NASA/CR–2012-217767

Pilot Test of a Novel Method for Assessing Community Response to Low-Amplitude Sonic Booms

Sanford Fidell
Fidell Associates, Inc., Woodland Hills, California

Richard D. Horonjeff
Consultant, Boxborough, Massachusetts

Michael Harris
Fidell Associates, Inc., Woodland Hills, California

September 2012

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question to help@sti.nasa.gov

- Fax your question to the NASA STI Information Desk at 443-757-5803

- Phone the NASA STI Information Desk at 443-757-5802

- Write to:
  STI Information Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/CR–2012-217767

Pilot Test of a Novel Method for Assessing Community Response to Low-Amplitude Sonic Booms

Sanford Fidell
Fidell Associates, Inc., Woodland Hills, California

Richard D. Horonjeff
Consultant, Boxborough, Massachusetts

Michael Harris
Fidell Associates, Inc., Woodland Hills, California

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Contract NNL10AA19C

September 2012

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

Table of Contents

1 SUMMARY 8
1.1 Purpose and Organization of Report 8
1.2 Background 8
1.3 General findings about immediate reactions to booms 10
1.4 General findings about entire-day reactions to booms 10
1.5 Findings about compliance with instructions for smartphone use 10
1.6 Response latencies and interview durations for immediate response interviews 10
1.7 Ease of use of smartphones 11

2 STUDY DESIGN 12
2.1 Nature of test participant sample 12
2.2 Types of interviews administered by smartphone 12
2.3 Distribution of smartphones to test participants 19

3 PRIMARY FINDINGS 20
3.1 Estimation of sonic boom exposure levels 20
3.2 Distributions of levels of individual sonic booms noticed by test participants 22
3.3 Relationship among metrics of estimated sonic boom exposure levels 22
3.4 Interpretability of findings of end-of-day interview data 95.3 23
3.5 Demonstration of analyzability of immediate response interview data 24
3.6 Development of formal dosage-response relationships 25

4 DISCUSSION OF METHODOLOGICAL FINDINGS 28
4.1 Reports of notice of individual sonic booms (immediate responses) 28
4.2 Response latencies and interview durations 28
4.3 Opinions about cumulative exposure to sonic booms (end-of-day interviews) 29
4.4 Debriefing interviews 31
4.5 Adequacy of recruitment incentives 31

5 DISCUSSION OF SUBSTANTIVE FINDINGS 32
5.1 Estimation of cumulative exposure to sonic booms 32
5.2 Dosage-response analyses of current findings 34
5.3 Comparisons of dosage-response relationship for end-of-day interview reports of annoyance with prior findings 37

6 LESSONS LEARNED 40
6.1 Recommendations about scheduling of intentional exposures to sonic booms 40
6.2 Recommendation for extension of scale of application of technique 42
6.3 Porting of application code to iOS (Apple) devices 43
6.4 Improvements to participant instructions 44
6.5 Minor improvements to features of smartphone reporting application 45
6.6 Measures useful for estimating exposure levels over a wide area 45

7 CONCLUSIONS 47

8 ACKNOWLEDGMENTS 48

9 REFERENCES 49

10 APPENDIX A: WRITTEN INSTRUCTIONS TO TEST PARTICIPANTS 50

11 APPENDIX B: ILLUSTRATIONS OF SECONDARY ANALYSES OF SMARTPHONE-COLLECTED INTERVIEW DATA 52

11.1 Response patterns to sonic booms 52
11.2 Response latencies and implications 56
11.3 Low battery conditions encountered by test participants 57
11.4 Percentages of test participants at home during day and nighttime periods 58
11.5 Questionnaire completion rates 59
11.6 Reports of notice of individual sonic boom events as functions of sound levels 61
11.7 Analysis of responses to question about individually memorable booms 64
11.8 Reports of annoyance of individual sonic boom events as functions of sound levels 67
11.9 Reports of startle associated with individual sonic boom events as functions of sound levels 68

List of Tables

Table 1: Frequency of self-reported response latency 11
Table 2: Locations of test participants when they reported individual sonic booms 28
Table 3: Numbers of test participants completing end-of-day interviews on each day of intentional booming period 30
Table 4: Comparison of variously estimated CDNL values and percentages of annoyance reports in varying degrees 33

List of Figures

Figure 1: Default home screen of government-furnished smartphone, intended to minimize effort required to report notice of a sonic boom. 13
Figure 2: Appearance of screen displaying initial questionnaire item. [Q1] 14
Figure 3: Appearance of screen displaying screening item for annoyance judgment. (A "No" response skips the next questionnaire item.) [Q2] 14
Figure 4: Appearance of screen displaying response alternatives for questionnaire item soliciting an annoyance rating. [Q3] 15
Figure 5: Appearance of screen for initial questionnaire item concerning startle. [Q4] 15
Figure 6: Appearance of screen for questionnaire item inquiring about location of test participant at time of notice of a sonic boom. [Q5] 16
Figure 7: Appearance of screen for questionnaire item inquiring about notice of rattling sounds. (A "No" response skips the next item.) [Q6] 16
Figure 8: Appearance of screen for questionnaire item inquiring about annoyance of rattling sounds. (A "No" response skips the next item.) [Q7] 17
Figure 9: Appearance of screen for questionnaire item inquiring about degree of annoyance of rattling sounds. [Q8] 17
Figure 10: Appearance of screen thanking test participants for reporting a sonic boom. 18
Figure 11: Exposure surface for a single sonic boom, calculated by short range geo-interpolation of sound level measurements made at thirteen monitoring points. 21
Figure 12: Illustration of interpretability of end-of-day annoyance judgments. 23
Figure 13: Illustration of interpretability of reports of notice and annoyance in immediate (single event) interviews. 24
Figure 14: Linear regression of percentage of at-home respondents highly annoyed by C-weighted sound exposure levels estimated by two methods. 27
Figure 15: Distribution of response latencies for reporting individual booms within the first fifteen minutes (900 seconds) of their occurrence 29
Figure 16: Distribution of durations of immediate response interviews 30
Figure 17: Percentages of test participants completing end-of-day interviews on each day of the intentional booming period. 31
Figure 18: Comparison of relationship between high annoyance and mean CDNL values for each day of intentional booming period as estimated by three methods. 34
Figure 19: Fit of the current data to the annoyance prevalence rates predicted by CTL analysis 35
Figure 20: CTL-based relationships between variously defined degrees of annoyance and estimated CDNL values 36
Figure 21: Similarity of current findings (filled red plotting symbols) to a prior determination (Borsky, 1965) of the prevalence of high annoyance with sonic booms. 38
Figure 22: Comparison of current data (filled red plotting symbols) with prior observations cataloged by Fidell (1996) 38
Figure 23: Prevalence of annoyance with low-amplitude sonic booms (filled red plotting symbols) in relation to similar findings of 44 other studies of the annoyance of aircraft noise (Fidell *et al.*, 2011.) 39
Figure 24: Chronology of sonic boom reports during participant possession of smartphones. 52
Figure 25: Time history of sonic boom responses for week 10/30/2011 through 11/05/2011. 53
Figure 26: Chronology of sonic boom responses for week 11/06/2011 through 11/12/2011. 54
Figure 27: Chronology of sonic boom responses for week 11/13/2011 through 11/20/2011. 54
Figure 28: Sonic boom response time history for 14 November 2011. 55

Figure 29: Response time history for a 1-1/2 hour period of intentional sonic booms on 31 August 2011. ... 55
Figure 30: Cumulative distribution function of observed response latencies as long as an hour following a boom. ... 56
Figure 31: Cumulative distribution function of observed response latencies up to 15 minutes following boom event. ... 57
Figure 32: Percentages of test participants encountering varying numbers of low battery conditions during the test period. ... 58
Figure 33: Comparison of at-home status between daytime and evening/nighttime periods ... 59
Figure 34: Participant at-home status by hour of day, for weekday/weekend periods. ... 60
Figure 35: Percentage of respondents answering questions on immediate response questionnaire (see Figure 2 though Figure 9). ... 61
Figure 36: Percentages of at-home participants noticing sonic booms as a function of maximum boom overpressure. ... 62
Figure 37: Percentages of at-home participants noticing sonic booms as a function of C-weighted sound exposure level. ... 63
Figure 38: Percentages of at-home participants noticing sonic booms as a function of maximum boom overpressure (logarithmic scale) ... 63
Figure 39: Observed relationship between C-weighted sound exposure level and square of maximum overpressure (dashed line is unity slope) ... 64
Figure 40: Relationship between percent of respondents reporting one boom to be louder than all others for the day and CDNL. ... 65
Figure 41: Relationship between percent of respondents reporting one boom louder than others and CSEL difference between loudest and next loudest boom. ... 66
Figure 42: Relationship between percent of respondents reporting one boom louder than others and CSEL difference between loudest and next loudest boom (with fit line). ... 66
Figure 43: Relationship between percent of respondents reporting one boom to be louder than all others for the day and the difference in CDNLs between that of the loudest boom and all the rest (with fit line). ... 67
Figure 44: Percentages of at-home test participants reporting three different degrees of annoyance to sonic booms as a function of C-weighted sound exposure level. ... 68
Figure 45: Percentages of at-home test participants reporting startle to sonic booms as a function of C-weighted sound exposure level. ... 69
Figure 46: Percentages of at-home test participants noticing rattle as a function of C-weighted sound exposure level. ... 69

1 SUMMARY

1.1 Purpose and Organization of Report

This document is the final technical report for NASA Contract NNL10AA19C. It describes a pilot test of a novel method for assessing the annoyance of residential exposure to sonic booms. The report presents information about data collection methods and about test participants' reactions to low-amplitude sonic booms. The latter information should not be viewed as definitive for several reasons. It may not be reliably generalized to the wider U.S. residential population (because it was not derived from a representative random sample); the sample itself was not large; and the uncertainty of acoustic measurements of the exposure of test participants to sonic booms is difficult to quantify.

Following a brief overview of findings in this section, a Study Design section provides further information about study methods. The report then presents details of primary findings, followed by discussion of the methodological and substantive results. A "Lessons Learned" discussion precedes Conclusions. Two appendices contain the instructions provided to test participants, and the findings of secondary analyses.

1.2 Background

The novel aspect of the current study is reliance on smartphones to collect near-real time opinions about the annoyance of sonic booms. Many people customarily carry cell phones with them as part of their daily routines.[1] Smartphone-based interviews can thus be conveniently conducted in close temporal proximity to the occurrence of sonic booms, not only while respondents are at home, but also while they are away from home. Questionnaires administered by smartphone can improve the precision, immediacy, and cost-effectiveness of field assessments of community response to infrequent and unanticipated sonic booms. Because the use of smartphones permits conduct of adaptive study designs, they can minimize the costs of unnecessary community exposure to impulsive noise, while widening the range of analyses that can be practically conducted. Near real-time data collection, as well as the availability of situational information about the circumstances of interviewing, offer novel opportunities for fine-grained analyses of noise-induced annoyance.

Edwards Air Force Base was chosen as the venue for the current pilot study for the convenience it affords in producing and measuring exposure and reactions to sonic booms generated by aircraft based at NASA's adjoining Dryden Research Center. Residents of this Air Force base also have long familiarity with sonic booms created by aircraft operations in a nearby supersonic flight corridor. During the first two weeks of November, 2011, residents of the base housing area at Edwards AFB were exposed to nearly 90 low amplitude sonic booms that were intentionally produced by NASA flight operations. (They were also exposed both intentionally and adventitiously to about 20 additional higher amplitude sonic booms during the same time period.)

Motorola Droid2 smartphones were distributed to 49 test participants, mostly spouses of military personnel living at Edwards AFB, between August and October of 2012. The test

[1] It was recently estimated that approximately half of U.S. households (about 60 million) have smartphone and/or other internet-enabled mobile devices.

participants were encouraged to use these government-supplied smartphones for their routine personal purposes, without charge, for the duration of the field study. They were also asked to complete two forms of interview. First, they were instructed to push a large red button on the home screens of these smartphones, and to complete a brief interview administered via smartphone, whenever they noticed a sonic boom at any time of night or day, whether at home or elsewhere. Second, they were instructed to answer several questions at the end of the day concerning their entire day's reactions to sonic booms. The survey was administered by the smartphone application, and required no connection to the database server.

Interview information collected by the smartphones was transmitted - without any test participant involvement, via wireless commercial digital network - to a remote, cloud-based server. The server created separate databases for responses to questionnaire items of the immediate and end-of-day interviews. The smartphones reported basic "health" information (*e.g.*, available memory, battery charge, at-home status, and network connectivity) to the server four times per hour. This information was transmitted to the server as soon as contact could be established, so that the status of smartphones could be archived regardless of server accessibility or communication link status. The server's password-protected databases were immediately available via the Internet to analysts to monitor the course of data collection, and for quality control-related purposes. Measures were taken to anonymize the identities of test participants to preclude disclosure of any personally-identifiable information.

Test participants made 2152 sonic boom reports during the two-week intentional booming period. Of these, 1717 (79.8%) were reports made from home, where sound level doses could reasonably be estimated. Of the 1717 at-home responses, 1631 (95.0%) were for indoor exposure to a boom. Since only 86 reports were received for the at-home/outdoor exposure condition, no attempt was made to compare indoor versus outdoor levels of annoyance for similar boom intensities, nor did the outdoor reports contribute to individual event analyses.

Of the 1631 indoor/at-home reports, 1413 (86.6%) could be unambiguously linked to an estimated outdoor boom level. The remaining 218 (13.4%) could not be positively linked for reasons discussed later. The most common reason was an inter-boom interval shorter than a response latency.

The text of the following subsections focuses on the 1413 immediate reaction reports for which it was possible to unambiguously attribute opinions expressed in interviews to specific sonic booms while test participants were indoors at home during the two-week long intentional booming period. Note that denominators for sample proportions are not necessarily 49 (the maximum number of test participants who could potentially have filed reports), but are adjusted for numbers of participants who were at home with charged smartphones at the times of occurrence of sonic booms.

Information about end-of-day interviews is analyzed at length in Section 5.3 on page 37 of this report.

1.3 General findings about immediate reactions to booms

The at-home, indoors responses indicated annoyance in some degree in 24% (338 of 1413) of the reports of notice of sonic booms during the intentional booming period[2]. These responses further indicated "high" ("very" or "extremely") annoyance in 5% (76 of 1413) of the cases. Test participants describe themselves as startled by booms in 29% (409 of 1413) of the reports.

Notice of rattle was reported in 48.6% (685 of 1413) of the cases. The mean of the peak overpressures of booms for which test participants noticed rattle was 0.67 psf, while the mean of the peak overpressures of booms for which test participants did not report rattle was 0.45 psf. The difference in overpressures for booms that were and were not associated with notice of rattle was unlikely to have arisen by chance alone ($F_{(df = 1412)} = 57.92$, $p < .0001$).

As is evident from the discussion of Sections 3.4 through 3.6 and Section and 4.5, and from the illustrations in Appendix B, the intensity of reactions to booms generally increased with increasing boom levels.

1.4 General findings about entire-day reactions to booms

Completion rates for interviews about test participants' exposure to full days of sonic boom exposure were comparable to those usually obtained by conventional social survey techniques. The percentages of respondents describing themselves as highly annoyed by whole days of exposure to sonic booms were well accounted for by the effective loudness of the exposure, as described in greater detail in Section 5.2.

The percentages of test participants highly annoyed by exposure to low-amplitude sonic booms closely resembled those measured by conventional social survey methods in Oklahoma City (Borsky, 1965). Greater percentages of test participants were highly annoyed by exposure to low-amplitude sonic booms than by exposure to conventional (sub-sonic) aircraft noise at similar cumulative exposure levels.

1.5 Findings about compliance with instructions for smartphone use

Compliance by the test participants with instructions to use their smartphones to report notice of sonic booms was excellent. During the entire (August-November) period during which test participants were in possession of government-furnished smartphones, they reported noticing a total of 157 distinct sonic booms. They collectively completed 3266 reports of notice of individual sonic booms during the two-week long intentional booming period. Of these, ten percent of the test participants reported noticing 64% or more of all sonic booms. Twenty percent reported noticing 58% or more of the booms. Fifty percent of the participants reported noticing 43% or more of the booms. The most common difficulty encountered by test participants in the use of smartphones was remembering to recharge them nightly.

1.6 Response latencies and interview durations for immediate response interviews

Test participants described the times of occurrence of sonic booms at the very beginning of the questionnaire (Item 1). They were instructed to select from one of the three categories shown

[2] Note that the divisors for percentages in this subsection are the number of at-home respondents providing an interview, not the total number of at-home participants (some of whom did not provide interviews).

in Table 1. Nearly 85% (2767 of 3266)[3] reported the boom as occurring "within the last few minutes."[4] (Section 2 of this report describes the individual questionnaire items to which test participants responded.) Actual response latencies (elapsed time between the occurrence of a boom and receipt of a report of noticing it) ranged from as little as 16 seconds to as long as 2 hours after the occurrence of a sonic boom. The response latencies were exponentially distributed, with a mean latency of 276 seconds and a standard deviation of 871 seconds (*cf.* Figure 15 on page 29).

The distribution of interview durations for immediate reports of notice of sonic booms was approximately lognormal, with a mean duration of 17.3 seconds and a standard deviation of 12.8 seconds (*cf*. Figure 16 on page 30).

Table 1: Frequency of self-reported response latency

Self-reported response latency	Number	Percent
Last Few Minutes	2767	84.7%
More Than Half Hour	248	7.6%
Last Hour	251	7.7%
Total	3266	100.0%

During the two-week period of intentional exposure to sonic booms, the test participants also completed 377 interviews about their end-of-day reactions to sonic booms. In the several months prior to the intentional booming period in November, 2011, the test participants completed an additional 2027 end-of-day interviews. The mean duration for the end-of-day interviews during the intentional booming period was 13.6 seconds.

1.7 Ease of use of smartphones

Test participants were provided with an automatic texting address and an automatically-dialable telephone hotline number that they could use to request live assistance in the use of their smartphones. Few respondents called to ask for such assistance, nor reported any difficulty in the use of the smartphones distributed to them. Smartphones were charged and available for use more than 91% of the time.

[3] These numbers include all interviews while the smartphones were in the participants' possession, not just during the intentional booming period.

[4] Not all of these interviews were usable in the dose-response relationships described later in this report, because not all could be unambiguously linked to a specific sonic boom.

2 STUDY DESIGN

2.1 Nature of test participant sample

NASA provided a purposive sample of 49 test participants in several batches, starting in early August and concluding in mid-October of 2011. All were self-selected volunteers residing in government-owned housing at Edwards Air Force Base who had 1) responded to various solicitations for volunteers, and 2) had described themselves as frequently at home during daytime weekday hours. Many of the test participants were neighbors; most were parents of young children and spouses of Air Force officers in their 20s and 30s. A few test participants were active duty Air Force enlisted personnel.

Given the purposive nature of their selection and qualification for participation, opinions expressed by test participants about their sonic boom exposure during the course of the pilot test are not necessarily representative of those of all base residents, nor of the U.S. public at large.

Test participants had no detailed information about the numbers, amplitudes, origin, or scheduling of sonic booms to which they would be exposed during the course of the pilot test, nor about the two week period during which their exposure would be primarily intentional rather than adventitious. They were exposed to a short set of "orientation" booms immediately prior to the start of the intentional booming period to familiarize them with low-amplitude booms.[5] Their only specific knowledge of the duration of the test was that their participation would end around the end of November, at which time they would be expected to return their government-furnished smartphones.

