072061
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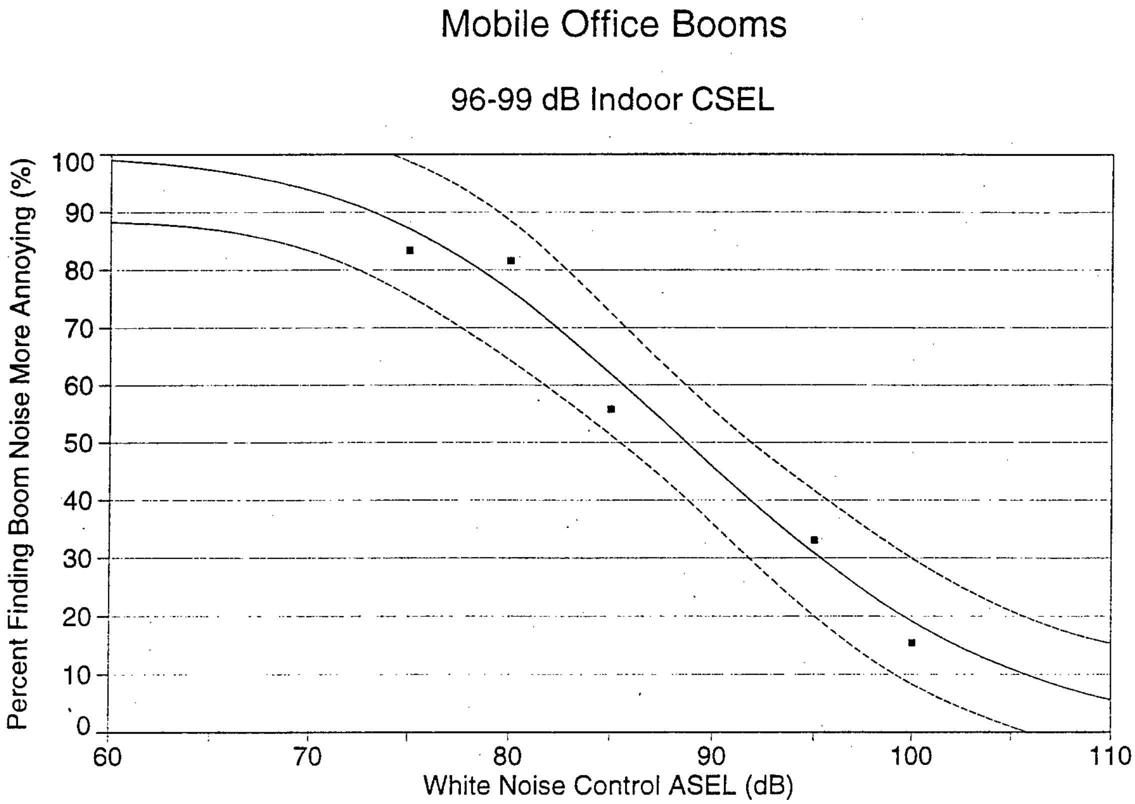

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r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9930937296	0.9792811888	4.8026564801	143.79595265

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-3.65434786	5.426389675	-0.67344000	-20.7954336	13.48673784
b	103.9052160	6.954321650	14.94110011	81.93764076	125.8727912
c	89.18302324	1.532054455	58.21139252	84.34351147	94.02253501
d	11.11011373	1.938299534	5.731886911	4.987339581	17.23288787

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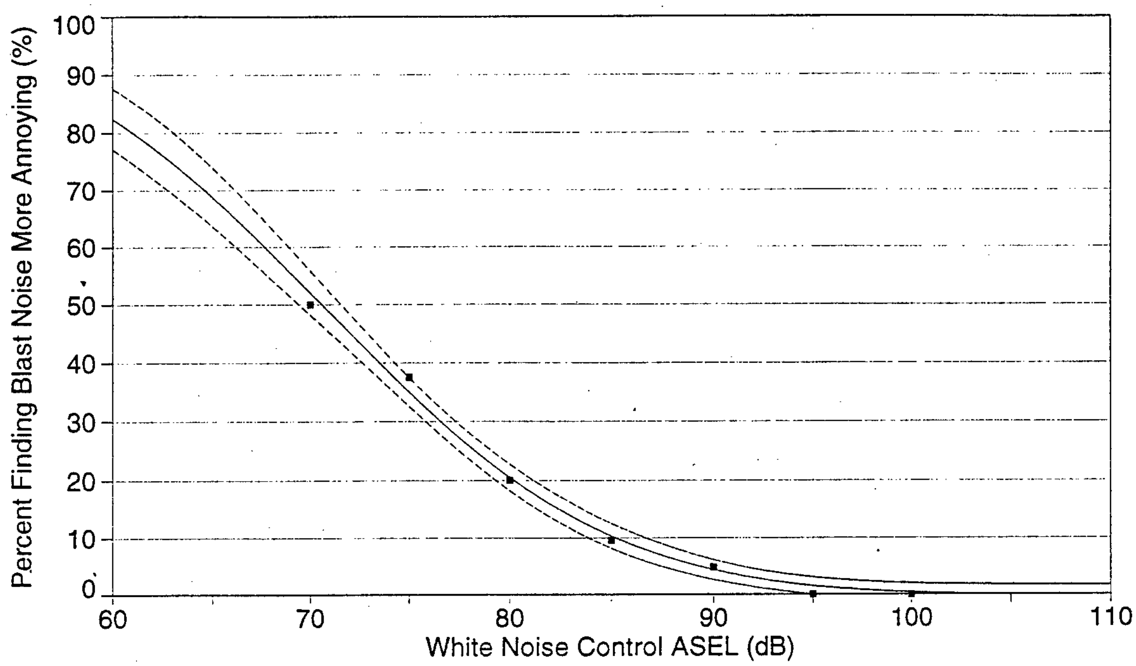
Wooden House Blasts

96-99 dB Indoor CSEL



Rank 1 Eqn 8012 [GaussCum] $y=a+0.5b(1+erf((x-c)/(2^{0.5}d)))$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9995314317	0.9990628634	1.2364323418	3555.2675603

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.20109485	0.718066119	-0.28005060	-2.05377424	1.651584547
b	100.5718436	1.137763844	88.39430442	97.63630386	103.5073833
c	70.55205141	0.443298363	159.1525196	69.40829915	71.69580366
d	-11.4975076	0.666520966	-17.2500314	-13.2171955	-9.77781962

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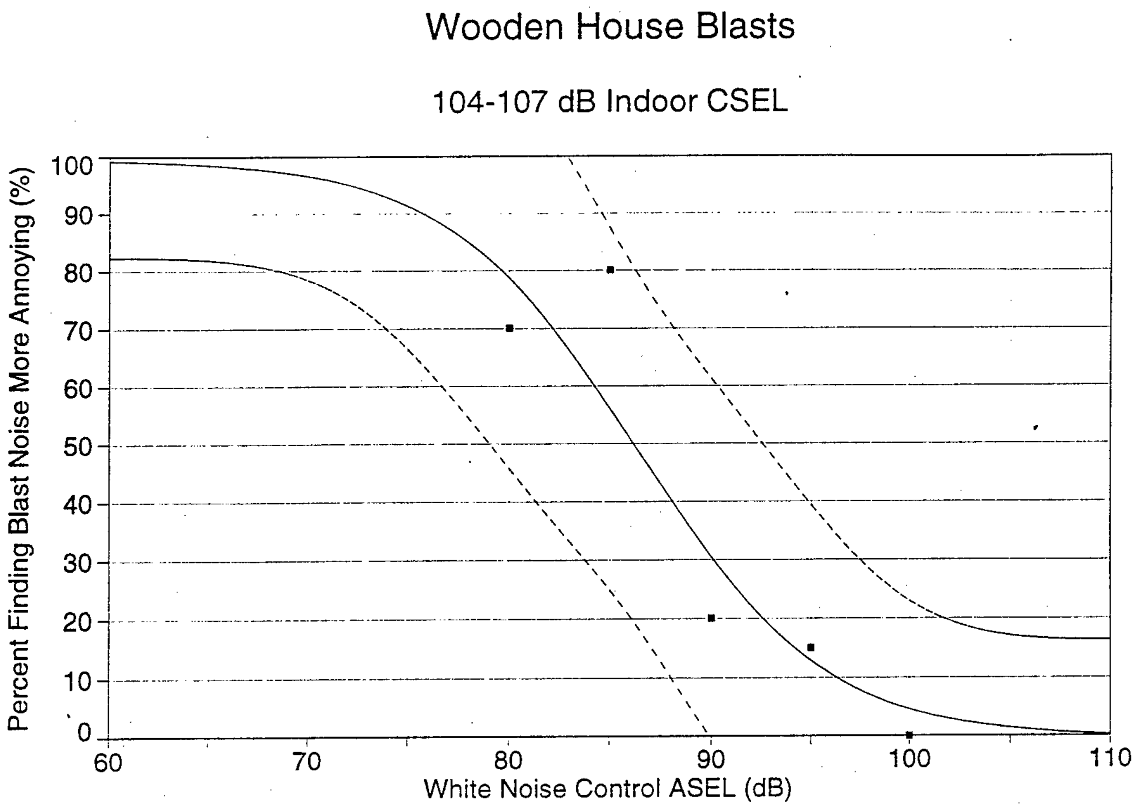