2.2 Types of interviews administered by smartphone

<u>Immediate interviews</u>

Test participants were asked to complete two forms of smartphone-based interviews. In the immediate response interview, test participants were asked to report notice of any sonic boom, at any place and time of day, as soon after the occurrence of the boom as practicably and safely possible. This interview solicited opinions about spontaneously-reported sonic booms in a free response context lacking a defined response interval. The default home screen of the smartphone displayed a single large, red virtual button similar to that shown in Figure 1 so that filing a report required no more effort than touching the screen of the smartphone to "push" the reporting button.

Upon pushing the "Report Boom" button, the smartphone autonomously administered an interview about the test participant's reactions to the boom. The questionnaire items were intended

[5] The nature of the inverted dive maneuver generated low-amplitude booms produced pairs of N-waves: an initial one (from the perspective of the test participants), and a yet-lower amplitude one heard a few moments later. The second pair of impulses was actually generated earlier in time, but arrived in the base housing area later because it propagated over a greater distance. The later-arriving pair of booms did not appreciably affect the CSEL of earlier arriving impulse pair. Test participants were warned of the "double boom" phenomenon, and asked to judge the annoyance of the booms heard in very rapid succession as individual events.

1) to confirm that the report was intentional and to estimate the reporting latency (per Figure 2);

2) to determine whether the test participant was bothered or annoyed by the boom, and if so, to what degree (*per* Figures 3 and 4)

3) to determine whether the test participant was startled by the boom (per Figure 5);

4) to determine whether the test participant was indoors or outdoors (per Figure 6); and

5) to determine whether the test participant noticed rattling sounds, and if so, whether the rattling sounds were annoying to any degree (per Figures 7 through 9).

Upon conclusion of the interview, a final screen thanked the test participant for the boom report (*per* Figure 10).

Figure 1: Default home screen of government-furnished smartphone, intended to minimize effort required to report notice of a sonic boom.

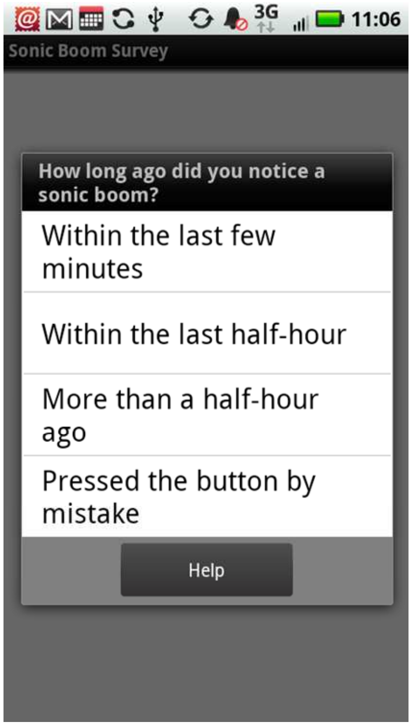

Figure 2: Appearance of screen displaying initial questionnaire item. [Q1]

Figure 3: Appearance of screen displaying screening item for annoyance judgment. (A "No" response skips the next questionnaire item.) [Q2]

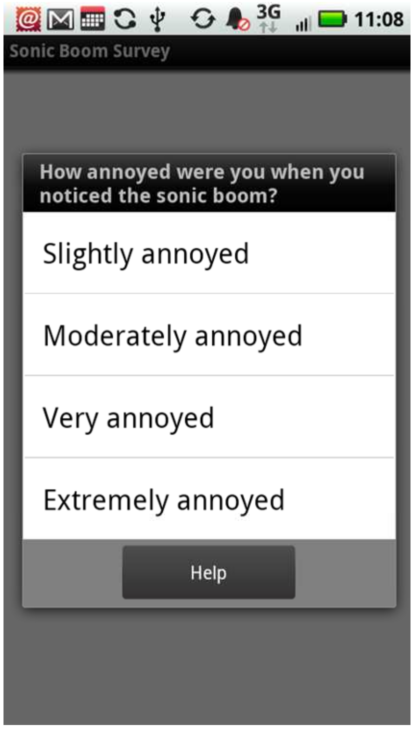

Figure 4: Appearance of screen displaying response alternatives for questionnaire item soliciting an annoyance rating. [Q3]

Figure 5: Appearance of screen for initial questionnaire item concerning startle. [Q4]

Figure 6: Appearance of screen for questionnaire item inquiring about location of test participant at time of notice of a sonic boom. [Q5]

Figure 7: Appearance of screen for questionnaire item inquiring about notice of rattling sounds. (A "No" response skips the next item.) [Q6]

Figure 8: Appearance of screen for questionnaire item inquiring about annoyance of rattling sounds. (A "No" response skips the next item.) [Q7]

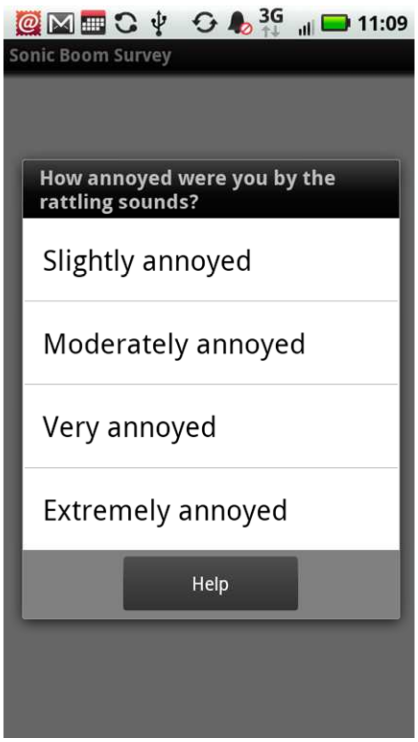

Figure 9: Appearance of screen for questionnaire item inquiring about degree of annoyance of rattling sounds. [Q8]

Figure 10: Appearance of screen thanking test participants for reporting a sonic boom.

End-of-day interviews

The smartphone administered a second form of interview at a time of the test participant's choosing at the end of the day. Whereas the test participant-initiated interview sought information about short-term reactions to individual sonic booms, the end-of-day interview focused on reactions to an entire day's worth of sonic boom exposures.[6] The smartphone displayed questionnaire items in the same format as those illustrated in Figure 1 through Figure 10 for the following questions:

How many sonic booms do you remember noticing today?

[*If any booms are recalled*] Considering all of the sonic booms that you noticed today, how annoyed would you say you were by all of them taken together?

[*If more than one boom was recalled*] Was any one particular sonic boom that you noticed today much more annoying than any of the others?

About what time of day did you notice the boom that was much more annoying than the rest of the booms?

[6] Test participants heard multiple sonic booms on some days, due both to supersonic military flight operations in the vicinity of Edwards AFB, and/or to multiple NASA flight operations specifically intended to produce low-amplitude sonic booms in the base housing area in the first half of November, 2011.

2.3 Distribution of smartphones to test participants

Half a dozen meetings were held between August and October of 2011 in an easily-accessible conference room at NASA Dryden Research Center to distribute smartphones and instruct volunteer test participants in their use. (NASA had made separate contractual arrangements for recruiting test participants, including approval of recruiting methods by an Institutional Review Board.) Appendix A contains the written instructions given to the test participants in the use of the smartphones.

Each test participant was provided with a smartphone and paraphernalia (holster, AC and car chargers, the manufacturer's manual, a short written summary of the major features of the phones and of their tasks as test participants, *etc*.) to use as they would their own mobile telephone for the duration of the study. They were requested to keep the phone with them throughout their daily routines, both while at home and while away from home. If they desired, they were permitted to transfer contact files, pictures, and a pre-existing mobile telephone number to the smartphone so that it could serve as their primary mobile communication device for the duration of the pilot test. If they chose not to do so, they were permitted to continue to use another personal cell phone in addition to the supplied smartphones.

3 PRIMARY FINDINGS

A total of 5390 potential opportunities (49 test participants multiplied by 110 booms) for reporting notice of sonic booms occurred during the two week intentional booming period (from 04 to 18 November 2011).[7] For a variety of reasons, about two-thirds of these potential opportunities proved not to be actual opportunities to assess residential reactions to sonic booms. In some cases, low-amplitude sonic booms may simply have been inaudible or otherwise escaped notice by test participants going about their daily business. Other reasons for not reporting booms ranged from test participants' lack of recognition of very low-amplitude booms as sonic booms, to temporary absences of test participants from Edwards AFB, to uncharged smartphones or smartphones otherwise without network access, and to a *post hoc* inability to unambiguously link boom reports with specific booms.[8]

Test participants used their smartphones to report notice of individual booms on 2152 occasions. Of these 2152 reports, 1717 (79.8%) were made when participants were at home. In the remaining 435 cases, test participants filed reports while somewhere other than home.

Of the 1717 at-home reports, 1631 occurred when the respondent was indoors. The remaining 86 outdoor responses were too few to merit separate analysis. In 1413 of the 1631 cases (86.6%), test participants were indoors with active smartphones[9], and their responses could be unambiguously linked to a specific dose sound level. These reports were received from as early as 7:31 AM to as late as 4:24 PM.

The great majority (1333 of 1413, or 94.3%) of the boom reports concerned booms intentionally created by NASA. The remainder (80 of 1413, or 5.7%) of the boom reports concerned adventitiously occurring sonic booms associated with other flight operations. The latter booms were generally of higher level than those intentionally created by NASA as low-amplitude booms. Test participants had no detailed prior information about the numbers, amplitudes, or sources of sonic booms.

3.1 Estimation of sonic boom exposure levels

In the two-week period of intentional booming during early November of 2011, test participants were exposed to a total of 110 sonic booms. Of these, 89 were intentionally created, and/or relatively low-amplitude sonic booms created by NASA aircraft, while 21 were generally higher amplitude booms created by military supersonic operations.

Measurements of sound pressure levels of intentionally created sonic booms within the base housing area at Edwards AFB were made under separate contract. These measurements were

---

[7] Many other opportunities for reporting sonic booms arose between August, 2011 and the start of the intentional booming period, but no consistent sound level estimates were available for most of booms reported prior to the start of the intentional booming period in November.

[8] The principal reason that a report could not be unambiguously linked to an individual boom was that it was received after the occurrence of a subsequent sonic boom. In one extreme case (a series of early morning booms, in rapid succession), few respondents provided interviews until the last boom of the series had occurred.

[9] The smartphones provided status reports four times per hour to a central server, which confirmed them as "active" for purposes of this study: that is, operating, with adequate battery power and digital network access.

made at thirteen monitoring points located within a few hundred meters of test participants' homes. Exposure estimates were provided to Fidell Associates in the form of estimates of sound levels for each of the booms immediately outside and inside the test participants' homes.

Three different estimating methods were employed to assign doses to each respondent for the individual booms. They were derived from geographically-interpolated measurements made at thirteen contractor-operated monitoring sites, and in some cases, at an additional, NASA-operated central monitoring site.

Method 1

The geo-referenced interpolation procedure involved complex, fine scale calculations that attempted to take account of short-range meteorological influences on propagation of sonic booms across the thirteen-station monitoring array. Figure 11 is a three dimensional exposure surface produced in this manner for a single sonic boom. The figure illustrates pronounced differences in estimated sonic boom levels over short ranges for a single boom.

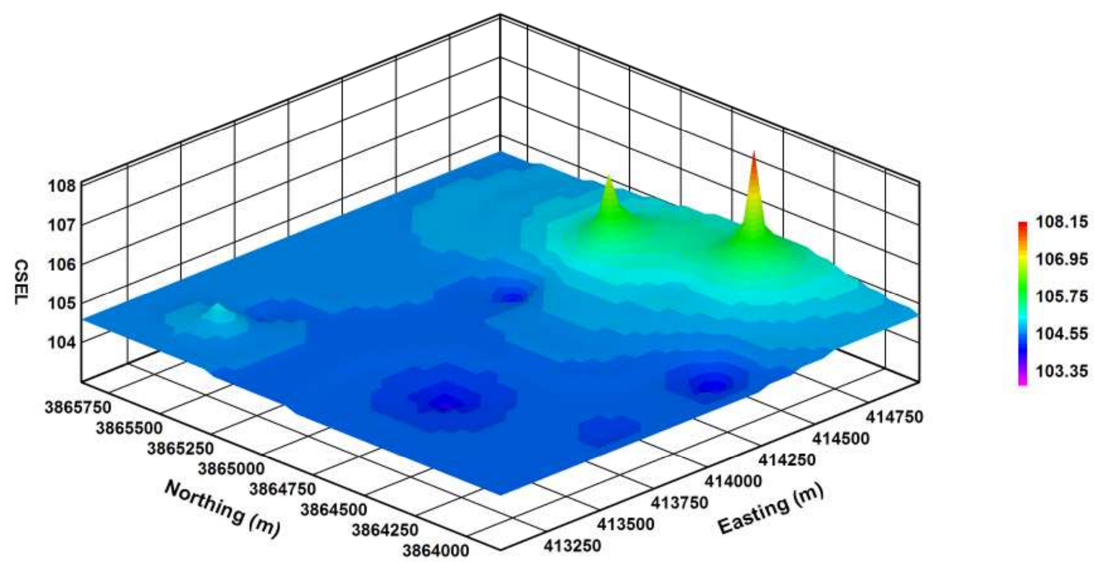

Figure 11: Exposure surface for a single sonic boom, calculated by short range geo-interpolation of sound level measurements made at thirteen monitoring points.

Point estimates of this sort may be useful for research purposes, such as constructing psychometric functions for single event annoyance judgments for different noise metrics. However, they require many assumptions and engineering judgments which are difficult to document, and may introduce statistical noise into dosage-response analyses.

<u>Methods 2 and 3</u>

Two other, less complex and less assumption-dependent sets of estimated sonic boom exposure levels were also constructed. One was a simple average of the measurements made at the thirteen monitoring points. Simple averaging yielded sound levels representative of the average exposure of the entire base housing area to sonic booms, rather than single-event exposure estimates at any test participant's home. A third estimate of exposure levels was made from sonic boom levels recorded at a single monitoring point near the centroid of the base housing area.

The latter two exposure estimates are similar to those which FAA relies upon for evaluating aircraft noise impacts, and are thus more appropriate than point estimates at individual homes for constructing dosage-response relationships between exposure to sonic booms and the prevalence of high annoyance. For purposes of making policy decisions about the acceptability of exposure to sonic booms to residential populations, the most reasonable level of analysis is not the exposure of any particular individual to any specific sonic boom, but rather the prevalence of a consequential degree of annoyance associated with area-wide exposure.

3.2 Distributions of levels of individual sonic booms noticed by test participants

For the 1413 reports of notice of sonic booms which could be unambiguously linked to a specific sonic boom, the mean C-weighted SEL of the booms was 93 dB, with a standard deviation of 6.2 dB. The corresponding A-weighted SEL values were 69 dB for the mean, and 9 dB for the standard deviation. The mean of the maximum unweighted overpressures of the reported booms was 0.56 psf, with a standard deviation of 0.41 psf. The observed relationship between maximum overpressure and CSEL is shown in Figure 39 on page 64.

3.3 Relationship among metrics of estimated sonic boom exposure levels

Estimates of sonic boom levels at the homes of test participants were based for the most part on contractor measurements at thirteen locations within the Edwards Air Force Base housing area, and on noise modeling and contouring algorithms intended to interpolate the measurements made at the fixed locations to the homes of test participants. (Estimates were also based in some cases on additional sonic boom measurements made by NASA at a central location within the base housing area.)

The estimates of sound levels and peak overpressures for each boom were expressed in units of a dozen noise metrics (including A-, C-, and Z-weighted sound exposure levels, variant forms of perceived and loudness levels, and sones and phons, for both outdoor and indoor cases), at each test participant's home address. A correlation matrix was prepared for the entire set of estimated boom levels at test participants' homes.

All of the estimated boom levels proved to be very highly correlated (typically, 0.90 or higher) with one another.[10] Thus, the various metrics differed from one another by little more than scale factors and constants within the current set of field measurements, and were therefore nearly perfectly predictable from one another. This high degree of co-linearity among noise

[10] This is not a novel finding. Mestre *et al.* (2011), for example, have recently demonstrated that most measures of aircraft noise, including those calculated by FAA's Integrated Noise Model software, are very highly correlated with one another.

metrics implies that for practical purposes of predicting the prevalence of high annoyance with sonic booms, any of the metrics is as good (or as poor) a predictor as any other.

Since much prior research on the annoyance of impulsive sounds related community opinions to C-weighted noise measures such as CSEL and CDNL, these metrics were used for the current dosage-response analyses as well. The grand average of single event CSEL values measured at thirteen monitoring stations for the booms occurring during the intentional booming period was approximately 92 dB, with a standard deviation of 8.1 dB and range of 34 dB across booms. The average, standard deviation and range were 54, 8.3 and 27 dB, respectively, for the end-of-day CDNL values.

3.4 Interpretability of findings of end-of-day interview data 95.3

Figure 12 is one illustration of the ready interpretability of responses to end-of-day questionnaire items. The figure plots percentages of respondents describing themselves as annoyed in varying degrees by each day's exposure to sonic booms during the intentional booming period. The prevalence of reported annoyance tends to increase with CDNL, and segregates itself into obvious groupings by degree of annoyance.

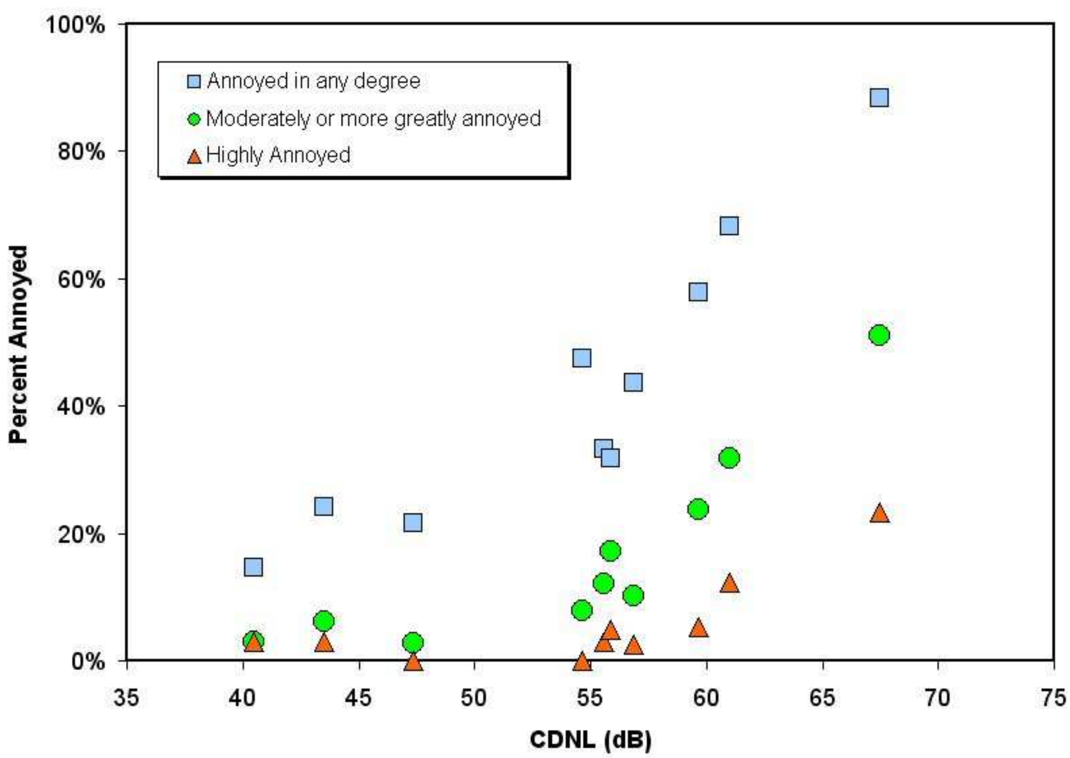

Figure 12: Illustration of interpretability of end-of-day annoyance judgments.