Rank 1 Eqn 8011 [Sigmoid] y=a+b/(1+exp(-(x-c)/d))

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9840239347	0.9520718041	8.8404454022	61.593635022

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.45325610	5.476686496	-0.08276101	-17.7532213	16.84670910
b	99.99816717	7.840040037	12.75480313	75.23275109	124.7635833
c	86.23058350	2.035415094	42.36510959	79.80103704	92.66012997
d	-4.68106846	1.740930643	-2.68883110	-10.1803863	0.818249345

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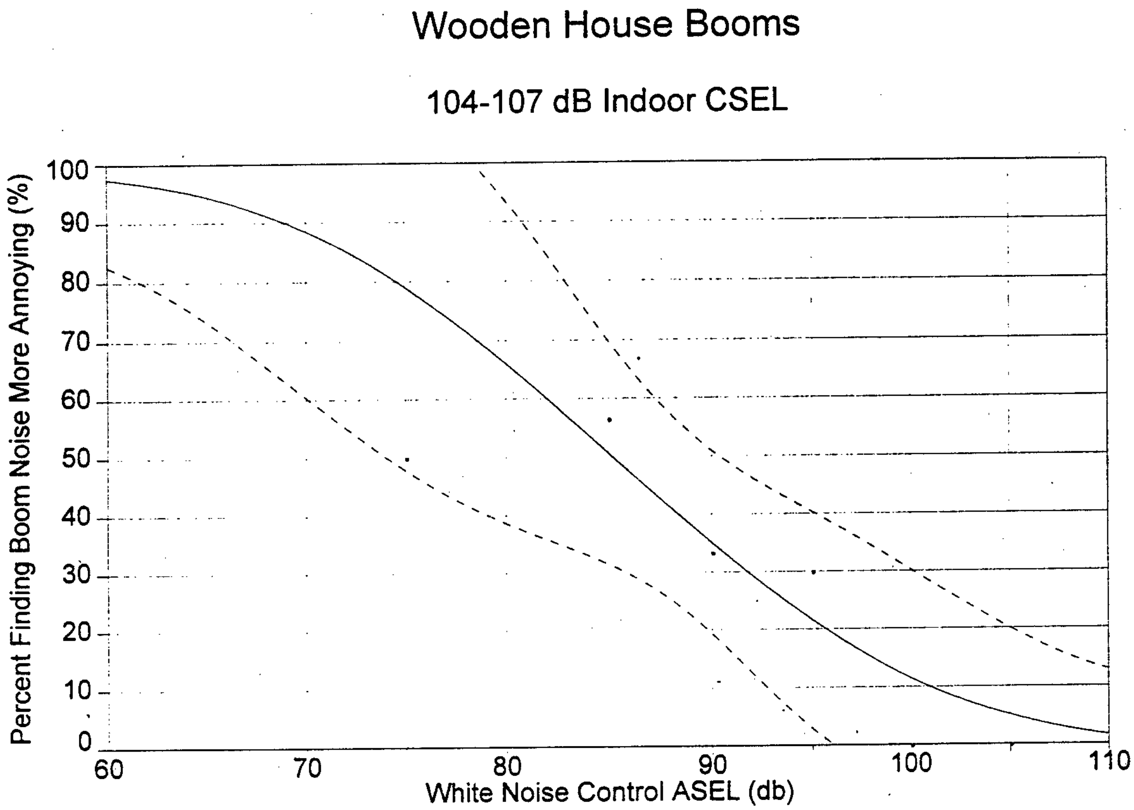

Rank 1 Eqn 8012 [GaussCum] $y=a+0.5b(1+erf((x-c)/(2^{0.5}d)))$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9877315562	0.9713736311	7.0266582425	107.34657366

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-1.14365124	4.486100913	-0.25493213	-13.614308	11.32700547
b	100.7990893	6.187722827	16.29017526	83.59819066	117.999988
c	85.45167634	2.283174969	37.42668762	79.10480814	91.79854454
d	-12.6653973	4.560231784	-2.77735824	-25.3421262	0.011331579

Date	Time	File Source
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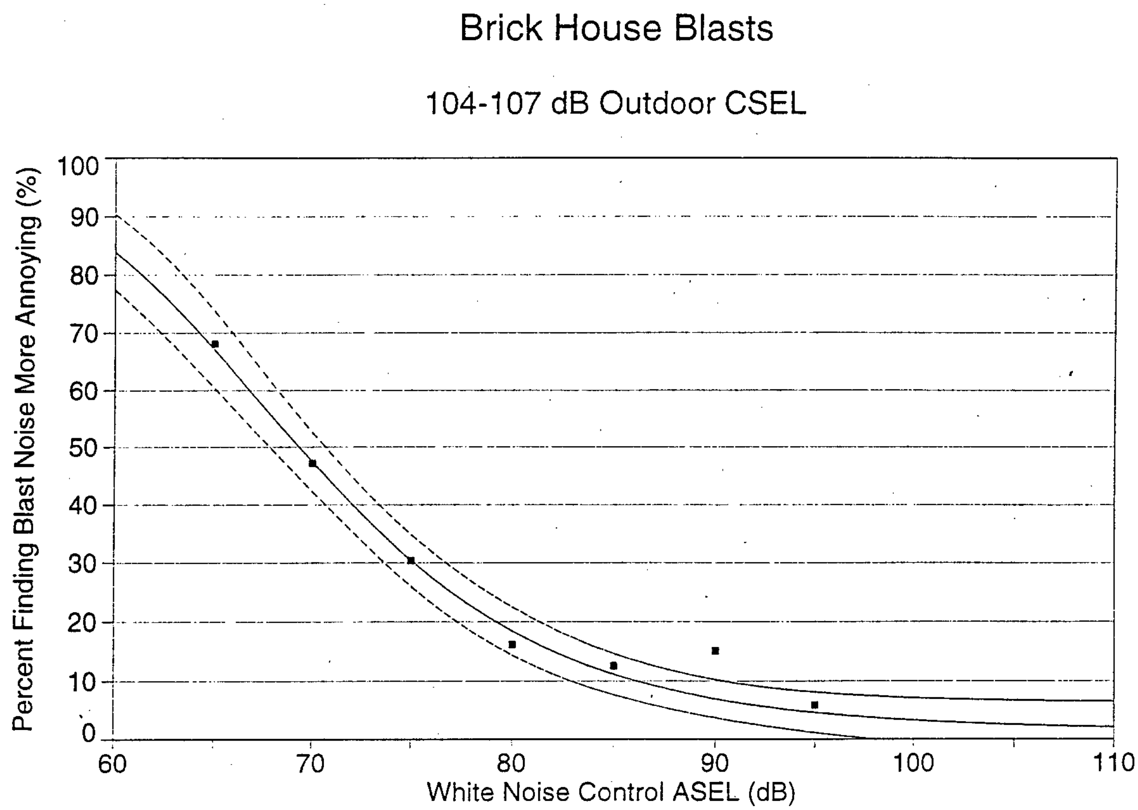
Appendix B: Transition Curves for Outdoor-measured Blast and Sonic Boom Data at NAS Fallon



Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9968341087	0.9936682175	2.7627273649	524.77803005

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	1.338704642	1.959045469	0.683345366	-3.71582039	6.393229677
b	102.2596642	3.931528617	26.01015387	92.11594368	112.4033848
c	68.70494604	0.771385500	89.06693995	66.71469753	70.69519455
d	10.55961653	1.103015394	9.573408123	7.713731120	13.40550195

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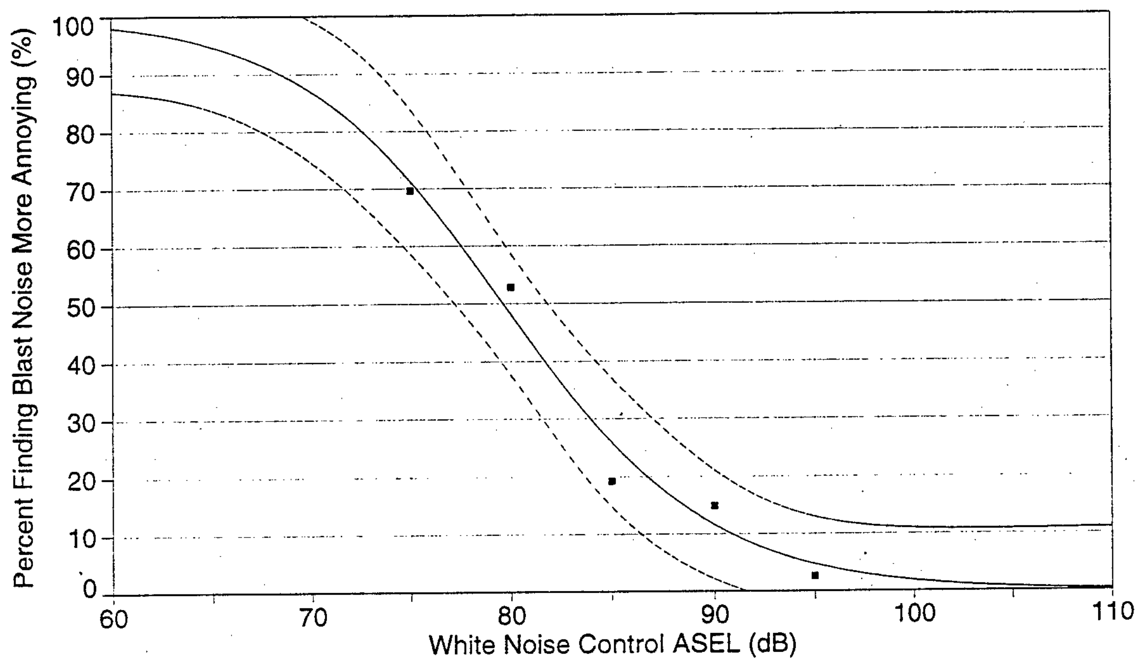
Brick House Blasts

108-111 dB Outdoor CSEL



Rank 1 Eqn 8011 [Sigmoid] y=a+b/(1+exp(-(x-c)/d))

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0.9937636882	0.9812910647	4.6317048161	159.35118809

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.03880543	3.544156521	-0.01094913	-11.2342216	11.15661073
b	100.1839176	5.474018014	18.30171500	82.89238171	117.4754535
c	79.60435372	0.939443625	84.73563670	76.63680353	82.57190390
d	-5.12242252	0.847143237	-6.04670178	-7.79841074	-2.44643431

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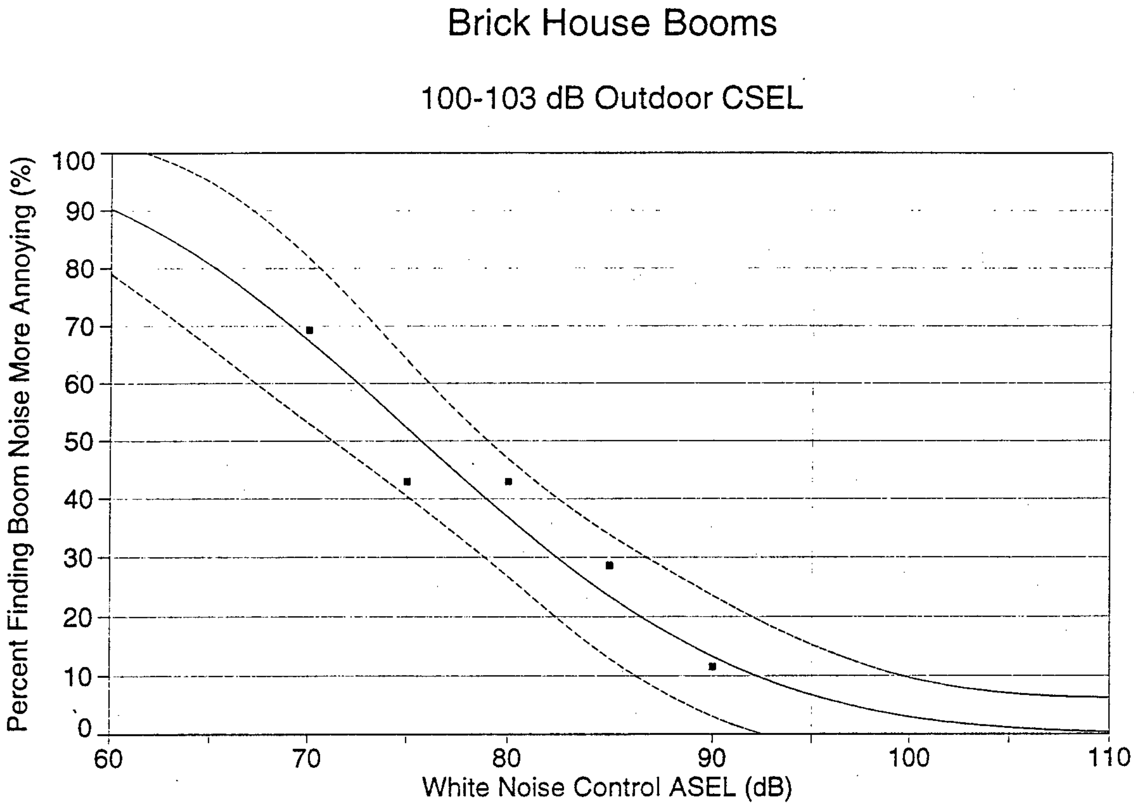

Rank 1 Eqn 8012 [GaussCum] $y=a+0.5b(1+erf((x-c)/(2^{0.5}d)))$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9978416602	0.9935249805	3.2441495816	462.31906722

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.08505026	1.972654684	-0.04311462	-6.31634675	6.146246243
b	102.8495146	4.287549432	23.98794842	89.30584073	116.3931885
c	75.25820649	1.557605428	48.31660518	70.33798333	80.17842964
d	-13.0927655	2.154643292	-6.07653506	-19.8989345	-6.28659649