A similar example of the interpretability of responses to the immediate response interviews is shown in Figure 13. The noticeability and annoyance in varying degrees once again cluster in distinct groupings. Figure 13 displays percentages of at-home participants as a function of the sonic boom's maximum overpressure, on a logarithmic scale. As in Figure 12, the percentages increase with increasing sound dose. Furthermore, the groupings for the various types of responses are ordered in the expected high-to-low order. That is, the greatest percentages of test participants reported noticing sonic booms, while lower percentages of test participants described themselves as annoyed by them in greater degrees.

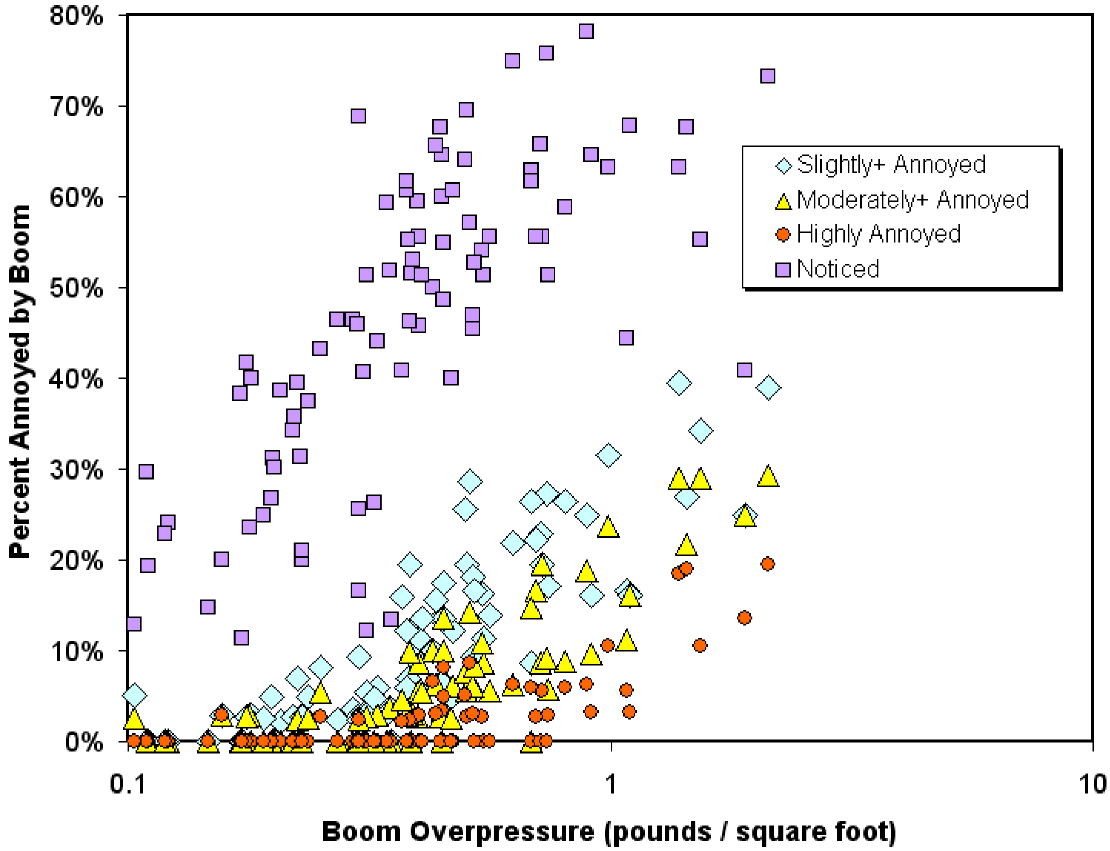

Figure 13: Illustration of interpretability of reports of notice and annoyance in immediate (single event) interviews.

3.5 Demonstration of analyzability of immediate response interview data

Another goal of the current pilot test was to demonstrate that interview data collected by smartphone could be statistically analyzed and otherwise treated in the same manner as interview data collected by other social survey methods. This was shown by performing a binary logistic regression through SPSS Binary Logistic. This analysis attempted to predict the probability of respondents describing themselves as highly ("very" or "extremely", N = 76) annoyed on the basis of five study variables: boom level (expressed in units of CSEL), day of study (1-9), ordinal number of boom for the day (1-27), time of day (AM or PM), and location of respondent at the time of occurrence of a boom (home indoors or home outdoors). Data were complete for 1413 cases.

All of the variables except location at the time of occurrence of a boom were significantly related to self-reports of high annoyance in univariate analysis. Prediction of high annoyance was enhanced by entry of the five predictors into the equation ($\chi^2_{(5, N = 1413)} = 95.30$, $p < 0.001$).

The classification equation, although highly accurate, was unhelpful. The accuracy of classification was 95%, but was predetermined by the *a priori* odds of self reports of high annoyance. The classification equation merely assigned all of the cases to the "not highly annoyed" category.

Because all of the predictors entered the equation simultaneously, each was adjusted for overlapping variance with other variables. The only variable with sufficiently unique predictive value was CSEL (Wald = 66.14, $p < .000$). Two other variables that were marginally related to high annoyance were day-of-study (Wald = 3.43, $p = .06$) and ordinal position of boom in the day (Wald = 2.71, $p = .10$). Time of day and location of respondent did not contribute to the equation.

The final prediction equation was:

$$\%\ \text{Highly\_annoyed} = -20.04 + 0.167(\text{CSEL}) + 0.13(\text{day-of-study}) + 0.05\,(\text{ordinal\_boom}) - 0.04(\text{AM\_PM}) - 0.02\,(\text{location-of-respondent}) \qquad \text{[Eq. 1]}$$

where:

CSEL = C-weighted sound exposure level
day-of-study = elapsed number of calendar days into study, with 04 Nov 2011 as day number 1.
ordinal_boom = the Nth sonic boom of the day
AM/PM = morning vs. afternoon distinction (AM=1, PM=2)
location-of-respondent (indoors = 1, outdoors = 2)

No substantive use should be made of this equation other than as an indication that interview data collected by smartphone lend themselves to the same sorts of analyses that can be conducted on interview data collected by other means.

Appendix B contains additional descriptive analyses and summary graphics of the interview data. Since the sample of interview respondents was small and non-representative, the analyses of Appendix B are of interest primarily as examples of the sorts of fine-grained analyses that smartphone-based interviewing can support.

3.6 Development of formal dosage-response relationships

Relationships between judged annoyance and estimated exposure of test participants to sonic booms were developed for opinions expressed in both immediate response (single-event) and end-of-day (cumulative exposure) interviews. The analyses reported here are limited to the two week intentional booming period in early November of 2011.[11]

[11] A larger set of boom reports could also, in principle, be subjected to dosage-response analyses. These include reports made by test participants who were not at home, and reports of notice of sonic booms received prior to the November start of operation of the thirteen noise monitoring stations as early as August of 2011. Not all of the 49 test participants were in possession of smartphones for all of this time period, and the amplitudes of only some of the sonic booms reported prior to November could be estimated with useful precision. Given that the primary goals of this pilot study were methodological rather than substantive, these analyses were not undertaken.

Annoyance judgments from the single event and cumulative exposure interviews were analyzed differently. The analysis of the single event interviews focused on the predictability of reports of "high" (that is, "very" or "extremely") annoyance among at-home test participants from estimates of C-weighted sound exposure levels of each boom. The analysis of the end-of-day judgments of cumulative annoyance focused on comparing the prevalence of annoyance with cumulative exposure with prior findings using all end-of-day reports regardless of participant at-home status during the day.

In the single event case, percentages of test participants describing themselves as highly annoyed by each boom were plotted against the CSEL of each boom. The numerator of the percentage calculation included all of the highly annoyed test participants who reported noticing a sonic boom while at home (and for whom the sonic boom which they reported could be positively identified).

The denominator for each percentage calculation took into consideration the numbers of reports of notice of sonic booms received by the server, as well as the numbers of smartphones at home and answering the server's periodic roll call (*i.e.,* charged, turned on, and connected to a digital network) at the time of each boom. This calculation excluded from analysis all data from test participants who were 1) *not* at home at the time of occurrence of sonic booms, 2) those who may have been at home, but whose cell phones could not be confirmed by server-based software as available for use shortly before the time of occurrence of sonic booms[12], and 3) those who failed to report notice of individual sonic booms prior to the occurrence of a subsequent boom.[13]

If it is assumed that test participants who failed to report notice of individual sonic booms simply didn't notice them, then it might be argued that excluding their data might lead to a slight overstatement of the percentages of test participants highly annoyed by individual sonic booms. It is unlikely on its face, however, that test participants would have systematically failed to notice highly annoying sonic booms.

A linear regression of percentages of highly annoyed test participants on CSEL values of individual booms at levels greater than 97 dB accounted for 51% of the variance in the association between individual boom levels and the prevalence of high annoyance ($r = 0.72$).[14] Figure 14 shows that the growth of the prevalence of annoyance with level in the non-asymptotic region was roughly 1.4 percent per one decibel increase in CSEL.

[12] In a few cases, the smartphone status report immediately prior to a boom indicated the smartphone was probably on its charger at the time of the boom. The fact that the participant provided a well timed match to a boom suggested that the participant removed the phone from the charger to report the boom. In all such cases, the smartphone remained off the charger until the next recharge was required.

[13] Test participants sometimes completed multiple interviews shortly after reporting a particular boom. The first interview in such sets usually corresponded to the most recently heard boom. The remaining interviews were clearly intended to respond to earlier booms which the participant had not previously reported. The order in which the missing interviews were provided could often be deduced by the answers to the questionnaire's "how long ago" question (see Figure 2).

[14] Note that this regression focuses on responses to only 18% (16 of 88) of the intentionally produced booms. The other 82% of the booms were presented at levels in the asymptotic region which few test participants found to be highly annoying.

The percentage of at-home respondents describing themselves as highly annoyed is plotted against the arithmetic average values of CSELs derived by two estimation methods. The circles represent CSEL values estimated at the residences of at-home participants, while the triangles represent area-wide estimates of CSEL values at all of the boom monitors. This yields a pair of plotting symbols for each sonic boom at the same points on the ordinate, but slightly different points on the abscissa. The linear regression was computed from the triangular data points (*i.e.*, using the area-wide average CSEL estimate). In general, the two estimates of sound levels of booms are within ± 0.5 dB of one another.

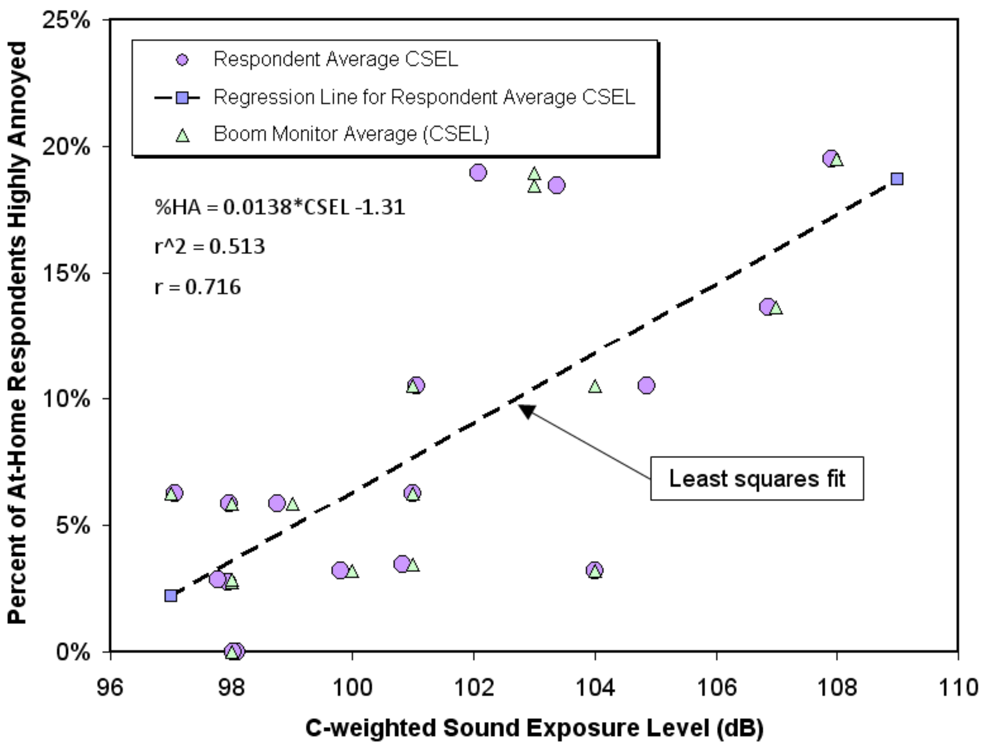

Figure 14: Linear regression of percentage of at-home respondents highly annoyed by C-weighted sound exposure levels estimated by two methods.

Responses to interviews about the cumulative annoyance of an entire day's exposure to sonic booms were analyzed differently (*cf*. Section 5.3), so that they could be compared directly with prior findings summarized in a report of the National Research Council's Committee on Hearing, Bioacoustics and Biomechanics (Fidell, 1996).

4 DISCUSSION OF METHODOLOGICAL FINDINGS

The findings presented in the prior section show that community reaction to sonic boom exposure may be usefully assessed using smartphone-based interviewing methods. Test participants complied well with instructions for reporting notice of sonic booms, whether indoors at home or outdoors and away from home. They repeatedly and reliably completed brief interviews about their short and long term reactions and opinions concerning exposure to booms. The responses to interviews seeking both short- and long-term opinions about sonic booms were systematically interpretable, and comparable to those produced by conventional social survey interviewing methods. This section contains further discussion and additional details about some of these findings.

4.1 Reports of notice of individual sonic booms (immediate responses)

The 49 test participants provided 2152 reports of notice of individual sonic booms during the intentional booming period.[15] Table 2 shows the locations of test participants at the times that they reported sonic booms. The bulk of them (86.4%, or 1860/2152) were indoors either at home or elsewhere when they reported noticing booms. Of these, 1631 (87.7%) were indoors at home at the time of the boom. Only 1413 (86.6%) of these 1631 responses, however, could be unambiguously linked to a sound level dose.

Table 2: Locations of test participants when they reported individual sonic booms

Locus of Respondent	Indoors	Outdoors	Sum
At Home	1631	86	1717
Away From Home	229	206	435
Sum	1860	292	**2152**

4.2 Response latencies and interview durations

Respondents indicated that 86% of their immediate reports (1845/2152) of notice of sonic booms during the intentional booming period were lodged within a few minutes of their occurrence. Figure 15 shows the log normal-appearing distribution of response latencies. Several reports with latencies in excess of 900 seconds (15 minutes) are omitted from the figure. The average number of observations in the omitted 10-seconds wide bins do not exceed 1. The median response time, however, was 41.9 seconds.[16] Section 11.2 shows cumulative distribution functions and the varying percentages of respondents who responded after specific latency periods.

[15] Not all of these reports could be unambiguously associated with individual sonic booms, particularly when long response latencies coincided with short inter-boom intervals.
[16] The distribution is so skewed that its arithmetic mean is not a useful indication of average response times.

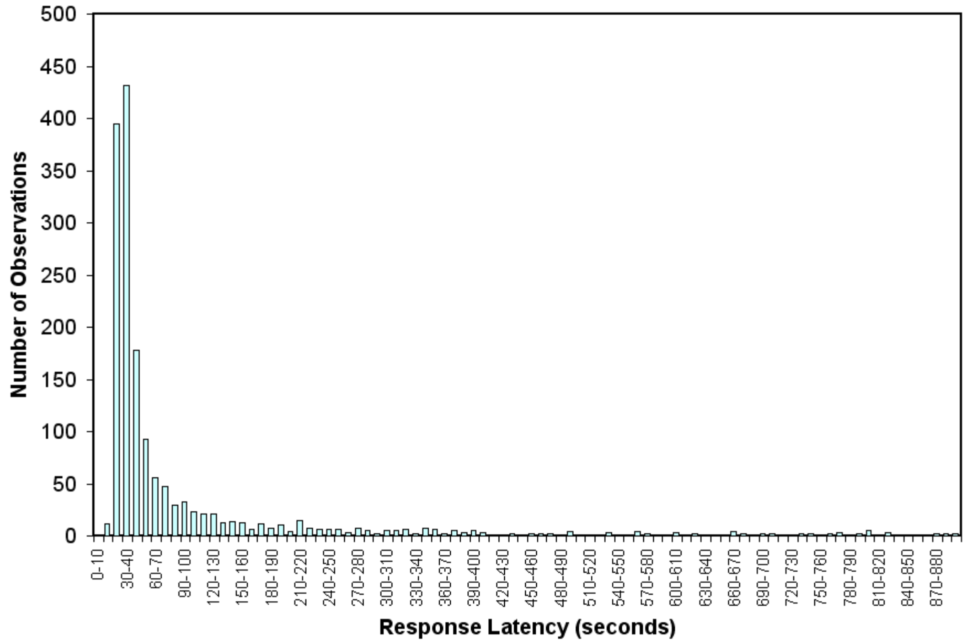

Figure 15: Distribution of response latencies for reporting individual booms within the first fifteen minutes (900 seconds) of their occurrence.

Figure 16 displays the first 2 minutes (120 seconds) of the same log normal-appearing distribution of interview durations, in five second wide bins. This plot provides greater resolution for the initial portion of the distribution, and reveals that the mode of the distribution lies somewhere between 10 and 15 seconds.[17]

4.3 Opinions about cumulative exposure to sonic booms (end-of-day interviews)

Table 3 and Figure 17 show the numbers and completion rates of end-of-day interviews for each day during the intentional booming period. The overall response rates compare favorably with those achievable by conventional social survey (telephone) interviewing methods.

[17] The response database includes information about the time (in milliseconds) which respondents required to answer each question. Future detailed analyses, if desired, can be conducted of this information. If a boom were noticed while an interview concerning reactions to a prior boom, for example, the point in an interview at which an additional boom occurred could be readily determined.