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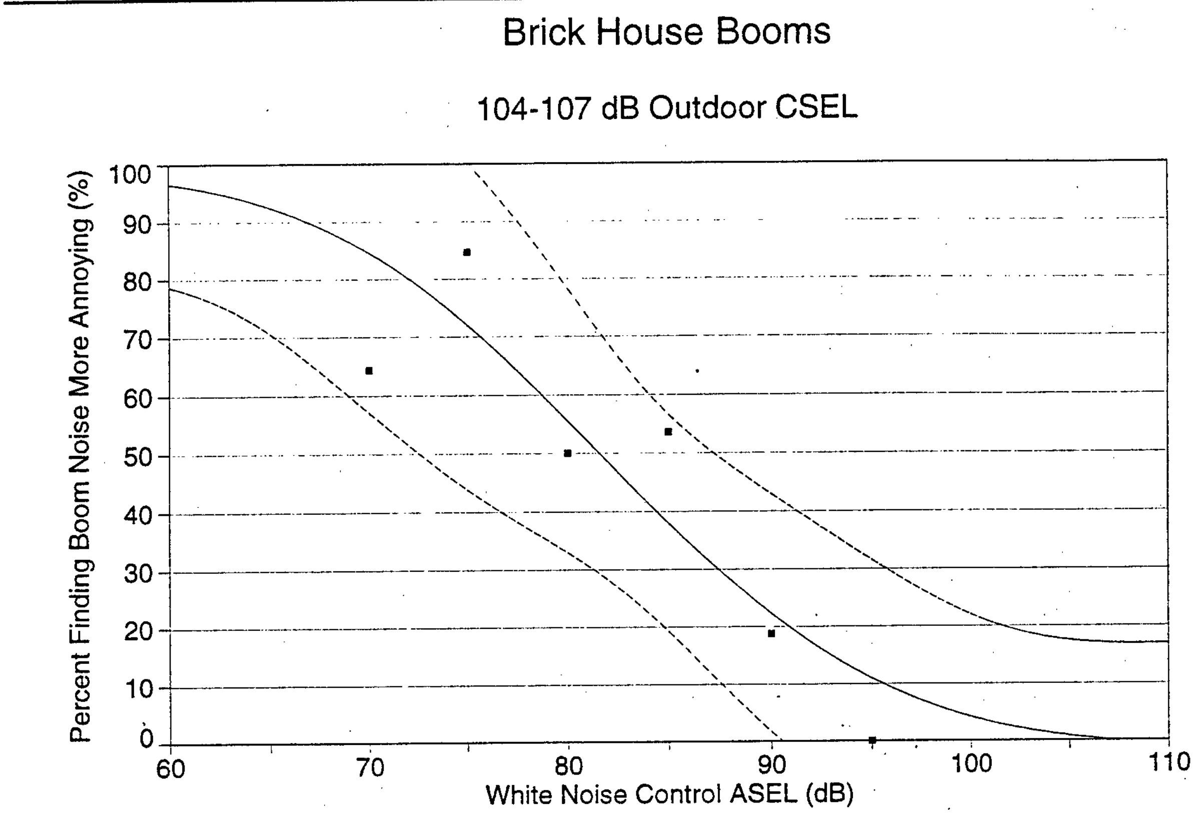

Rank 1 Eqn 8012 [GaussCum] $y=a+0.5b(1+\mathrm{erf}((x-c)/(2^{0.5}d)))$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9690132894	0.9276976754	10.352011537	41.695865614

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-1.21799138	6.794272222	-0.17926738	-20.1050022	17.66901944
b	100.3845431	10.00091224	10.03753864	72.58357612	128.1855101
c	81.85932636	2.634697618	31.06972345	74.53528035	89.18337238
d	-11.2503060	3.924778140	-2.86648203	-22.1605735	-0.34003853

Date	Time	File Source
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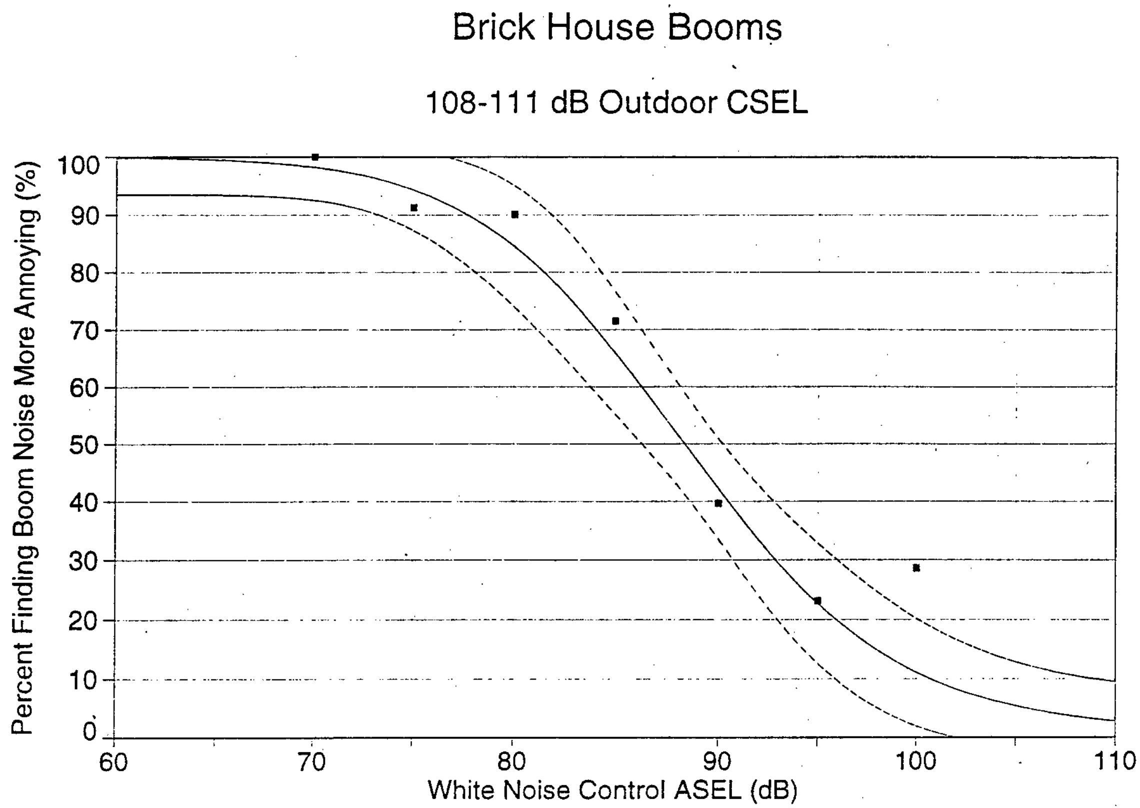
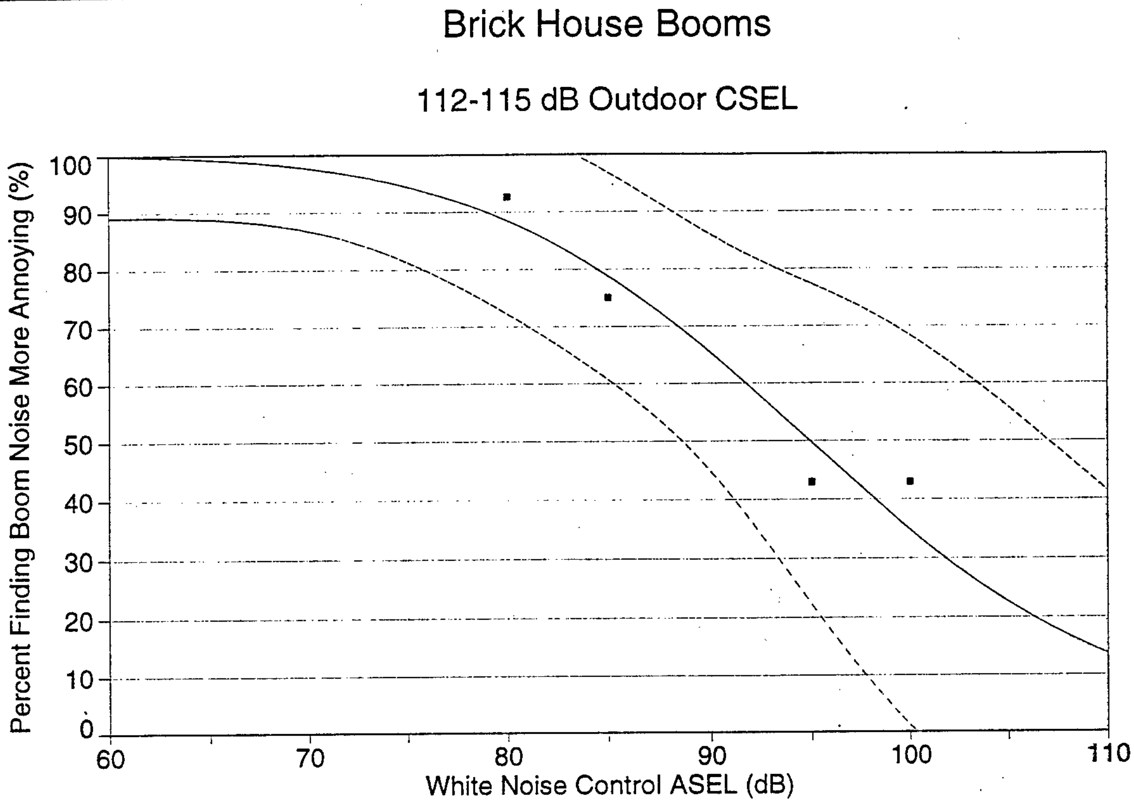


Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9940574425	0.9881148850	4.4413524949	278.79619165

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.530355457	2.724191523	0.194683616	-6.49831972	7.559030633
b	99.43330463	3.838665204	25.90309374	89.52918056	109.3374287
c	88.29635970	0.858731476	102.8218508	86.08075020	90.51196919
d	17.12049760	2.991740339	5.722588080	9.401520844	24.83947436

Date	Time	File Source
Feb 6, 1997	12:25:20 PM	C:\tcwin3\new\obb10.prn



Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9971915061	0.9859575303	4.2250673941	236.70848234

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	100.4203628	2.810303330	35.73292669	88.76783800	112.0728877
b	-103.029270	5.653216416	-18.2248940	-126.469531	-79.5890083
c	95.25508136	2.605396255	36.56068868	84.45217468	106.0579880
d	-11.6117363	2.917218318	-3.98041389	-23.7075690	0.484096388

Date	Time	File Source
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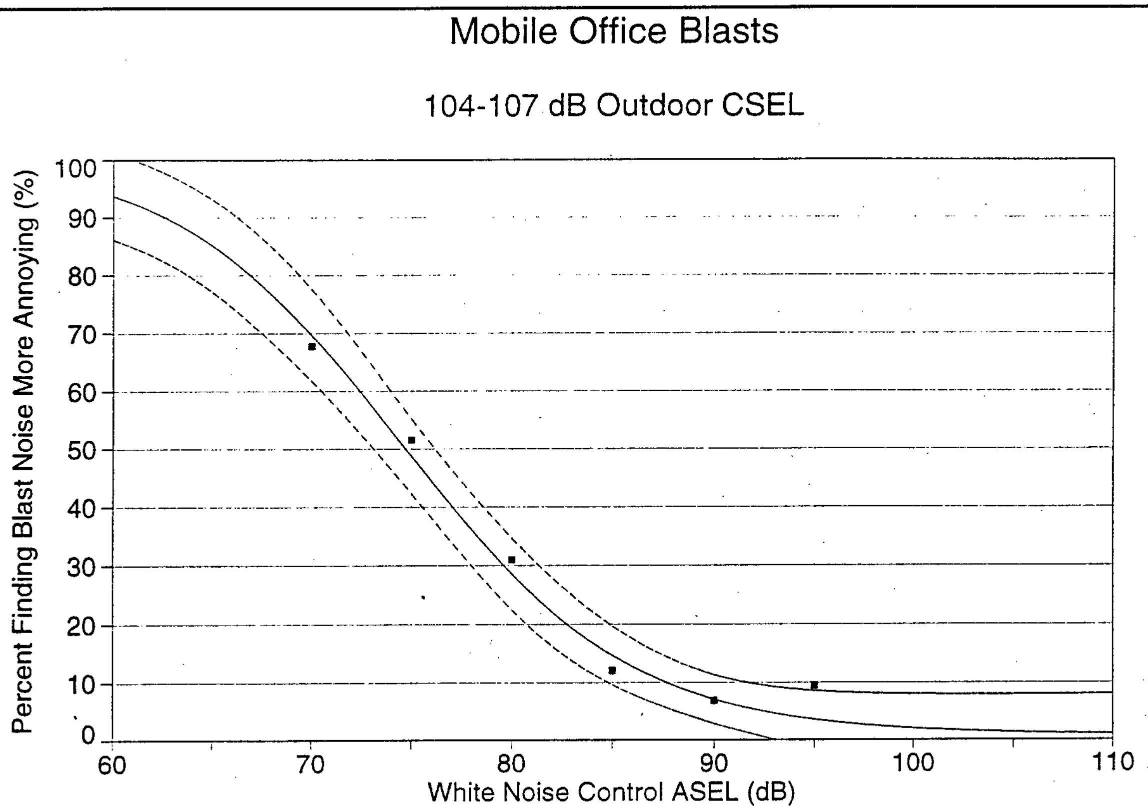

Rank 1 Eqn 8011 [Sigmoid] y=a+b/(1+exp(-(x-c)/d))

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9953359359	0.9891171837	3.2538727095	284.54037912

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.837493931	2.620262372	0.319622165	-6.44642437	8.121412230
b	100.1559025	4.821434597	20.77305011	86.75307073	113.5587342
c	74.49640082	0.794247971	93.79488965	72.28851607	76.70428557
d	-5.72122171	0.701070950	-8.16068860	-7.67008896	-3.77235446

Date	Time	File Source
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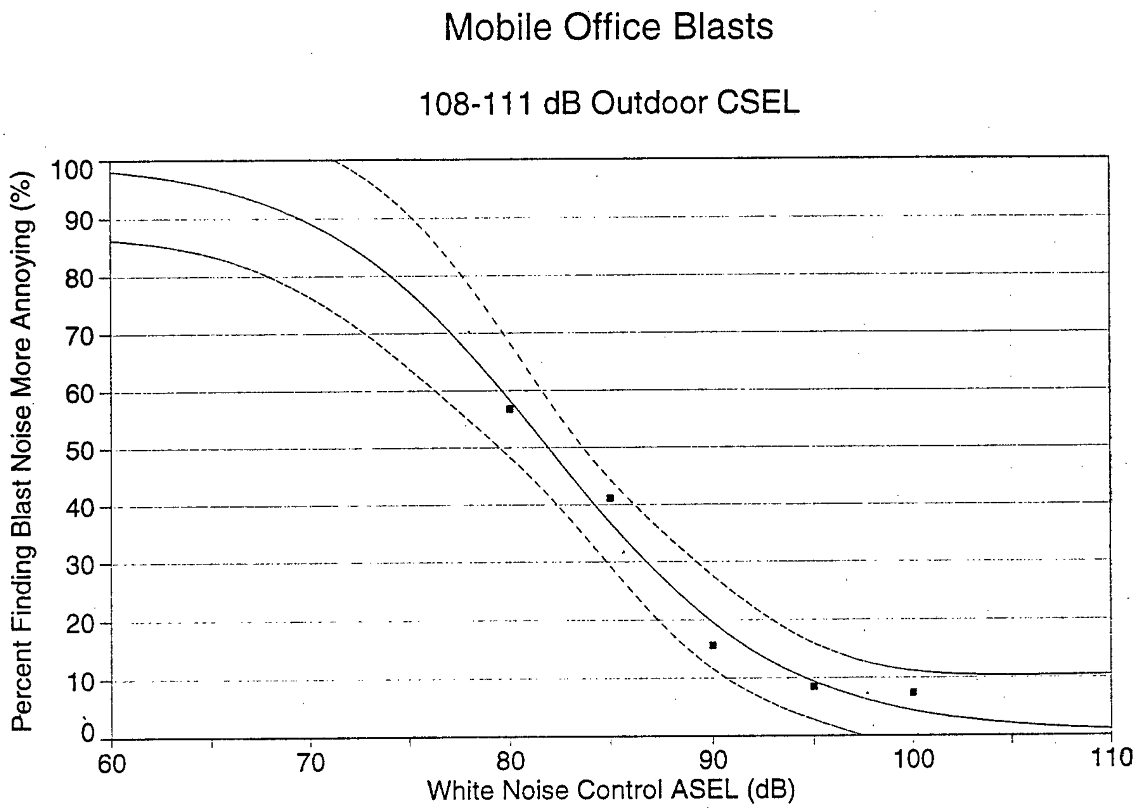

Rank 1 Eqn 8011 [Sigmoid] y=a+b/(1+exp(-(x-c)/d))