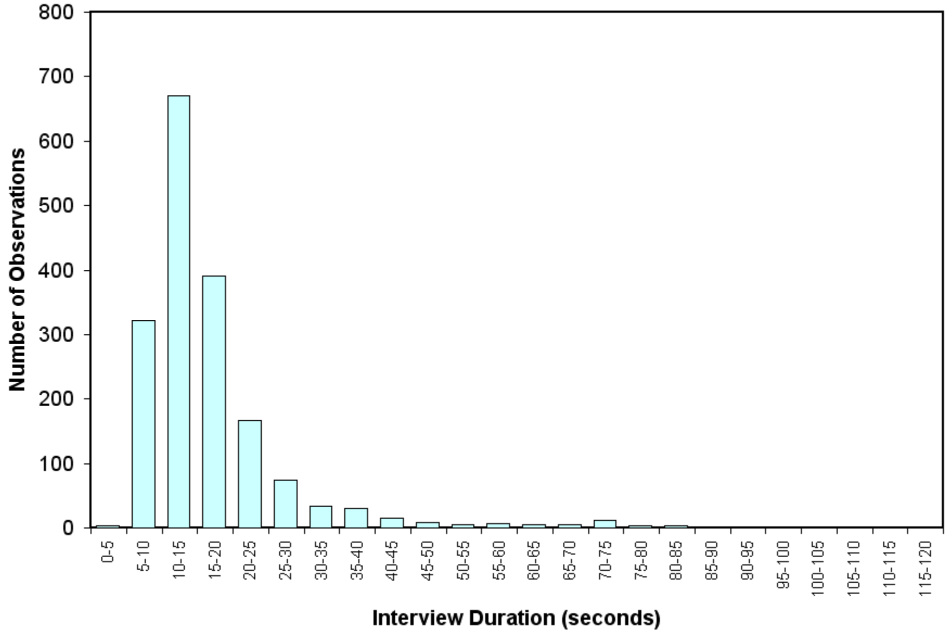

Figure 16: Distribution of durations of immediate response interviews

Table 3: Numbers of test participants completing end-of-day interviews on each day of intentional booming period

Date	Number of Interviews	Response Rate
11/04/11	38	77.6%
11/07/11	33	67.3%
11/08/11	41	83.7%
11/09/11	39	79.6%
11/10/11	37	75.5%
11/14/11	38	77.6%
11/15/11	41	83.7%
11/16/11	43	87.8%
11/17/11	33	67.3%
11/18/11	34	69.4%
Total	377	76.9%

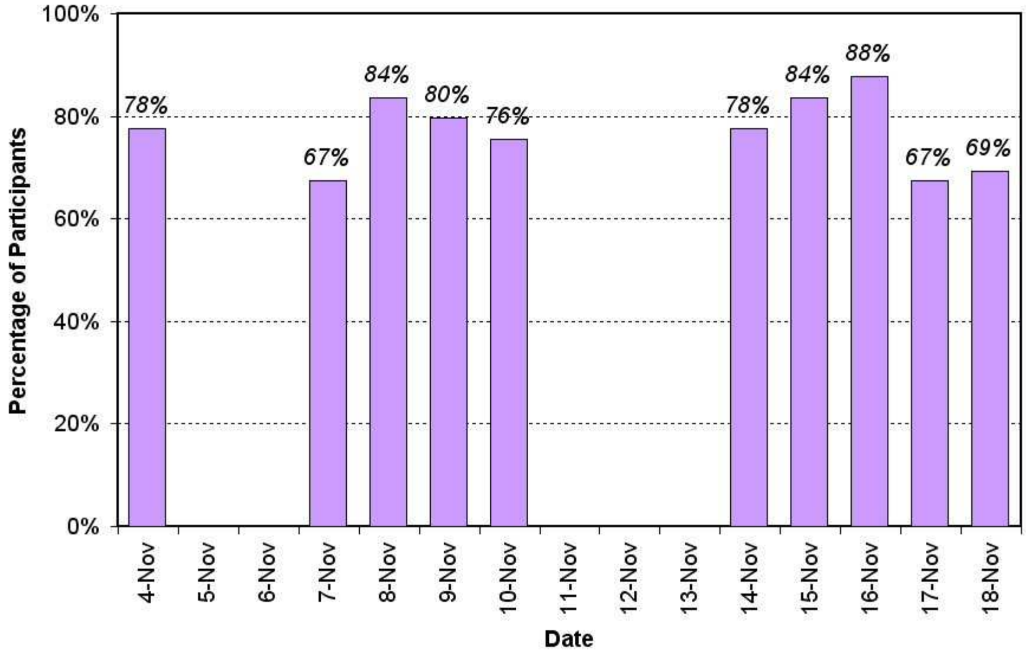

Figure 17: Percentages of test participants completing end-of-day interviews on each day of the intentional booming period.

4.4 Debriefing interviews

About half of the test participants attended a meeting at Dryden Research Center organized to thank them for their participation in the pilot test, and to provide them with $50 gift certificates. They also completed informal, written debriefing interviews. The test participants uniformly indicated that they had enjoyed participating in the pilot test, were satisfied with the level of technical support provided, would willingly participate again in any future extension of the test program, and would recommend participation to their friends. They expressed no dissatisfaction with any aspect of the test protocol, and only minor dissatisfaction with the necessity for recharging their smartphones every night.

4.5 Adequacy of recruitment incentives

The only direct incentive offered for participation in the pilot test was cost-free personal use of a smartphone for the duration of the study. The 49 participants were awarded $50 gift certificates at the end of the study, after they had already indicated their willingness to take part in the study. The award was made solely in the interests of maintaining parity with participants recruited into a parallel NASA-sponsored study conducted at the same time.

Among spouses of active duty Air Force personnel residing in base housing, participation in the study appears to have been sufficiently enjoyable that no inducement beyond free use of a smartphone was required. It is unclear whether the general population would be as willing to participate in a similar study conducted elsewhere.

5 DISCUSSION OF SUBSTANTIVE FINDINGS

5.1 Estimation of cumulative exposure to sonic booms

As noted earlier, a contractor measured sonic boom levels at thirteen spatially distributed sites within the base housing area during the intentional booming period. (NASA Dryden Research Center operated a fourteenth monitor near the centroid of the base housing area as well.) Three estimates of cumulative daily exposure of test participants to sonic booms during the intentional booming period were developed from these measurements.

First, estimates of daily exposure were developed from predictions of individual boom CSEL values at each test participant's home. This required numerous assumptions and considerable processing of the measurements to create and contour an expected exposure surface, as described in Section 3.1 and illustrated in Figure 11. Second, estimates of daily exposure were developed from the means of the measured levels for each of the booms at each monitoring site. Third, estimates of daily exposure were developed from a single, centrally located monitoring site near NASA Dryden's central monitoring position.

Table 4 compares the estimates of CDNL[18] values derived by the above three methods. The mean differences across days among the three estimates are meaninglessly small (less than 0.2 dB) in the context of the uncertainty (±0.5 dB) of the original measurements. Further, the correlations among the various estimates of daily cumulative exposure are all in excess of $r = 0.99$. It follows that in these circumstances, the more complex measurement and estimation methods yield little or no benefit.

[18] Because no sonic booms occurred during the DNL "nighttime" period, these figures do not differ from 10 or 12 hour C weighted Leq values.

Table 4: Comparison of variously estimated CDNL values and percentages of annoyance reports in varying degrees

Test Day	Date	CDNL Noise Exposure Estimates (dB)			Observed Annoyance		
		Grand Mean of 13 Monitors[1]	Mean of Individual Household Estimates	Single Monitor at Interview Area Centroid	Slightly+ Annoyed	Moderately + Annoyed	Highly Annoyed
1	11/04/11	54.7	54.6	54.2	47.4%	7.9%	0.0%
2	11/07/11	55.6	55.5	55.6	33.3%	12.1%	3.0%
3	11/08/11	55.8	55.8	55.8	31.7%	17.1%	4.9%
4	11/09/11	56.8	56.8	56.4	43.6%	10.3%	2.6%
5	11/10/11	47.5	47.3	47.4	21.62%	2.7%	0.0%
6	11/14/11	59.7	59.6	59.8	57.9	23.7	5.3%
7	11/15/11	60.6	61.0	60.5	68.3	31.7%	12.2%
8	11/16/11	67.4	67.4	67.5	88.4	51.2%	23.3%
9	11/17/11	43.6	43.5	43.3	24.2%	6.1%	3.0%
10	11/18/11	40.7	40.4	40.4	14.7%	2.9%	2.9%
Coefficient of Determination [2]		- - - -	0.999	0.999			
Mean Difference		- - - -	-0.02	-0.18			
Std Dev of Differences		- - - -	0.17	0.20			

[1] Predictor variable for computing correlations between remaining two CDNL estimates.
[2] Variance accounted for (r^2).

The data of Table 4 are plotted in Figure 18 to illustrate the practical implications of the high correlations among estimated exposure levels. The curve fitted to the data figure is a minimal rms error fit of the data to an effective loudness function (described in greater detail in the next section of this report), using the “grand mean of 13 monitors” data as the CDNL predictor variable.

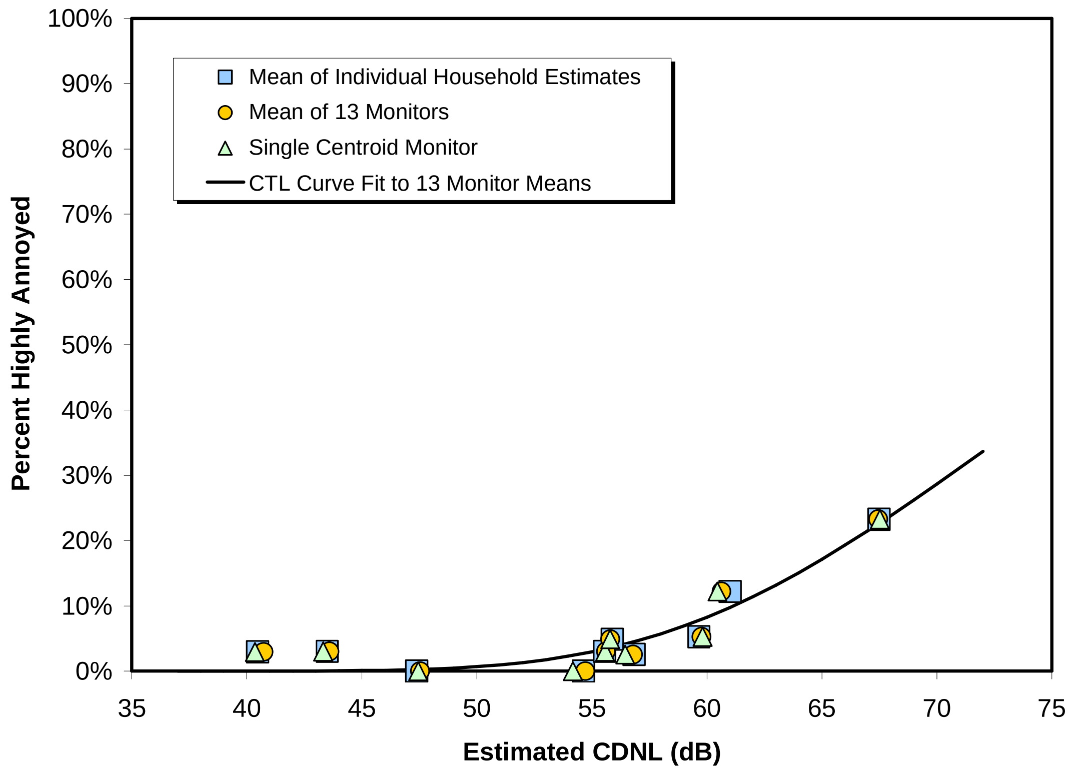

Figure 18: Comparison of relationship between high annoyance and mean CDNL values for each day of intentional booming period as estimated by three methods.

5.2 Dosage-response analyses of current findings

Fidell *et al*. (2011) and Schomer *et al.* (2012) have recently published descriptions of a systematic, first-principles approach to inferring dosage-response relationships between cumulative transportation noise exposure and the prevalence of high annoyance in communities. The approach is based on the assumption that the rate of growth of annoyance in a community closely resembles the rate of growth of the effective (that is, duration-corrected) loudness of noise exposure. The slope of the dosage-response relationship is therefore fixed, while a second variable, a Community Tolerance Level, or CTL, is used to characterize the position of the dosage-response relationship on the exposure axis.

Annoyance prevalence rates in CTL analyses are predicted as

$$p(HA) = e^{-(A/m)}, \quad \text{[Eq. 2]}$$

where:

A is a scalar, non-acoustic decision criterion originally described by Fidell *et al.*, (1988), and

m is an estimated noise dose, calculated as

$$m = (10^{(DNL/10)})^{0.3} \quad \text{[Eq. 3]}$$

The value of the scalar quantity A in a given community is that which minimizes the root-mean-square error between predicted (*cf.* Eq. 2) and empirically measured annoyance prevalence rates (Green and Fidell, 1991; Fidell *et al.,* 2011). Since *m* is just a transform of DNL, a quantitative estimate of the tolerance parameter, A, can be derived from knowledge of %HA and DNL at an interviewing site. When the annoyance prevalence rate (p[HA]) is held constant, the decision criterion, A, and the transformed noise dose, m, are linearly related by[19]:

$$A = m \cdot \ln[1 / p(HA)] \qquad \text{[Eq. 4]}$$

Figure 19 shows the fit of the annoyance prevalence rates measured in the current pilot study to the predicted dosage-response relationship. Note that cumulative exposure is expressed in A-weighted units in Figure 19. The product-moment correlation between predicted and observed annoyance prevalence rates is a nearly perfect r = 0.94 (R^2 = 0.89).[20]

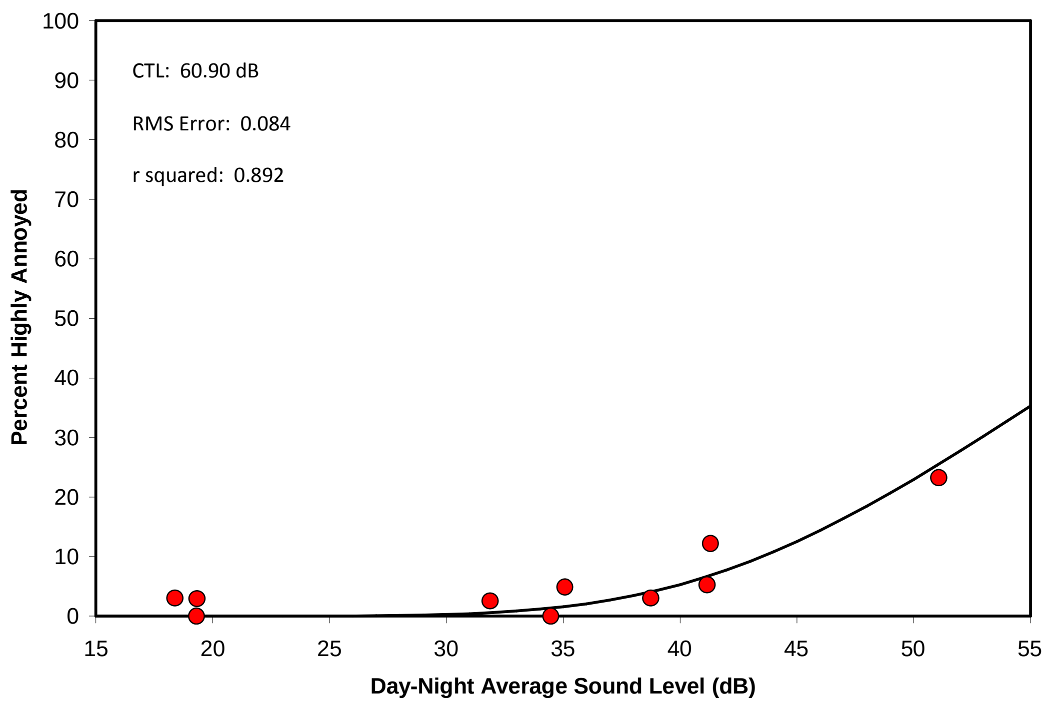

Figure 19: Fit of the current data to the annoyance prevalence rates predicted by CTL analysis.

A CTL value is defined as a value of (in this case) CDNL at which half of a community describes itself as “highly” annoyed by exposure to sonic booms. The CTL approach can also be extended to create dosage-response relationships for degrees of annoyance less extreme than “highly annoyed.”

[19] Equation 4 simply rearranges the terms of Equation 2.
[20] The product-moment correlation for C-weighted DNL values is trivially higher (r = 0.95),

Figure 20 compares dosage-response relationships for the prevalence of annoyance in three cumulative[21] categories. "Annoyed to any degree" is the sum of responses "slightly", "moderately," "very," or "extremely"; "moderately or more greatly annoyed" is the sum of responses in the "moderately," "very," and "extremely categories; and "highly annoyed" is the sum of responses in the "very" and "extremely" categories. (Note that a yellow diamond plotting symbol for moderate or greater annoyance at 41 dB lies immediately behind an orange circle symbol for high annoyance at the same CDNL value.)

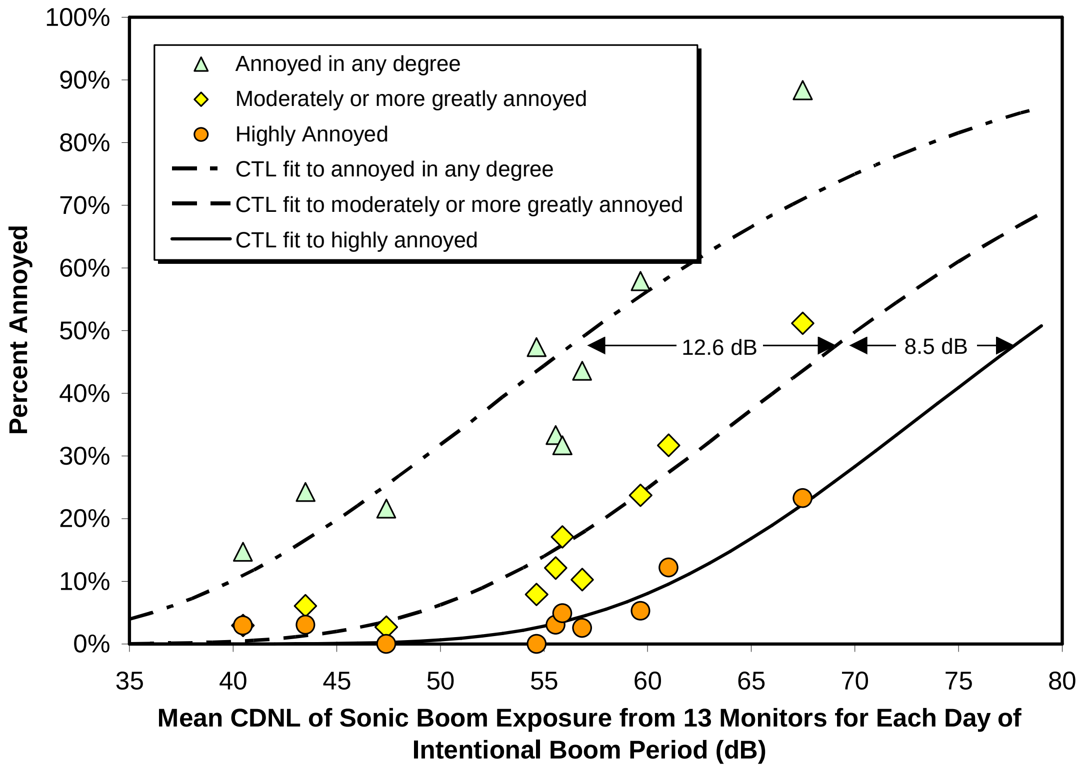

Figure 20: CTL-based relationships between variously defined degrees of annoyance and estimated CDNL values

The decibel differences shown at the median of the curves are an indication of the differences in sound levels associated with the definitions of annoyance in varying degrees. The CDNL values of the data points in Figure 20 are computed using the area-wide averaging method at all thirteen noise monitor sites.