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9941344690	0.9824034071	3.7921644289	169.48754961

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.332419910	3.410975822	0.097455956	-10.4423000	11.10713982
b	99.80794105	5.547845050	17.99039810	82.28319750	117.3326846
c	81.85556952	0.863916436	94.74940643	79.12659749	84.58454156
d	-5.68440907	0.929062879	-6.11843310	-8.61916816	-2.74964998

Date	Time	File Source
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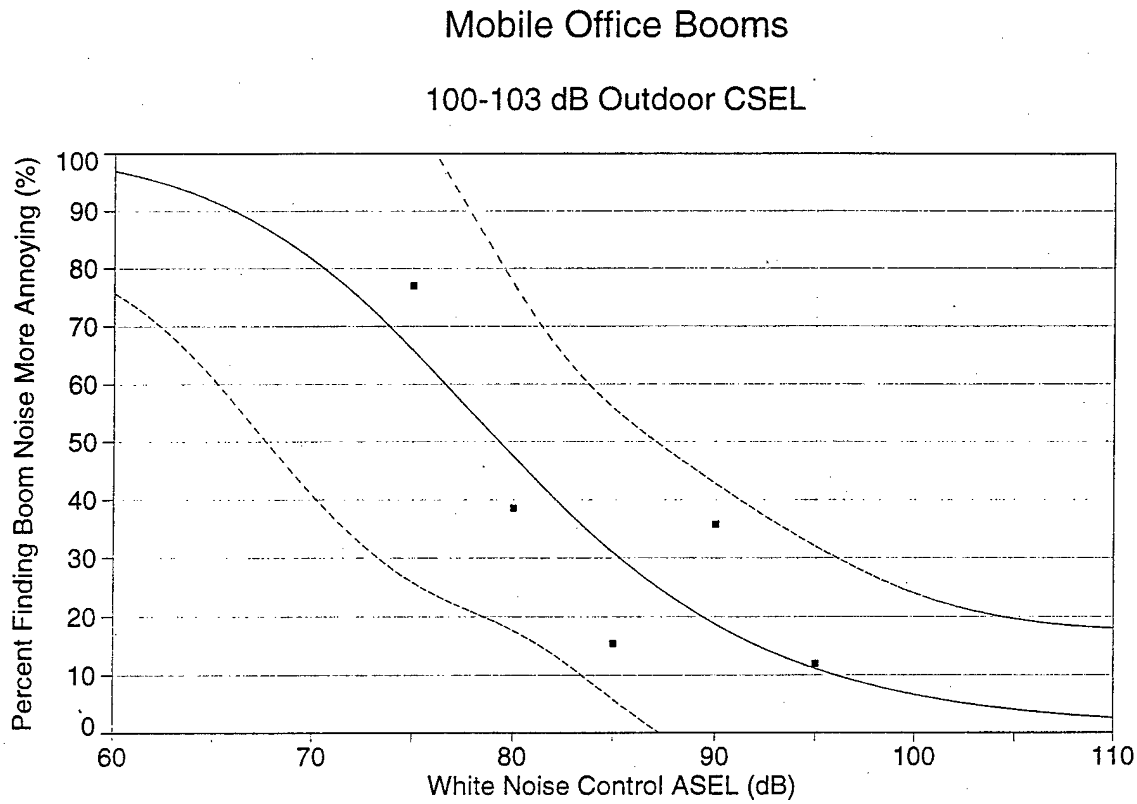
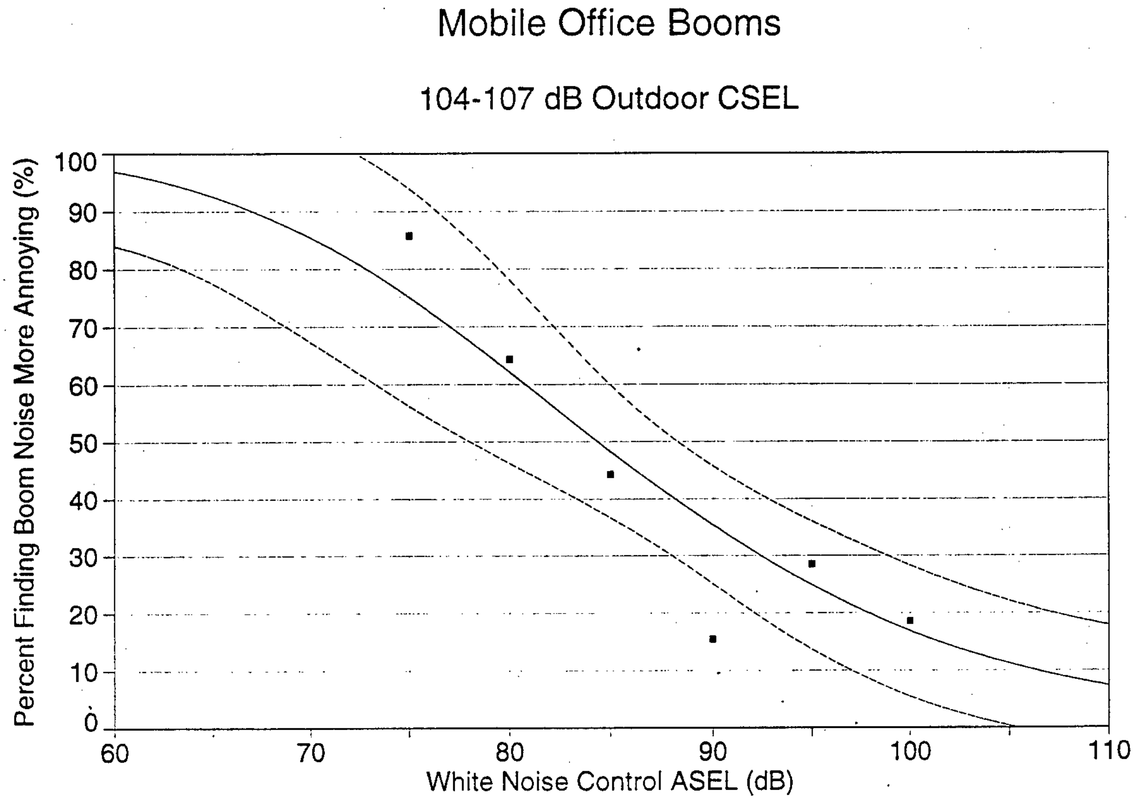


Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9828523378	0.9485570134	8.8409062851	57.316987356

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	0.437209107	6.033697945	0.072461219	-18.6222650	19.49668322
b	100.2968591	8.927379783	11.23474766	72.09671299	128.4970053
c	79.13315030	3.019957961	26.20339466	69.59359245	88.67270814
d	11.65879898	5.012779161	2.325815402	-4.17575812	27.49335608