[21] In principle, the same analysis could be applied to annoyance in individual (non-cumulative) annoyance categories. Analyses of this sort could permit more detailed regulatory analyses of sonic boom exposure levels which could identify, for example, exposures which are only slightly annoying. In practice, the current data set does not contain enough information to be informative about reactions to sonic booms at higher exposure levels.

5.3 Comparisons of dosage-response relationship for end-of-day interview reports of annoyance with prior findings

For reasons noted earlier, the substantive findings of the current pilot test about the relationship of annoyance to sonic boom exposure should not be viewed as definitive. It is nonetheless of interest to compare them with prior findings about the relationship between cumulative exposure to sonic booms and the percentage of people reporting high annoyance due to sonic booms.[22]

Figure 21 shows that the current findings about the relationship between exposure to sonic booms and the prevalence of a consequential degree of annoyance with them, shown as filled red plotting symbols, are quite similar to observations made in Oklahoma City almost half a century ago (Borsky, 1965), shown as open blue plotting symbols.[23]

Figure 22 compares the current findings (filled red plotting symbols) with all of the data in the 1996 CHABA report (Fidell, 1996) on the annoyance of high energy impulsive sounds. The additional data include the findings of interviews about annoyance from sources such as artillery and shooting range noise, as well as the findings of a social survey on the annoyance of sonic booms conducted in small communities near the U.S. Air Force's Nellis Range in eastern Nevada and Edwards Air Force Base (Fields *et al*., 1994).

The value of CTL for the pilot test data set is 61 dB. This implies that half of the current sample would describe itself as highly annoyed by boom exposure at a DNL value of 61 dB. As illustrated in Figure 23, this value of CTL is notably lower than the grand mean for all aircraft survey findings, or L_{ct} = 73.3 dB (*per* Fidell *et al.*, 2011). The open blue plotting symbols in Figure 23 represent the findings of 44 studies of the annoyance of conventional (sub-sonic) aircraft noise. The filled red plotting symbols in Figure 23 are the findings of the present pilot test. (Note that three plotting symbols of DNL less than 30 dB and high annoyance values of 3 percent or less are not shown in this figure.) In other words, A-weighted decibel for decibel, test participants were 12 dB less tolerant of sonic booms than of subsonic aircraft noise.

The abscissa of Figure 23 plots A-weighted DNL (not CDNL), because aircraft noise exposure is conventionally measured in units of DNL. Assuming that the findings of the current pilot test are generalizable to a wider population, Figure 23 indicates that exposure to sonic booms (red data points) of low level tends to highly annoy greater percentages of community residents than does subsonic aircraft noise of similar exposure level.

---

[22] Although smartphone-based interviewing methods permit adjustments to be made to individual CDNL estimates (for times when respondents are away from home), no effort was made to do so in the current analysis. Prior analyses of dosage-response relationships aircraft noise exposure all summarize geographic associations between community-wide outdoor sound levels and the prevalence of annoyance. Since reports of annoyance with sonic booms made while respondents were away from were excluded from the current analysis, changing the predictor variable from community-wide to personal exposure probably would have had little effect on the findings in any event.

[23] Note that these comparisons are made in C-weighted units to facilitate comparisons with prior findings of social surveys of reactions to sonic booms.

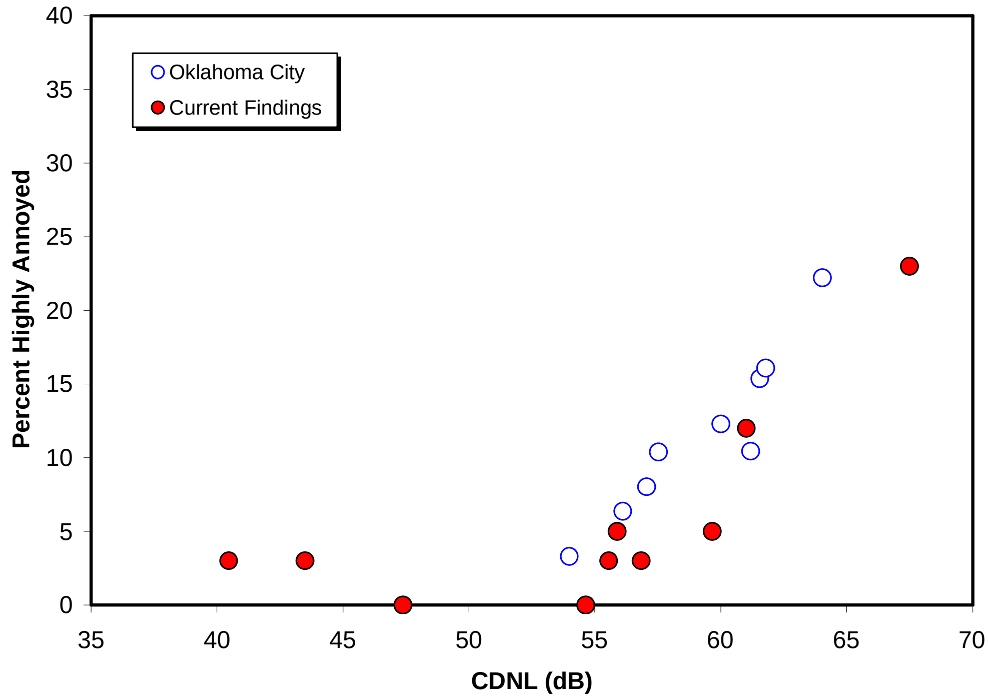

Figure 21: Similarity of current findings (filled red plotting symbols) to a prior determination (Borsky, 1965) of the prevalence of high annoyance with sonic booms.

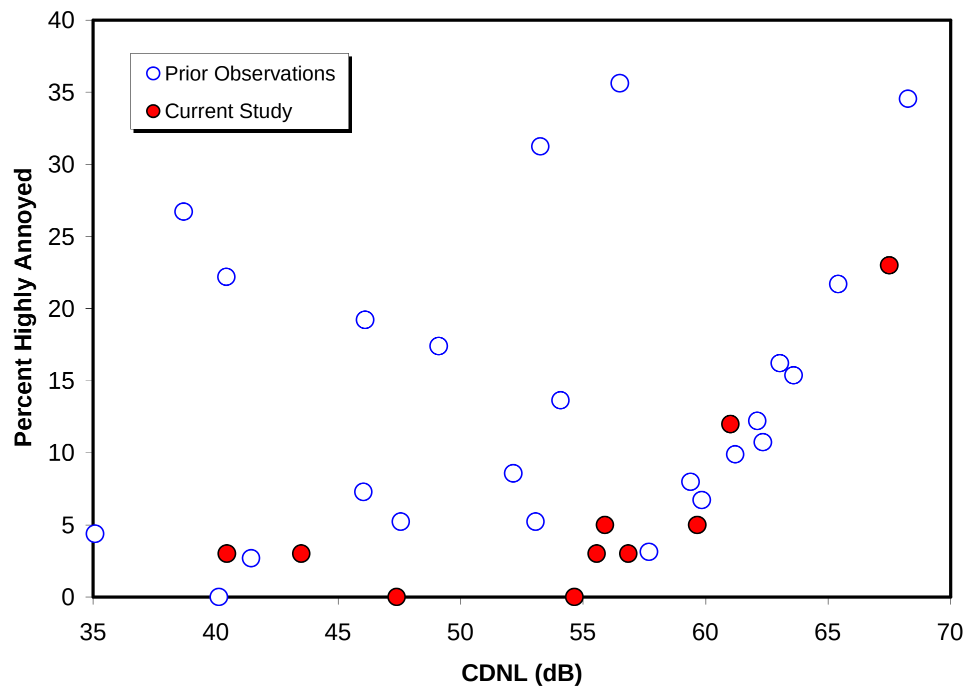

Figure 22: Comparison of current data (filled red plotting symbols) with prior observations cataloged by Fidell (1996).

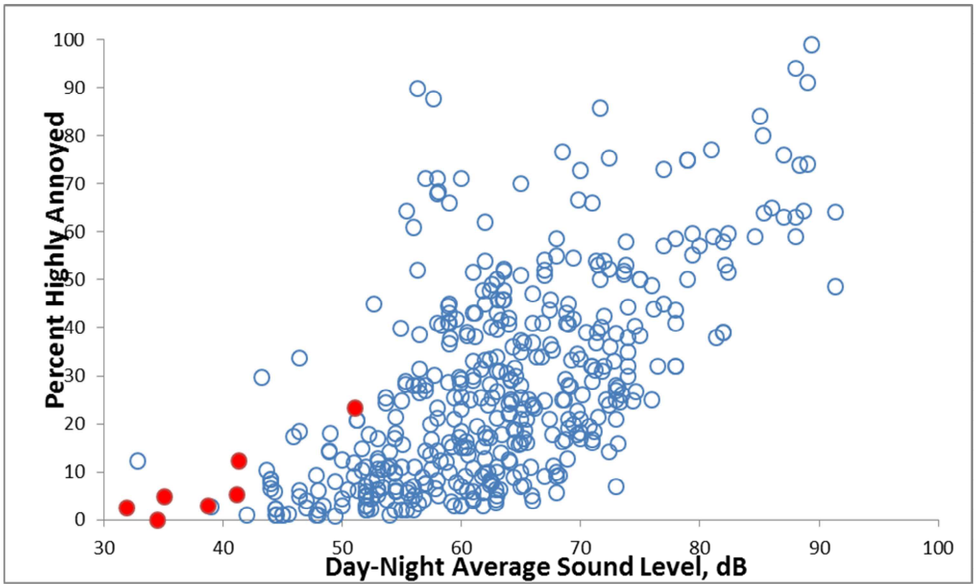

Figure 23: Prevalence of annoyance with low-amplitude sonic booms (filled red plotting symbols) in relation to similar findings of 44 other studies of the annoyance of aircraft noise (Fidell *et al.*, 2011.)

6 LESSONS LEARNED

If the methods developed in the present pilot test are to be applied on a larger scale in a future study, several modifications of the methods could reduce costs and improve the overall efficiency of data collection.

6.1 Recommendations about scheduling of intentional exposures to sonic booms

When paid laboratory subjects are asked to make judgments about the annoyance of test sounds, experimental convenience and cost are major determinants of the rate and number of judgments that they are asked to make. In a social survey-like field study intended to collect information from unpaid volunteers about the effects of sonic booms in residential settings, other factors must also be weighed in scheduling controlled exposures to sonic booms. In particular, the advantages in face validity, reliability, and accuracy of subjective assessment of sonic boom impacts which smartphone-based interviewing offer should take priority over the experimenter's convenience in producing and scheduling sonic booms.

Convenient as smartphone-based interviewing may be, reporting notice of a boom still requires a minimal diversion of attention from daily routine. The ability and/or willingness of test participants to promptly and consistently report notice of sonic booms depends on several factors: particularly, the inconvenience of the method of filing a report, the inter-boom interval, and possibly the number of booms occurring within short periods of time.[24]

Smartphone-based interviews of the sort described in this report are very convenient. They are initiated with trivial effort, require little time to complete, and provide test participants with some control over the timing of the unavoidable short interruption of their ongoing activities. Pressing a button on a device which is customarily ready-to-hand, and which respondents commonly use for many other purposes, requires considerably less time and bother than other forms of interviewing.

The other factors noted above that affect the ability and willingness of people to repeatedly report notice of sonic booms – the inter-boom interval, the number of booms occurring within short periods of time, and the time of occurrence of booms – are under the experimenter's control. The pace and timing of controlled exposure to sonic booms should not exceed the pace of exposure in settings to which inferences about sonic boom impacts are to be generalized. Further, the rate and number of sonic boom exposures should not be so great as to impose unreasonably on the good will of volunteer study participants, nor on their ability to respond promptly and reliably.

The pace of exposure should also not be so great as to complicate the association of responses with exposure episodes. If two or more sonic booms occur in rapid succession, it is

[24] Incentives offered for prompt or accurate responding could conceivably improve the promptness and reliability of reports of sonic booms. In principle, for example, small incentives could be offered for interviews completed within a minute or two of occurrence of a sonic boom, or for total numbers of hits (reports received within a few minutes of the occurrence of sonic booms) per day. Small disincentives could likewise be imposed for false alarms (reports of non-existent booms). These measures were not taken in the present study in order to preserve as much comparability as possible with the conditions of prior field surveys about the annoyance of sonic booms. Such measures could be worth considering in similar future studies, however, depending on detailed research goals.

sometimes not possible to unambiguously attribute responses to specific noise events. Thus, in a series of successive booms within a brief period of time, delayed reports of notice of earlier sonic booms may not be distinguishable from prompt responses to later booms, leading to collection of unanalyzable data.

This situation arose on several occasions in the present study, most notably on a day when multiple intentional and adventitious booms occurred within minutes (or even seconds, in some cases) of one another. Closer coordination of shared supersonic airspace to avoid temporal "collisions" of sonic booms within a target residential area can be both costly and inconvenient. However, planning of intentional exposure schedules should not give greater weight to the costs of producing individual sonic booms than to unambiguous attribution of responses to them.

If a minimal inter-boom interval of at least a quarter hour cannot be maintained for other reasons, then test participants should be given explicit instructions about the order in which to report their prompt and delayed reactions to sonic booms. These instructions should indicate that test participants must always respond first to the most recent boom noticed. In the event that they recall one or more prior unreported same-day booms after reporting notice of the most recent one, they should be instructed to file delayed reports for each in a specific order, preferably the most recent prior unreported boom first. Alternatively, they could be instructed *not* to report sonic booms if more than five minutes have elapsed since the time of notice.

It may also be helpful to seek greater temporal resolution in responses to the question, "How long ago did you notice a sonic boom?", than "within the last few minutes", "within the last half hour", and "more than a half hour ago." Greater temporal precision may be unnecessary in many cases, but it may be helpful in others. For example, suppose hypothetically that a test participant known to have been at home has failed to report three booms in succession. The failure to report three booms could simply be due to their low amplitude, but the booms could also have been noticed at times when it was inconvenient for the test participant to file a prompt response.

When the hypothetical test participant finally reports noticing a later boom, and then recalls noticing (but not reporting) two prior booms that day, to which of these three booms should the two delayed reports be attributed? This situation occurred in the current study, when two test participants were exposed to four booms in one morning. They both provided their first response of the morning shortly after the fourth boom, and both indicated that they had noticed the boom "within the last few minutes." It was therefore possible to unambiguously attribute their responses to the most recently occurring boom.

Next, however, both test participants filed delayed reports of noticing a single additional boom, when in fact three had been produced. Both test participants also indicated that the previously unreported boom had been noticed more than half an hour ago. The only boom that came close to occurring in this time period was the first of the morning, so their reports of their delayed responses were assigned to that boom[25].

---

[25] Attribution of delayed responses to prior booms could also take into consideration boom amplitudes, but some might object that assuming that responses were attributable to higher level booms forces a positive slope on any resulting dosage-response relationship. The region of the dosage-response curve of greatest interest – where its slope differs from its lower asymptotic value – is the one in which conclusions are most sensitive to such data processing assumptions.

In another case, the study design exposed test respondents to five booms between 7:20 and 8:03 AM. Most of the responses to this series of booms were not received until after the last of them, suggesting that test participants either were not yet fully awake when the booms began, or that they may not have had their cell phones handy shortly after awakening.

On yet other occasions when test participants belatedly reported noticing more than one previously unreported boom later in the day, they had already provided an unambiguous report of reactions to the next most recent boom. To avoid errors of attribution of responses to booms in such cases, it was sometimes necessary to simply entirely exclude observations from analysis. Although discarding data in such cases may be preferable to erroneous attributions of reports of boom effects to particular booms, it is nonetheless wasteful to do so if the problem can be avoided by broader consideration of all of the constraints on the design of the exposure schedule.

6.2 Recommendation for extension of scale of application of technique

If samples of hundreds or thousands of respondents are anticipated in a future study, it may not be cost-effective to provide each respondent with a government-furnished smartphone and service contract. An obvious solution to minimizing such costs is to permit respondents to download the "Report Boom" application to their own personal Android smartphones and/or other internet-enabled mobile devices, possibly including tablets.[26] Some of the implications of doing so are noted in Section 6.4.

1) The interviewing application code should be checked to confirm that it works as intended on Android platforms later than the Droid2. The application code may not need to be polled several times an hour to determine the host phone's location, but may need to be modified to permit remote deactivation.

2) Since study participants will not be using government-configured smartphones, it may be necessary to confirm that other applications will not interfere with the sonic boom reporting application.

3) Methods of recruiting study participants will have to be revised as suitable to residential conditions of target communities, which may be less constrained than those of Edwards AFB. For example, depending on the duration of the intended study, alternative forms of incentives for participation may have to be devised. These could range from small, one-time payments for downloading the application to daily payments for continued study participation. If consistent with other study goals, payments might also be made for prompt reporting of *bona fide* sonic booms, with adjustments for false alarms.

4) If it is suspected that the opinions of smartphone users about sonic booms differ systematically from those of other residents, measures may have to be taken to quantify and correct for such potential biases. It may also be necessary to devise methods for determining the total numbers of test participants actively participating in the study on any given day, or at the time of occurrence of any particular boom, so that the denominator for calculations of percentages of respondents similarly affected by each boom can be confirmed.

[26] It is also possible, of course, to port the Android software to iOS (Apple) smartphones, but it is unclear what further constraints this might impose on the design or cost of near-real time interviewing software. Apple might or might not insist on incorporating (or removing) certain design features, and the terms of Apple's privacy policy and end user agreement might conflict with the need to protect personally identifiable information.

The personnel costs of measures of this sort may be unaffordable in larger scale implementations of smartphone interviewing studies, but are probably not essential either. Communication between test participants and project personnel should probably be limited to text messaging.

6.3 Porting of application code to iOS (Apple) devices

The "Report Boom" application was developed for smartphones which use the Android platform. Android and iOS (Apple) mobile devices currently have roughly equal shares of a rapidly growing market. If the Report Boom application is to be made available for free downloading within defined geographic areas or telephone exchanges, it could be helpful to port the application to iOS platforms. There is little reason to believe that opinions of users of different brands of smartphones about sonic booms differ systematically, but in any local market, one brand or another of smartphone may be more popular, or provide more reliable network connectivity.

Porting the application could impose constraints on the design or cost of near-real time interviewing software. Most features of "Report Boom" application would transfer directly and simply to other platforms, although smartphone location reporting would probably require modification. Moreover, because Apple exerts considerable proprietary control over iOS applications, it might insist on incorporating (or removing) various design features, and the terms of its privacy policy might conflict with the need to protect personally identifiable information.

Some additional implications of porting Report Boom to other platforms to facilitate a larger-scale study using respondent-owned devices are noted below.

1) The sonic boom reporting application code must be checked to confirm that it works as intended on Android platforms other than the Droid2, as well as on iOS platforms (if they are to be used).

2) Since study participants will not be using government-configured smartphones with known configurations and options, it would be necessary to confirm that other applications on the participants' smartphones will not interfere with the sonic boom reporting application.

3) The pilot study made extensive personal support available to test participants. Test participants were provided with a toll-free telephone number to call at any time of day for technical assistance, including questions about test procedures, reports of broken or misplaced equipment, and the like. The status of test participants' smartphones was also closely monitored, and reminder calls were placed to test participants who had not used their smartphones for extended periods, were not at home for extended periods, or had forgotten to recharge their phones. The personnel costs of measures of this sort may be unaffordable in larger scale implementations of smartphone interviewing studies, but are probably not essential either. Communication between test participants and project personnel could probably be accomplished by text messaging, email and voicemail.

4) Before applying the sonic boom reporting software to an expanded participant population, several scalability and system design issues need to be addressed. The most notable questions concern whether a major increase in numbers of participants affects smartphone-to-server communication, and whether current database creation, downloading, and maintenance procedures are adequate to support a much larger study. If it is suspected that the opinions of smartphone users about sonic booms differ systematically from those of other people, measures may have to be taken to quantify and correct for such potential biases. It may also be necessary

to devise methods for determining the total numbers of test participants actively participating in the study on any given day, or at the time of occurrence of any particular boom, so that the denominator for calculations of percentages of respondents similarly affected by each boom can be confirmed.

5) Methods of recruiting study participants will have to be revised as suitable to residential conditions of target communities, which may be less constrained than those of Edwards AFB. For example, depending on the duration of the intended study, alternative forms of incentives for participation may have to be devised. These could range from small, one-time payments for downloading the application to daily payments for continued study participation. If consistent with other study goals, payments might also be made for prompt reporting of bona fide sonic booms, with adjustments for false alarms. These measures were not taken in the present study in order to preserve as much comparability as possible with the conditions of prior field surveys about the annoyance of sonic booms. Such measures could be worth considering in similar future studies, however, depending on detailed research goals.

6.4 Improvements to participant instructions

The process of associating specific interview data with specific sonic booms was largely automated by means of spreadsheet macros. Nonetheless, manual intervention was sometimes required to resolve ambiguities when reports of notice of sonic booms lagged their occurrence by lengthy intervals (*e.g.*, half an hour or more), and/or when additional booms occurred before test participants completed interviews about their reactions to one or more earlier booms. Most such ambiguities could be resolved through careful examination of individual cases. In some cases, however, it was necessary to discard otherwise-valid interview data when it was not possible to definitively associate particular responses with particular booms.

Such cases were difficult to resolve because the order in which test participants reported their reactions to multiple prior sonic booms was unclear. The response categories of Questionnaire Item 1 ("How long ago did you notice a sonic boom?") were "within the last few minutes", "within the last half-hour", and "more than a half-hour ago?" When multiple booms occurred in relatively rapid succession, these categories were not always sufficient to permit confident assignment of interview data to individual booms.

In principle, greater temporal resolution in response categories could help to clarify assignment of late interviews to individual booms. For example, respondents might be asked to select whether a boom was noticed within the last 10 minutes, 10 – 20 minutes ago, 20 – 30 minutes ago, *etc*. At some point, however, test participants may not be able to recall when booms occurred with meaningful precision, and may find the requirement to keep track of when booms occurred to be frustrating and inconvenient.

Other solutions to this problem are conceivable as well. They include switching from a free response paradigm to some other form of reporting (say, hourly, or prompted); instructing respondents not to report notice of sonic booms if more than five minutes have elapsed between the time of notice and the time of reporting; or providing specific instructions to test participants about the order in which reactions to previously unreported booms are provided. Yet another approach would be to enforce a minimal inter-boom interval long enough to unambiguously assign 90% or 95% of the interviews to particular sonic booms.

6.5 Minor improvements to features of smartphone reporting application

Several minor improvements to the application software may also be useful:

1) The most common operational glitch in the pilot study was an occasional failure by some participants to keep their smartphones' batteries charged. Participants in future studies could receive "low battery" reminders of various forms. These might include pop-up messages from the smartphone software, text messages to the smartphone and perhaps to other phones known to be nearby, emails to the participants' email accounts, "robo-call" voicemails to their landlines. If a smartphone's battery charge level were so low that only one or two sonic boom reports could be successfully accomplished, the software could (for example) temporarily block other smartphone operations.

2) Tradeoffs between battery life, frequency of automated communications between smartphones and the central server, and the level of detail of information reported to the server, should be re-examined. On the one hand, newer model smartphones may have enough power to last for more than a day in the present application. On the other hand, it might be possible to identify and report the smartphone's location and status less frequently at some times of day than at others (e.g., at night). It might also be possible to minimize the power required for GPS-based determination of "at-home" status by relying more heavily on home local area wi-fi or 3/4G wireless connectivity.

A change in study design should also be considered, such that status reports from individual smartphones would be solicited only immediately prior to the scheduled time of occurrence of known sonic booms. This design modification might be appropriate for exposure situations in which the total numbers of booms audible to test participants could be carefully controlled (i.e., in areas remote from supersonic flight corridors, military operating areas, joint military/civil airspace, etc.), and in which the frequency of exposure to booms could be limited to a few per day.

3) Every smartphone in the pilot test was equipped with a COTS[27] application that provided data security, limited unauthorized use of the device, defended against malicious applications, protected against viruses and other malware, and allowed the smartphone to be deactivated remotely if it was lost or stolen. These features would not necessarily be required if participants in a future study were using their own, rather than government-furnished devices. Participants could be advised to install such protective code on their smartphones at their own expense. The sonic boom application code should nonetheless be modified to permit remote deactivation.

4) Improvements might be useful in automated data quality control capabilities, to more quickly and thoroughly perform some of the operations that were done manually by the experimenters during the pilot test to detect anomalous conditions (such as duplicate entries) in the accumulating databases. If communication with field instrumentation were possible, the timeliness of assignment of boom reports to specific booms could also be greatly improved, while minimizing manual post-processing.

6.6 Measures useful for estimating exposure levels over a wide area

If an expanded study entails exposing residents to sonic booms over areas greater than a few square kilometers, costs for installing and servicing dense arrays of monitoring instruments could well prove prohibitive. In such cases, a coarser spatial sampling of boom levels suffices to yield boom level estimates of adequate precision. As shown in Section 5.2, complex measurements of

[27] Commercial Off-The-Shelf

sonic boom levels at multiple points, intended to yield estimates of sonic boom levels at the homes of individual test participants, produce no useful increase in precision of estimation of community response to sonic boom exposure.

The goal of large scale measurement of boom levels should not be to validate or calibrate model-predicted, point estimates of boom levels at the residences of study participants, but rather to estimate wide-area exposure levels. For such purposes, a small number of boom monitoring points is more than adequate, since fine scale variation in boom levels over short ranges is not of interest in the context of combining opinions of residents of hundreds or thousands of households many kilometers distant from one another.

7 CONCLUSIONS

Smartphone-based interviewing is a useful adjunct and a powerful addition to conventional methods of assessing the effects of sonic booms on exposed populations. Compliance with instructions for smartphone use to report notice of sonic booms in the current pilot study was excellent. No test participants voluntarily failed to complete the study; the data were readily interpretable; and nearly all test participants indicated that they would choose to participate in such a study again if given the opportunity, and would recommend participation in such a study to friends.

The findings of the current study were also consistent with those of earlier social surveys of the annoyance of exposure to high energy impulsive sounds. The similarity of the present findings to those of Borsky (1965) is striking.

Several modifications of details of the pilot test procedures for smartphone-based assessment of sonic boom impacts on residential population could facilitate their implementation on a larger scale. These include the following:

1) The application code for reporting booms could be generalized beyond a single operating system, and to permit use with Internet-enabled portable communication devices (*e.g.*, tablets) other than smartphones.

2) The method of estimating levels of exposure to sonic booms should be simplified to improve characterization of uncertainty and estimation of dose levels.

3) Specific instructions should be provided to test participants about the order in which they should file delayed reports of notice of sonic booms.

4) Design of the schedule of intentional exposure to sonic booms should give greater consideration to maintaining a minimum inter-boom interval of at least fifteen minutes to avoid collection of unanalyzable response information.

8 ACKNOWLEDGMENTS

The authors thank Larry Cliatt and Ed Haering of NASA Dryden Research Center for assistance with field arrangements for data collection. We are also grateful to Matthew Sneddon for assistance in processing sonic boom measurements; to John Roses of Interviewing Service of America for quality control and related assistance during field data collection; to Linda Fidell for assistance with statistical analyses; and to Gregory Milette of Gradison Technology for assistance in software development.

9 REFERENCES

Borsky, P. (**1965**) "Community reactions to sonic booms in the Oklahoma City area", USAF Aerospace Medical Research Laboratory, Report AMRL-TR-65-37, Wright-Patterson Air Force Base, OH.

Fidell, S. (*ed.*) (**1996**) "Community response to high energy impulsive sounds: an assessment of the field since 1981", Working Group on Assessment of Community Response to High-Energy Sounds", Committee on Hearing, Bioacoustics, and Biomechanics, National Research Council, National Academy of Science, National Academy Press, Washington, D.C.

Fidell, S., Schultz, T. J., and Green, D. (**1988**) "A theoretical interpretation of the prevalence rate of noise-induced annoyance in residential populations," J. Acoust. Soc. Am. 84, 2109–2113.

Fidell, S., Mestre, V., Schomer, P., Berry, B., Gjestland, T., Vallet, M., and Reid, T. (**2011**) "A first-principles model for estimating the prevalence of annoyance with aircraft noise exposure", J. Acoust. Soc. Am. 130 (2), pp. 791-806.

Fields, J., Moulton, C., Baumgartner, R, and Thomas, J. (**1994**) "Residents reactions to long-term sonic boom exposure: preliminary results", Proceedings of 1994 NASA Sonic Boom Conference, NASA Langley Research Center, Hampton, VA. (See also Fields, J.M. Reactions of Residents to Long-Term Sonic Boom Noise Environments, NASA Contractor Report 201704, Contract NAS 1-20103, NASA Contractor Report 201704, June 1997)

Green, D. M., and Fidell, S. (**1991**). "Variability in the criterion for reporting annoyance in community noise surveys," J. Acoust. Soc. Am. 89, 234–243.

Mestre, V., Schomer, P., Fidell, S., and Berry, B. (**2011**) "Technical support for Day-Night Average Sound Level (DNL) replacement metric research", USDOT/RITA/Volpe Center Purchase Order DTRT57-10-P-80191, Requisition No. DTRT-RVT-41-1113.

Schomer, P., Mestre, V., Fidell, S., Berry, B., Gjestland, T., Vallet, M., and Reid, (**2012**) "Role of community tolerance level (CTL) in predicting the prevalence of the annoyance of road and rail noise" J. Acoust. Soc. Am., 131(4), 2772-2786.

10 APPENDIX A: WRITTEN INSTRUCTIONS TO TEST PARTICIPANTS

NASA is starting a study of reactions to sonic booms at Edwards Air Force Base, and would like to lend you an Android smartphone for several months to keep with you while you're at home and while you're out and about. If you happen to notice a short sound that you think might be a sonic boom at any time of day, please push the "Report Boom" icon displayed on the screen of your smartphone at your earliest convenience. Your smartphone will then ask you a few questions about the sound that you heard. It will automatically forward your answers to these questions to a computer that will combine them with other people's answers to the same questions. You will also receive occasional phone calls asking you to answer a few questions about sonic booms that you may have heard earlier in the day.

We'd like you to keep the smartphone with you and handy as you go about your daily activities, and to use it as your personal mobile telephone, as you would any other cell phone: to make and receive domestic telephone calls and text messages, to access the Internet, to run apps that you install on it, and so forth.[28]

In return for your help, you will not have to pay anything at all for the smartphone or its use during the course of the study. You would have to purchase any application programs for the phone that you would like to install, and at the end of the study, you will have to return the smartphone to NASA. Your answers to questions about your reactions to sonic booms will never be associated with you as an individual in any written report describing the results of this study.

FREQUENTLY ASKED QUESTIONS

ARE THERE ANY LIMITATIONS ON THE USE OF THE PHONE?

Yes:

1) The smartphone is for your personal use only. Please do not lend it to friends, children, or other family members for any purpose other than to make a quick call if necessary.

2) Please do not use the phone to call outside North America.

3) Please do not download or install applications on the phone that might interfere with the intended use of the phone. Please call us (at ###-###-####) if you are thinking about purchasing any application.

4) The smartphone will let you connect to the Internet, so that you can (for example) read your e-mail, check the news, or visit social networking sites. Please don't use this government-furnished telephone to browse adult entertainment web sites.

[28] Since your smartphone was purchased with U.S. government funds, it should not be used for inappropriate purposes during this study, such as visiting adult entertainment web sites, or for purposes that are not in the interests of the United States. You may use it in any way you like after the study ends if you wish to buy the phone.

5) We'd like you to charge the phone every night, so that it is ready for use at all times.

HOW WILL I LEARN HOW TO USE THE SMARTPHONE?

We will arrange for face-to-face training and practice in the use of the phone. We'll also check with you after the initial training to see whether you have any questions about the use of the phone. The smartphone itself will contain a telephone number that you can call if you run into any difficulty in using the phone during the course of this study.

WILL NASA EAVESDROP ON MY TELEPHONE CONVERSATIONS?

No. Your conversations on the smartphone will be as private as those made with any other cell phone. NASA is interested only in learning about people's reactions to sonic booms.

WILL THE SMARTPHONE RECORD SOUNDS WHEN I'M NOT USING IT?

No. Separate instruments will be used to make acoustic measurements of sonic booms at several locations throughout the base housing area.

WILL THE SMARTPHONE RECORD MY LOCATION THROUGHOUT THE DAY?

NASA's only interest in your location is to confirm whether you are at home or not at home when a sonic boom occurs. The smart phone will know your home address, and will record the times when it leaves the vicinity of your home. The phone will record the time again when it returns to your home. It will not track you as you go about your daily life, nor report your location at any time other than when you notice a sonic boom.

11 APPENDIX B: ILLUSTRATIONS OF SECONDARY ANALYSES OF SMARTPHONE-COLLECTED INTERVIEW DATA

The graphics in this Appendix illustrate the sorts of secondary analyses that are enabled by the creation of highly detailed, automated and centralized server-based databases of interview findings. For reasons noted in Section 1.1, the findings should not be viewed as definitive.

11.1 Response patterns to sonic booms

The temporal pattern of responses by themselves permitted easy indications of times of occurrence of sonic booms. Figure 24 shows all of the sonic boom responses collected from the time of issue of the first smartphones in August 2011 through the end of November 2011. Date and time are shown on the abscissa, while test participants (assigned numbers 1 through 49 for plotting purposes) are shown on the ordinate. The staircase appearance of the plotting symbols documents when additional smartphones were distributed to successive groups of participants.

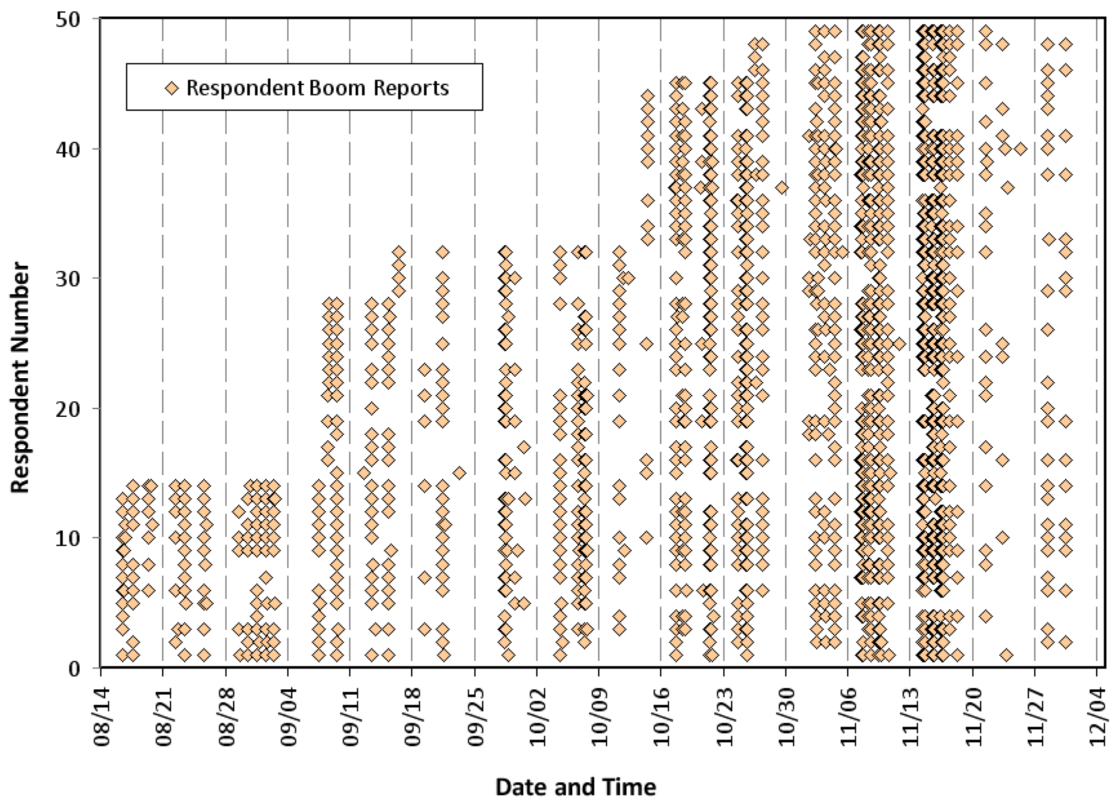

Figure 24: Chronology of sonic boom reports during participant possession of smartphones.

Figure 25 through Figure 27 show weekly response patterns that encompass the intentional booming period of 04 through 18 November 2011. These plots begin on a Sunday and end on Saturday. The intentional booms were generated by relatively closely-timed clusters of flights.

These three graphs show the timing of the clusters, but insufficient temporal resolution precludes the ability to show response patterns linked to individual flights from graphics like these.

Figure 28 expands the time axis to show the response pattern for a single day (14 November 2011). Each sonic boom triggers a cluster of responses. The figure also shows the variability of response times across respondents, as well as some cases in which the response to an earlier boom is received after a later boom has occurred. In a few cases, responses to booms were not received for as long as an hour after the boom. The figure illustrates the difficulty of assigning responses to the proper boom when booms occur too closely together in time.

Figure 29 shows response time histories in even greater temporal detail than Figure 28. On 31 August 2011, five intentional sonic booms were generated with nominal six-minute spacings between booms. Five response clusters may be seen in the figure (only 14 smartphones had been distributed before this date). This figure shows 1) the variations in response times among test participants; 2) delayed responses to two booms (participant number 4); 3) delayed responses to all booms until after the last boom (participant number 14); 4) delayed responses to all booms until approximately seven minutes after the last boom (participant number 9); and 5) a few responses that could not be associated with booms.