Date	Time	File Source
Feb 6, 1997	12:18:22 PM	c:\tcwin3\new\omb02.prn

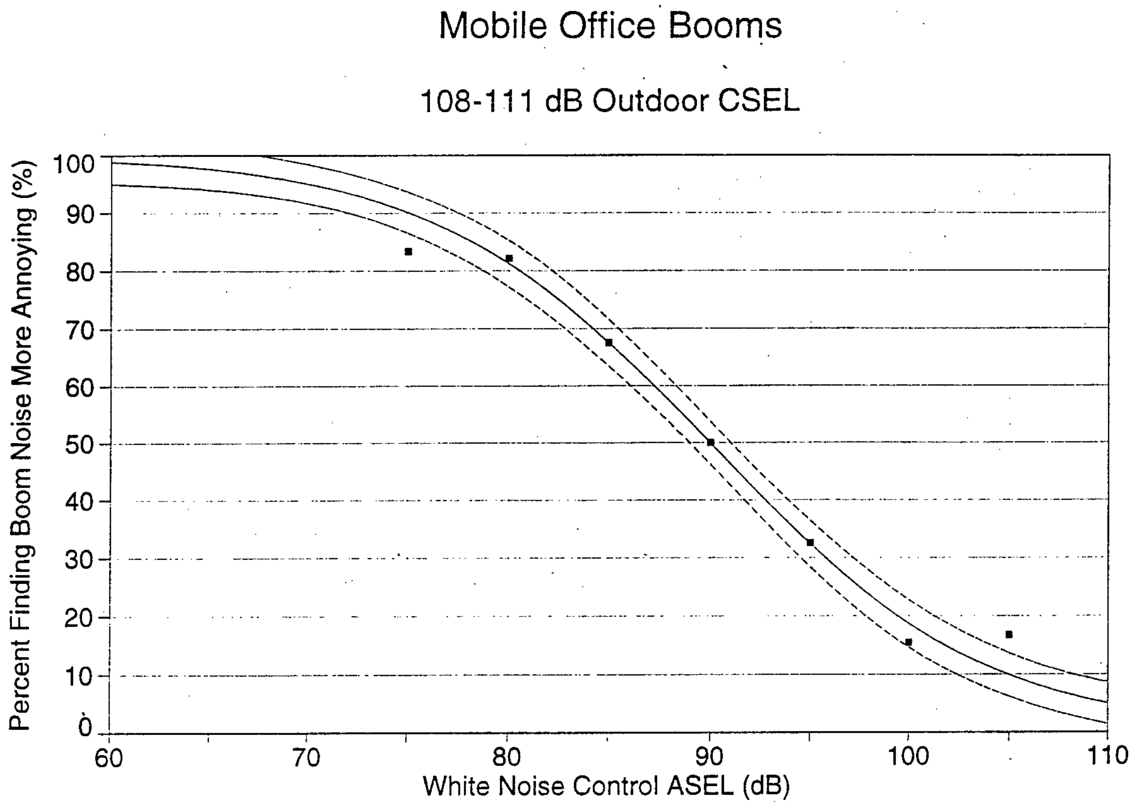


Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9845696813	0.9639959230	6.5381696836	85.076633843

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-1.20267000	6.106414700	-0.19695190	-18.1775448	15.77220482
b	102.5702441	8.710890210	11.77494397	78.35533600	126.7851522
c	84.33876721	2.166286786	38.93241087	78.31682982	90.36070461
d	9.063750021	2.429879959	3.730122546	2.309064961	15.81843508

Date	Time	File Source
Feb 6, 1997	12:19:03 PM	c:\tcwin3\new\omb06.prn



Rank 1 Eqn 8011 [Sigmoid] y=a+b/(1+exp(-(x-c)/d))

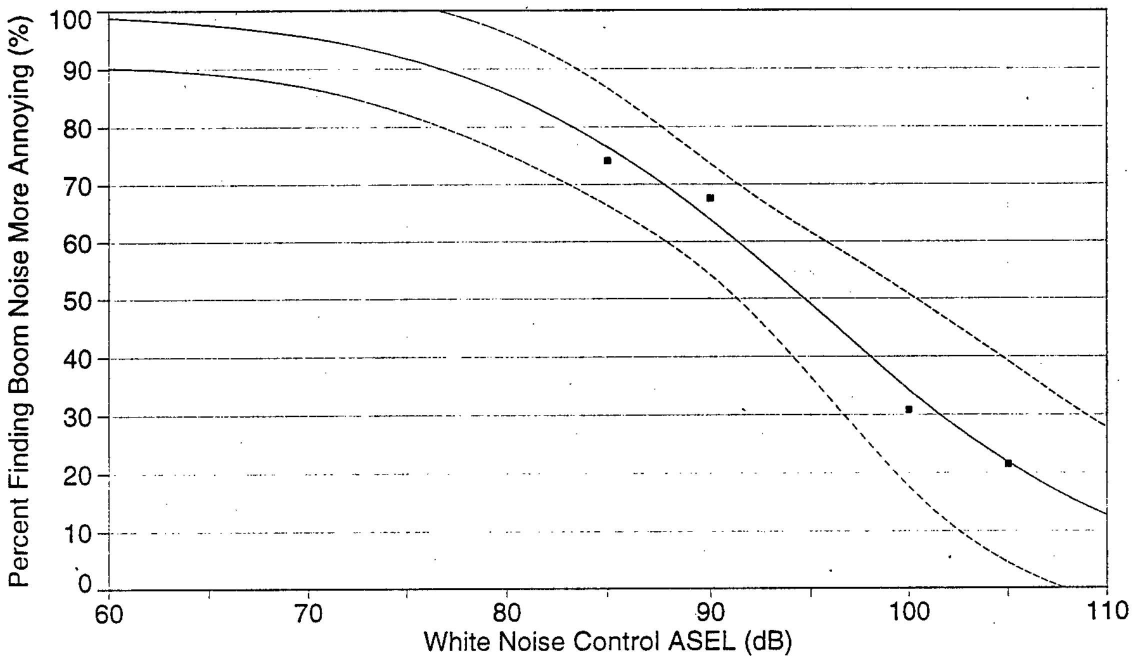
r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9978458934	0.9956917867	2.3872540957	772.04928597

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.11461161	1.711517952	-0.06696489	-4.53049193	4.301268715
b	100.1641836	2.509271222	39.91763933	93.69002343	106.6383438
c	89.97841879	0.565824112	159.0218885	88.51853836	91.43829922
d	-6.83408400	0.471422487	-14.4967289	-8.05039919	-5.61776880

Date	Time	File Source
Feb 6, 1997	12:19:48 PM	c:\tcwin3\new\omb10.prn

Mobile Office Booms

112-115 dB Outdoor CSEL



Rank 1 Eqn 8011 [Sigmoid] y=a+b/(1+exp(-(x-c)/d))

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9982130646	0.9910653230	3.0420255208	372.41154862

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-1.60122795	2.729185118	-0.58670551	-12.9174076	9.714951726
b	101.8712292	3.839198363	26.53450526	85.95253673	117.7899216
c	94.89363319	1.252283751	75.77646290	89.70121592	100.0860504
d	-8.34797879	1.244142224	-6.70982676	-13.5066384	-3.18931922