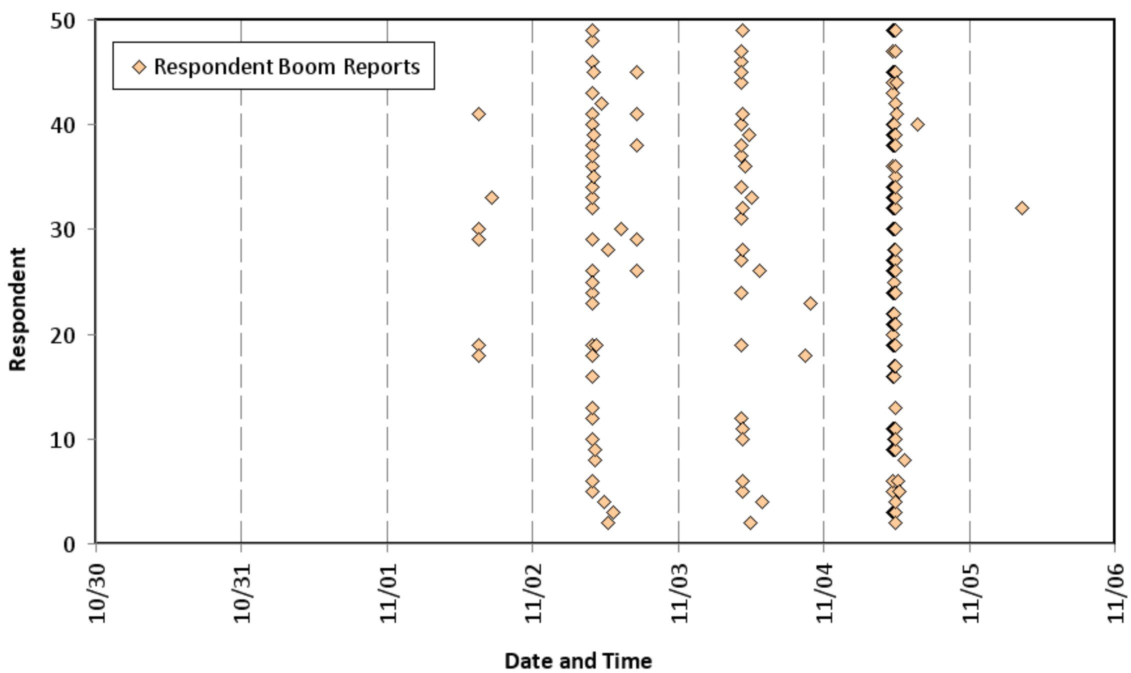

Figure 25: Time history of sonic boom responses for week 10/30/2011 through 11/05/2011.

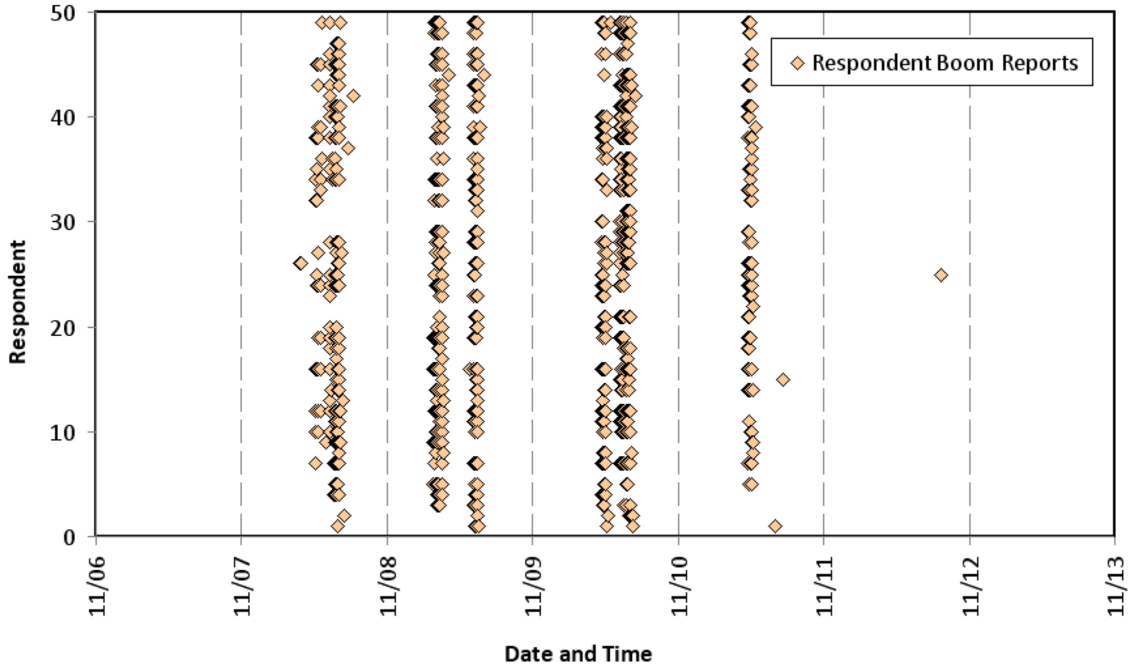

Figure 26: Chronology of sonic boom responses for week 11/06/2011 through 11/12/2011.

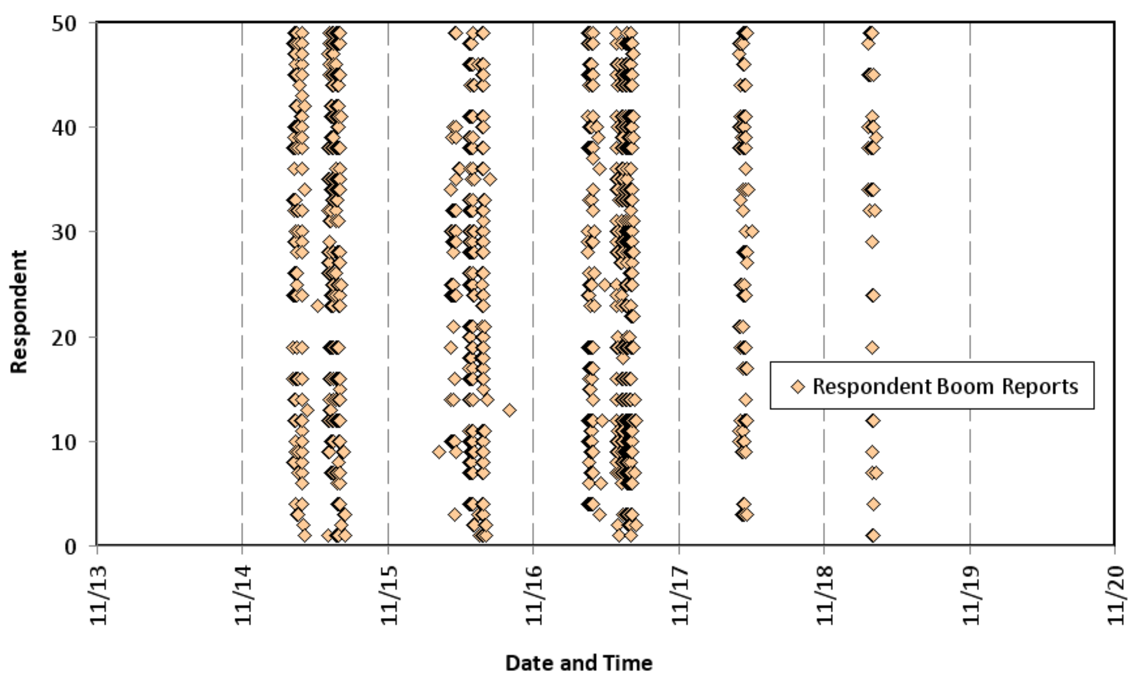

Figure 27: Chronology of sonic boom responses for week 11/13/2011 through 11/20/2011.

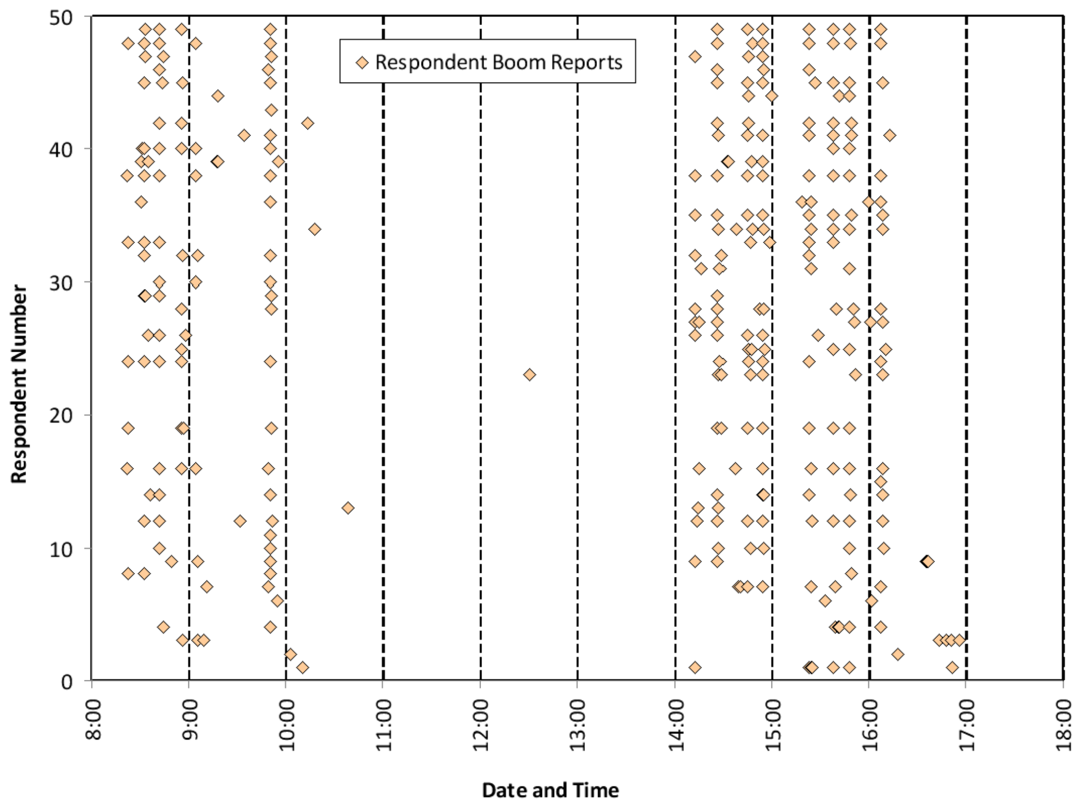

Figure 28: Sonic boom response time history for 14 November 2011.

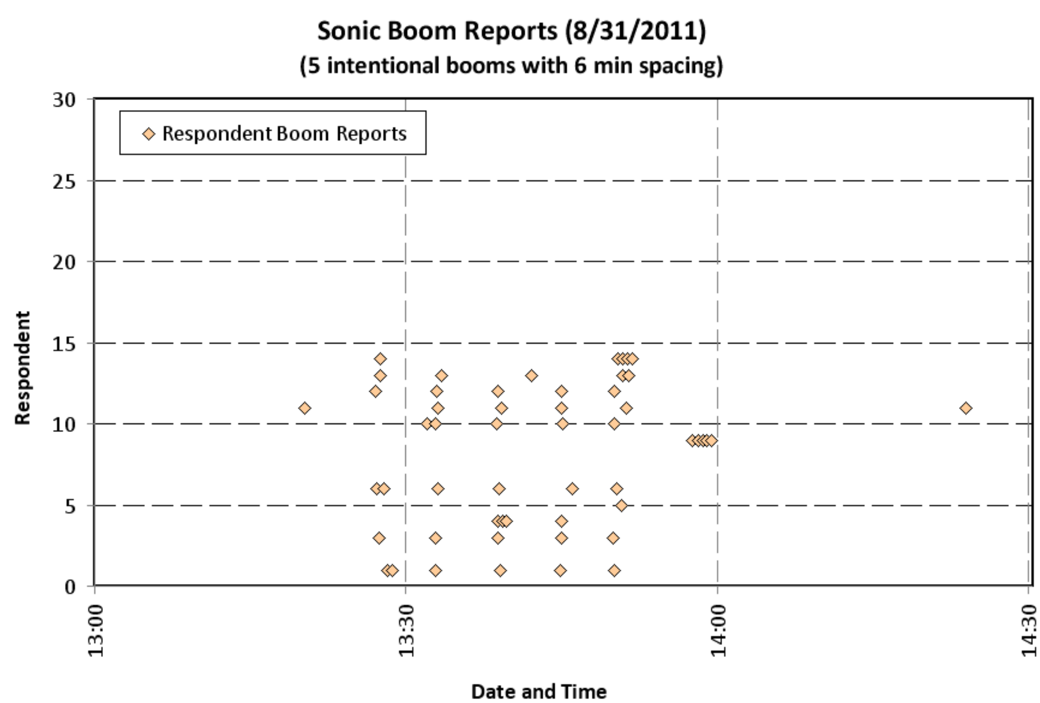

Figure 29: Response time history for a 1-1/2 hour period of intentional sonic booms on 31 August 2011.

11.2 Response latencies and implications

Section 4.1, along with Figure 15 and Figure 16, showed distribution density functions for response latencies following a sonic boom. Figure 30 (below) shows the cumulative distribution of latencies within an hour following a boom. The slow asymptotic rise to 100 percent after approximately 90 percent of respondents had completed interviews is noteworthy.

Figure 31 displays only the first 15 minutes of the data of Figure 30. This presentation permits greater detail to be seen in the length of time required to acquire various percentages of completed interviews. For example, just over forty seconds was required to complete half of the interviews. Within about six minutes of the occurrence of a boom, 90 percent of the responses were completed, and a little more than three minutes was required to collect 80 percent of the responses. However, nearly 1700 seconds (28 minutes) was required to collect 95 percent of the responses, an increase of 22 minutes beyond the 90 percent point.

The findings presented in these two figures bear on the ability to unambiguously assign the proper doses to responses based on the length of inter-boom intervals. They also raise questions about whether delayed reactions are reported with the same accuracy as prompt reactions.

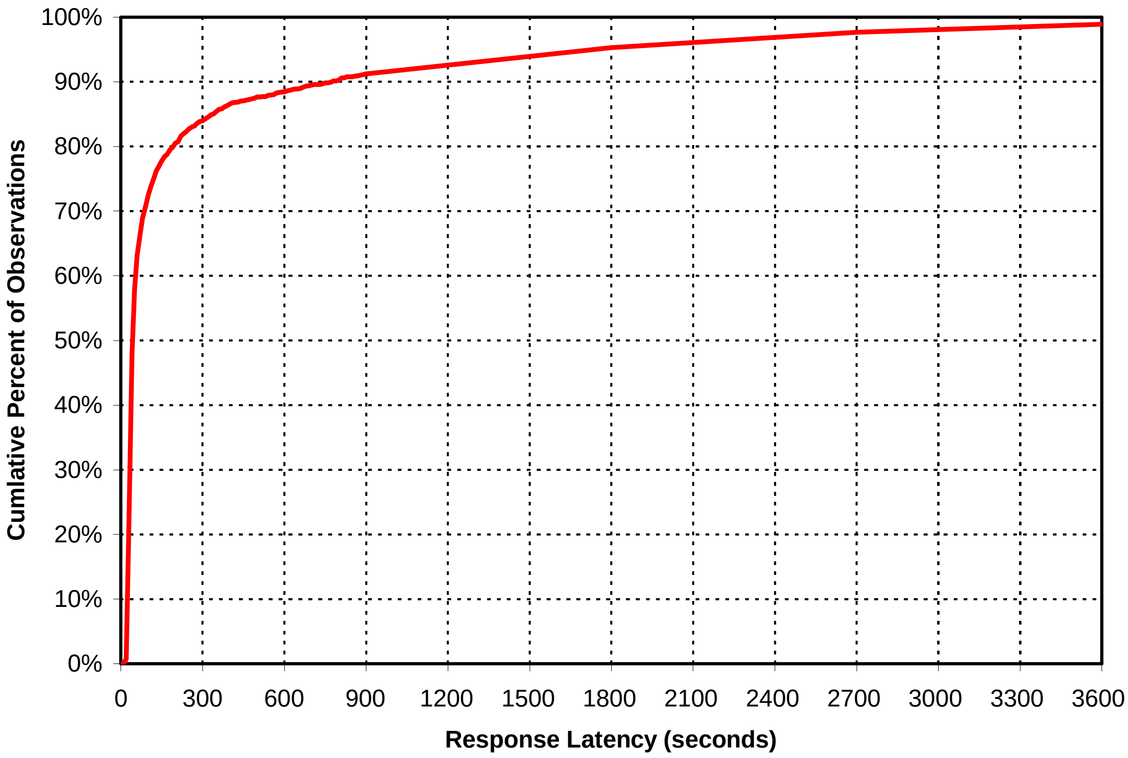

Figure 30: Cumulative distribution function of observed response latencies as long as an hour following a boom.

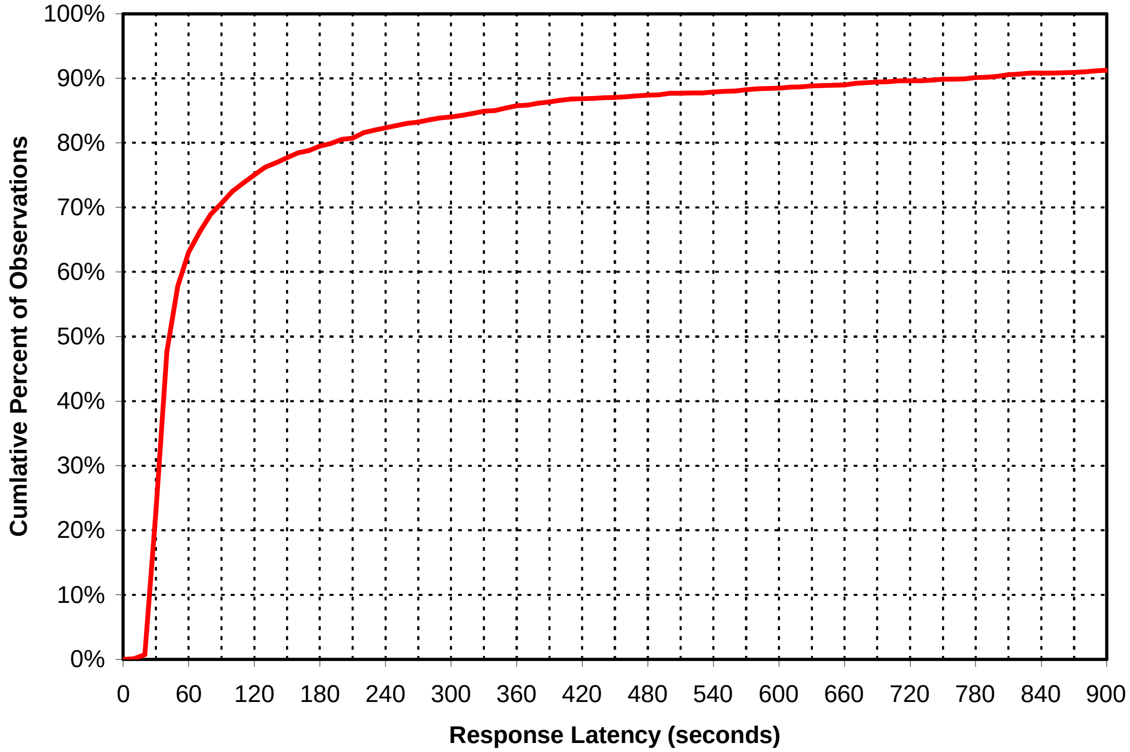

Figure 31: Cumulative distribution function of observed response latencies up to 15 minutes following boom event.

11.3 Low battery conditions encountered by test participants

As configured and used in the present pilot test, the battery life of the Droid2 smartphones that were distributed to test participants was approximately 24 hours.[29] In practice, this meant that most smartphones had to be recharged every night.

Many of the test participants were familiar with earlier (that is, less capable but lower power) cell phones, which did not require daily recharging. Figure 32 plots the frequency with which test participants experienced low batteries. The abscissa indicates the number of low battery failures encountered during the 15-day test period. The largest number encountered by any participant was 11. The ordinate shows the percentage of the 49-person participant pool experiencing a given number of failures. For example, 13 participants (or 27%) never experienced a single low battery failure. Another 11 (22%) experienced just one such failure, and so on. The median number of shutdowns attributable to low battery power is between one and two.