Date	Time	File Source
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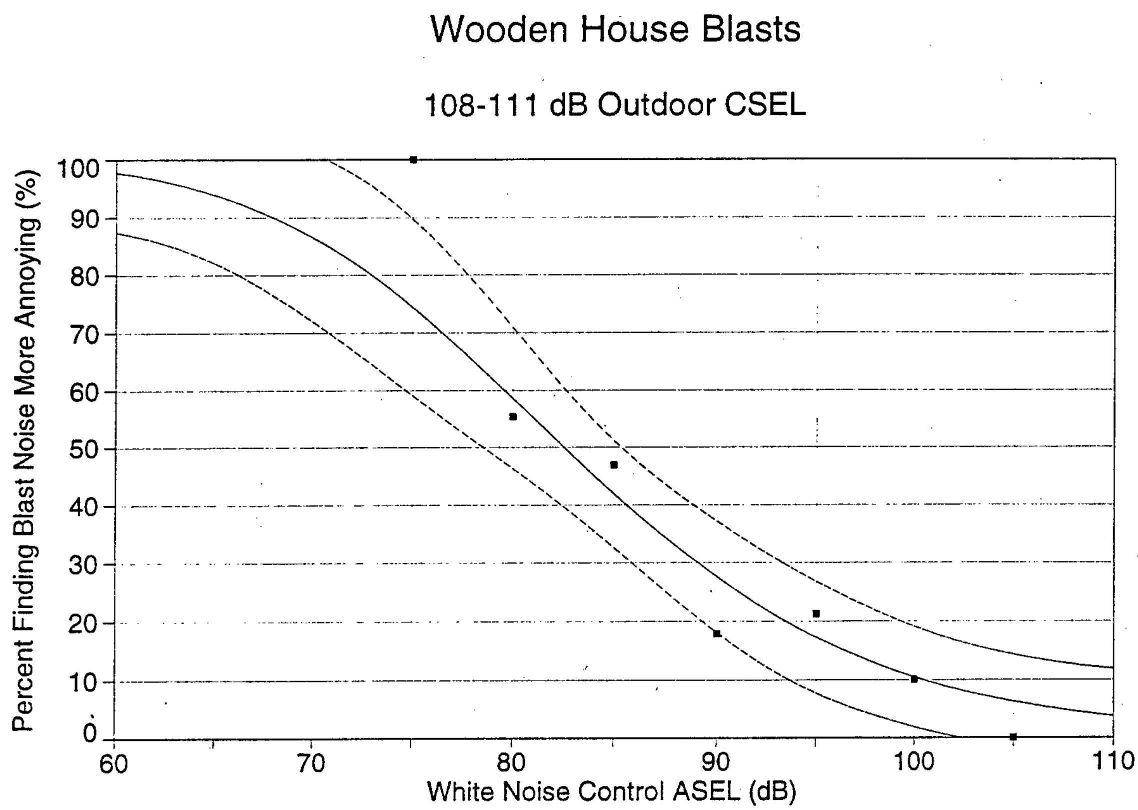
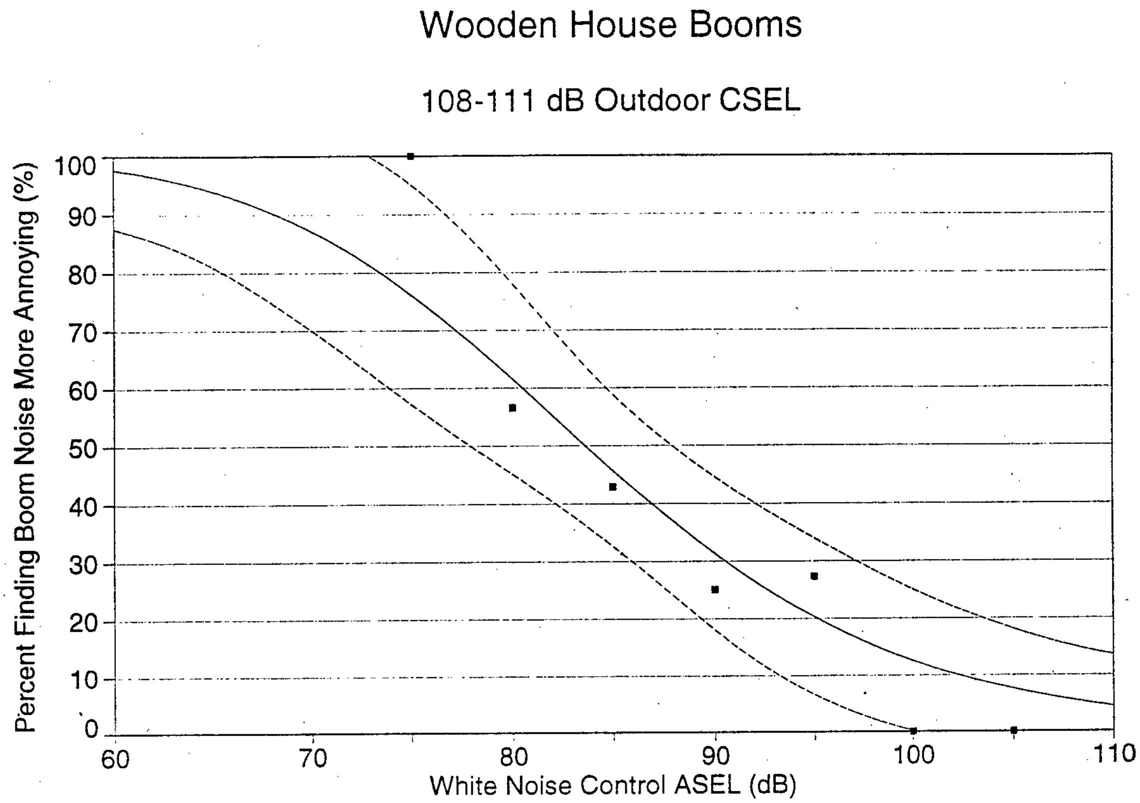


Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9862771743	0.9725543486	6.0452019292	119.78548200

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-0.35621429	4.505231349	-0.07906681	-11.9801429	11.26771430
b	101.0045278	6.480210155	15.58661299	84.28496459	117.7240909
c	82.47994043	1.541273310	53.51415606	78.50330760	86.45657326
d	11.01626954	2.438958169	4.516793148	4.723523755	17.30901533

Date	Time	File Source
Feb 6, 1997	12:34:25 PM	C:\tcwin3\new\owc10.prn



Rank 1 Eqn 8013 [LgstcDoseRsp] $y=a+b/(1+(x/c)^d)$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9872647173	0.9745294346	6.6401834599	129.20335035

Parm	Value	Std Error	t-value	95% Confidence Limits	
a	-1.16355733	4.436947746	-0.26224274	-12.6113077	10.28419302
b	101.8465883	6.304180472	16.15540493	85.58119858	118.1119780
c	83.69953750	1.973155993	42.41911831	78.60860597	88.79046904
d	10.44719339	2.857314348	3.656298229	3.075048572	17.81933821

Date	Time	File Source
Feb 6, 1997	12:31:05 PM	C:\tcwin3\new\owb10.prn

Appendix C: Regression Line Fits

Table C1. Previous indoor-measured blast data.

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.7975614979	0.7845009493	3.53014905	126.07269696

Parm	Value	Std Error	t-value	95% Confidence Limits	P>|t|
Intercept	47.59037657	3.468042284	13.72254796	40.52678659 54.65396655	0.00000
Slope	0.541981124	0.048269593	11.22820987	0.443667266 0.640294981	0.00000

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	1571.1119	1	1571.1119	126.073	0.00000
Error	398.78247	32	12.461952		
Total	1969.8944	33			

Table C2. Previous outdoor-measured blast data.

R^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.7944876648	0.7812288045	3.8459003405	123.70841515

Parm	Value	Std Error	t-value	95% Confidence Limits	P>|t|
Intercept	58.33385204	3.778238485	15.43943091	50.63846504 66.02923904	0.00000
Slope	0.584895452	0.052587027	11.12242847	0.477787992 0.692002912	0.00000

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	1829.7649	1	1829.7649	123.708	0.00000
Error	473.31038	32	14.790949		
Tota l	2303.0753	33			

Table C3. New (Fallon) outdoor-measured sonic booms.

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.8942298732	0.8589731643	1.572045612	59.181257546

Parm	Value	Std Error	t-value	95% Confidence Limits	P>|t|
Intercept	53.09782541	7.184721625	7.390380334	36.0417505 70.15390031	0.00015
Slope	0.642225982	0.083482564	7.692935561	0.444043654 0.84040831	0.00012

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	146.25626	1	146.25626	59.1813	0.00012
Error	17.299292	7	2.4713274		
Total	163.55556	8			

Table C4. New (Fallon) outdoor-measured blasts.

r^2 Coef Det	DF Adjusted r^2	Fit Std Err	F-value
0.844372644	0.688745288	0.9980055502	16.276816605

Parm	Value	Std Error	t-value	95% Confidence Limits	P>|t|
Intercept	80.31857835	6.974697573	11.51570767	58.28663889 102.3505178	0.00141
Slope	0.36187399	0.089695909	4.034453694	0.078539149 0.645208832	0.02739

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	16.211955	1	16.211955	16.2768	0.02739
Error	2.9880452	3	0.99601508		
Total	19.2	4			

Table C5. New (Fallon) outdoor-measured blasts and booms combined.

r^2 Coef Det	DF Adjusted r^2	Fit Std Err	F-value
0.5633939352	0.4840110143	2.579349685	15.48473044

Parm	Value	Std Error	t-value	95% Confidence Limits	P>|t|
Intercept	76.40086992	8.132022277	9.395064022	58.65334266 94.14839717	0.00000
Slope	0.384651289	0.097749685	3.935064223	0.17131995 0.597982628	0.00198

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	103.02061	1	103.02061	15.4847	0.00198
Error	79.836538	12	6.6530448		
Total	182.85714	13			

Distribution

NAS Fallon 89496-5000
ATTN: Code 188 (10)

NAVFAC 22332-2300
ATTN: Code 20 (10)

USAF Armstrong Laboratory (3)
ATTN: AL/OFBN 45433-7901

SERDP (2) 22102

Defense Tech. Info. Ctr. 22304
ATTN: DTIC-FAB (2)

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3/98