[29] Battery life depended not only on power use for the application software developed for the current pilot test, but also on the use of smartphones for other purposes. Thus, battery life varied greatly among test participants who made little use of their smartphones for purposes other than reporting sonic booms, and those who used their smartphones extensively for other power-intensive uses (*e.g.*, map and navigation applications and image processing), and/or made heavy use of their smartphones for social media, file downloading, texting, calling, and other miscellaneous applications.

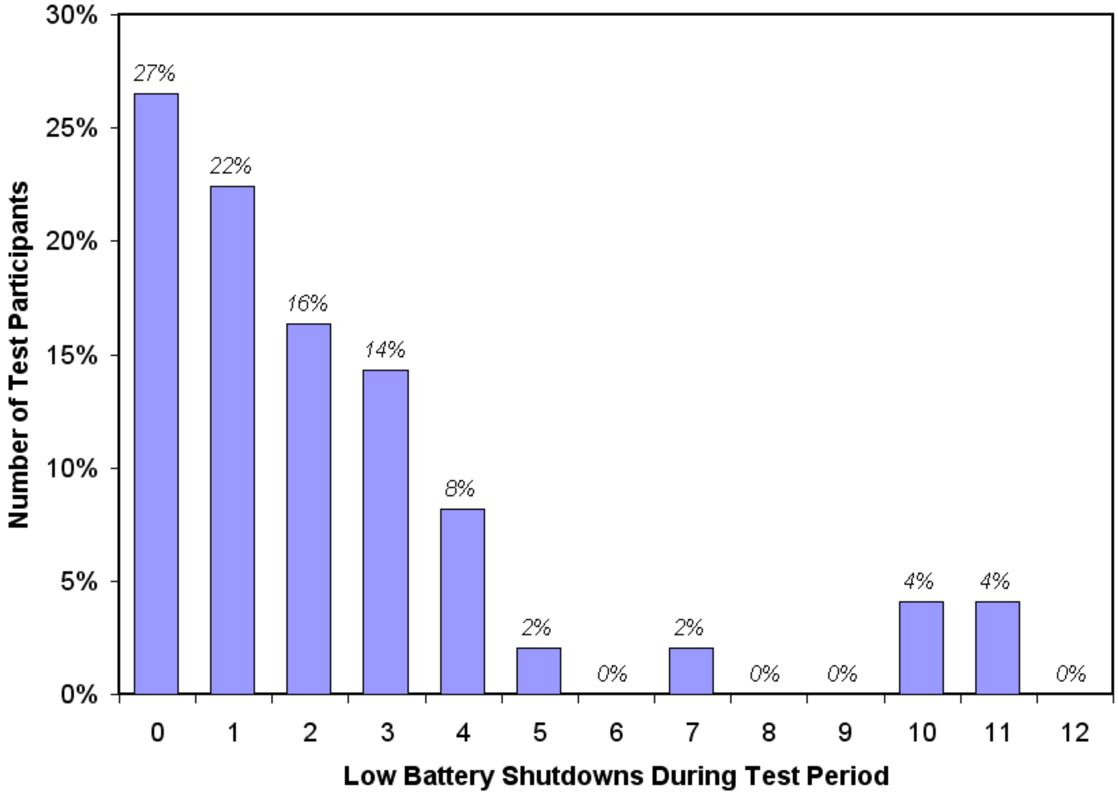

Figure 32: Percentages of test participants encountering varying numbers of low battery conditions during the test period.

11.4 Percentages of test participants at home during day and nighttime periods

Figure 33 and Figure 34 show percentages of at-home and not-at-home time during day and night time periods inferred from the 15-minute periodic smartphone position and status reports. Figure 33 shows pairs of bars for at-home and not-at-home conditions. The left-hand blue bars illustrate daytime conditions (7am to 7pm), while the right-hand bars show evening and night conditions (7pm to 7am). Test participants spent somewhat greater percentages of time at-home time during evening and night periods than at other times of day.

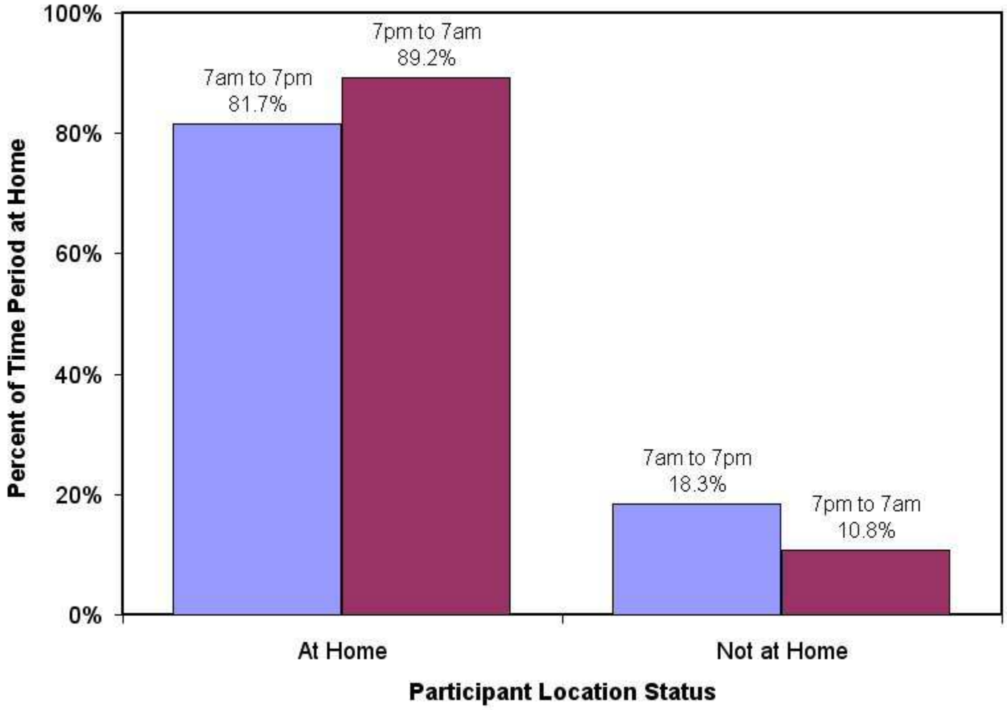

Figure 33: Comparison of at-home status between daytime and evening/nighttime periods

Figure 34 presents participant at-home status in greater detail. This figure shows the percentage of time test participants were at home by hour of the day. Each data point shows the average across all smartphone status reports during the weekdays and weekend days of the test period. The data are dichotomized by weekday (circles) and weekend (squares) since all sonic booms during the test period were observed between Monday and Friday. The vertical lines bracket the period of the day during which sonic booms (intended and adventitious) were observed.

The diurnal pattern shows greater variability over the weekend than during weekdays. At no time did the percentage of at-home participants drop below 80 percent during weekdays. The comparable minimal value for weekends was 75 percent.

11.5 Questionnaire completion rates

The percentages of respondents answering each of the interview questions are shown in Figure 35. (The figure numbers identified in the caption refer to questionnaire items shown in earlier figures in this report.) The figure shows two set of bars. The leftmost bar of each pair indicates the percentage of respondents initiating an interview who also answered each questionnaire item.

Questions 1 through 5 were asked of every respondent without any conditionality. The figure shows that all respondents answered these questions. Question 6 was asked only to the 1543 respondents who answered "Indoors" in response to Question 5. Of these 1543 respondents, all answered Question 6. Question 6 asked if participants had noticed rattle. A total of 743 participants responded in the affirmative. Question 7 asked whether those 743 were bothered or annoyed by rattle. All 743 participants answered that question, of whom 273 responded that the rattle was annoying in some degree. Question 8 was posed to those 273, who were asked about their degree of annoyance with the rattle. All 273 (100%) answered the last question.

These results clearly indicate that test participants were able to follow the on-screen directions and were engaged enough by the brief questionnaire to follow through to completion all questions that were asked of them.

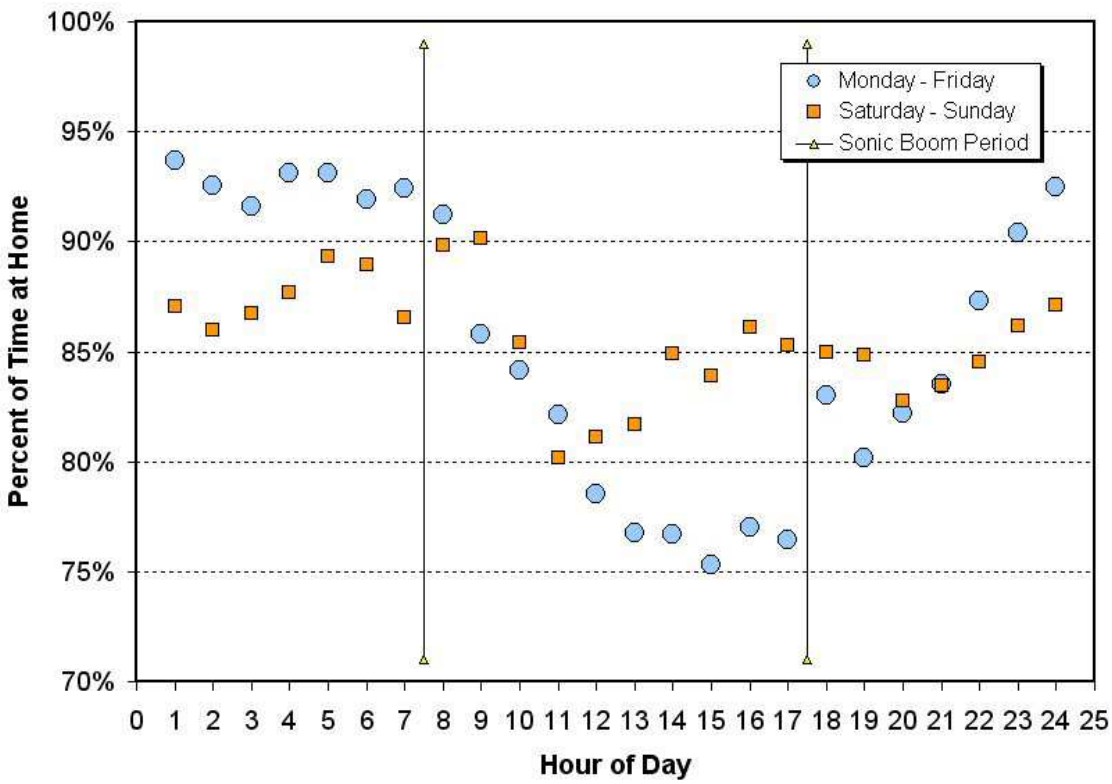

Figure 34: Participant at-home status by hour of day, for weekday/weekend periods.

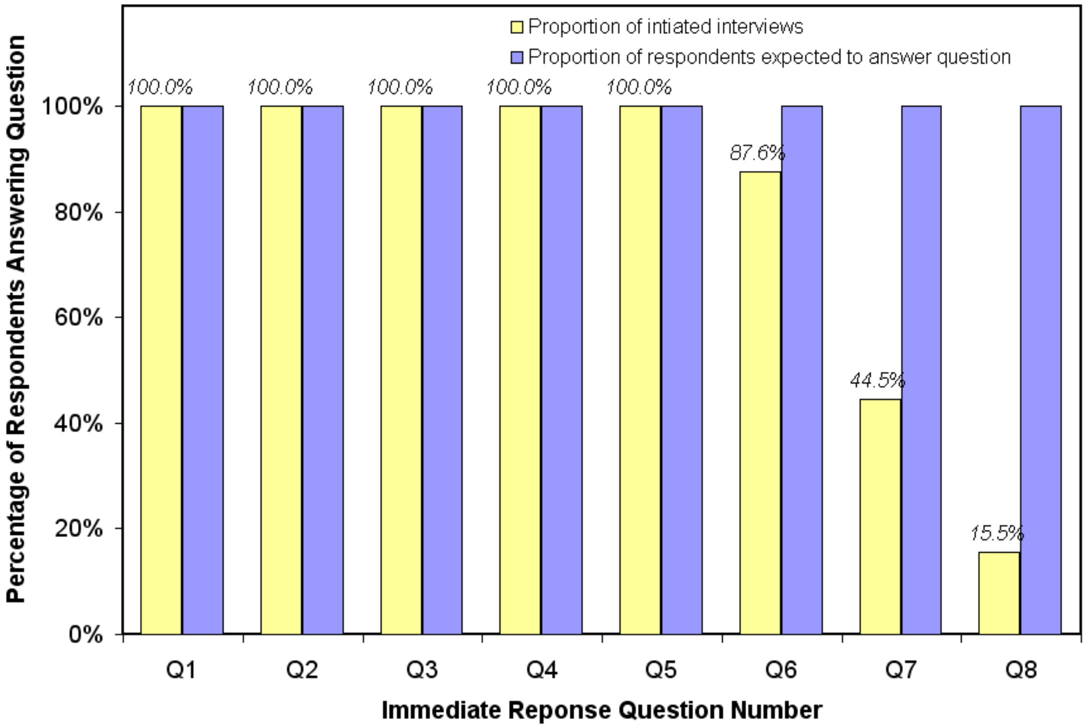

Figure 35: Percentage of respondents answering questions on immediate response questionnaire (see Figure 2 though Figure 9).

11.6 Reports of notice of individual sonic boom events as functions of sound levels

Figure 36 shows the percentages of at-home test participants reporting notice of individual sonic booms as a function of maximum overpressure. The lowest intentional boom overpressure presented to test participants was 0.1 psf. This overpressure went unnoticed by most test participants. No intentional booms went completely unnoticed by all at-home participants. The present dataset thus does not contain information necessary to determine a dose that completely escapes notice.

Figure 37 re-plots the same data in Figure 36 as a function of C-weighted sound exposure level. The lowest CSEL of an intentionally-produced boom was 74 dB.

For direct comparison with Figure 37 the data of Figure 36 are re-plotted on a logarithmic scale in Figure 38 to emphasize the similarity of the plots shown in this figure and Figure 37. This similarity is the predictable outcome of a very high correlation between the two metrics. Figure 39 provides a visual illustration of the high correlation between the two sound level variables by plotting average values of CSEL versus average values of 10*log[maximum overpressure squared] for each boom. The average values shown are those across all test participant homes for each sonic boom during the test period.

The unity slope line aids interpretation of the data. The slope of the data points appears to be slightly greater than unity. This observation is consistent with lower boom intensities having greater proportions of low frequency spectral content below 20 Hz than higher boom intensities, a portion of the spectrum deemphasized by the C-weighting function.

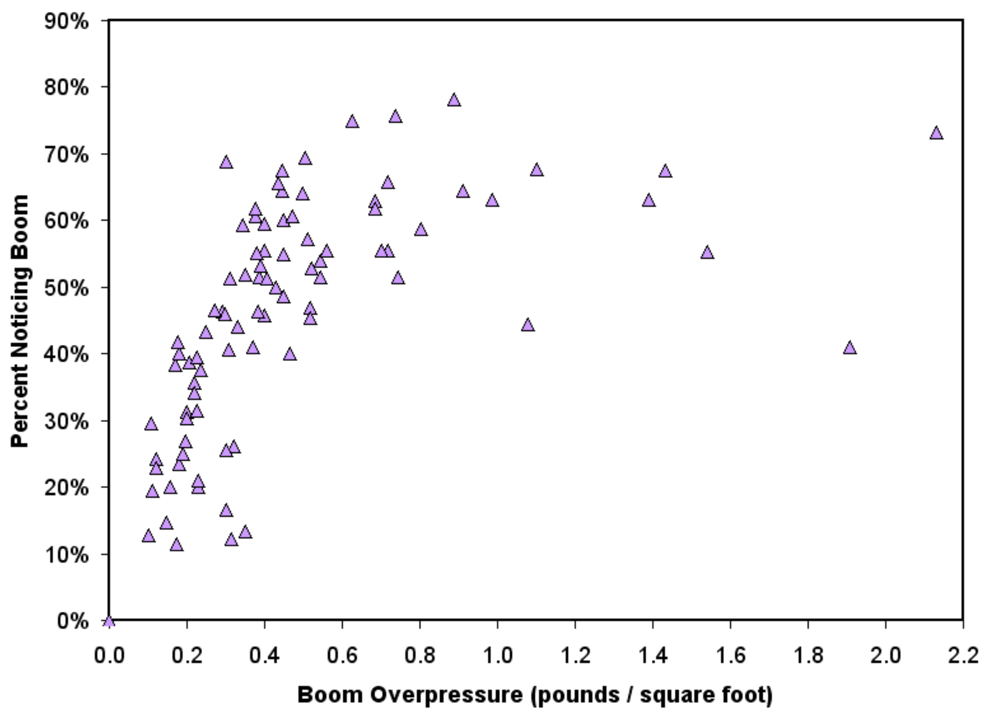

Figure 36: Percentages of at-home participants noticing sonic booms as a function of maximum boom overpressure.

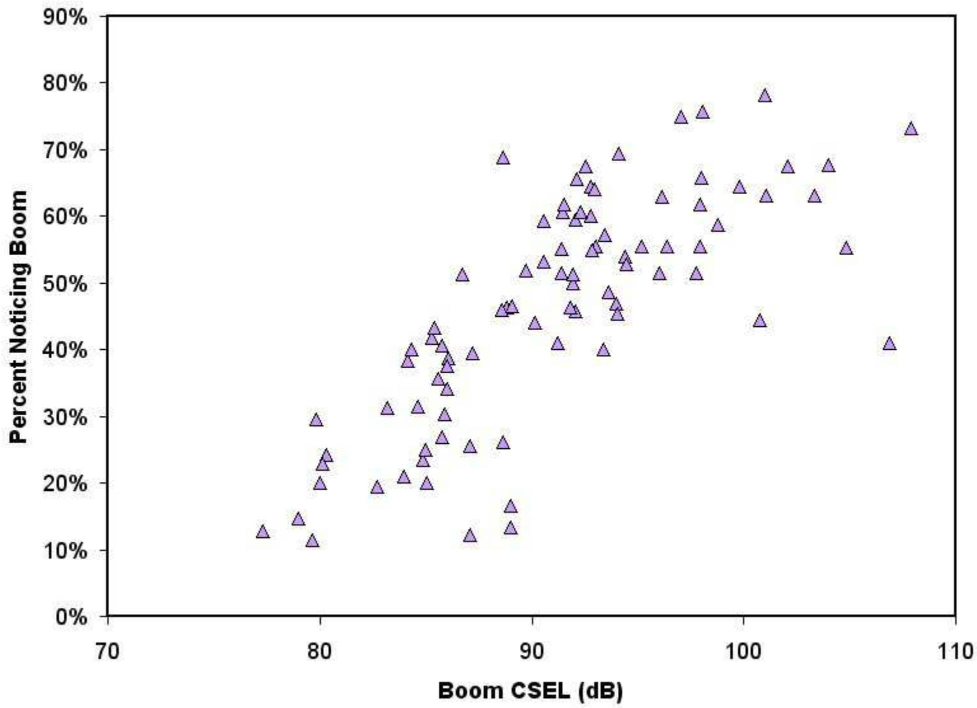

Figure 37: Percentages of at-home participants noticing sonic booms as a function of C-weighted sound exposure level.

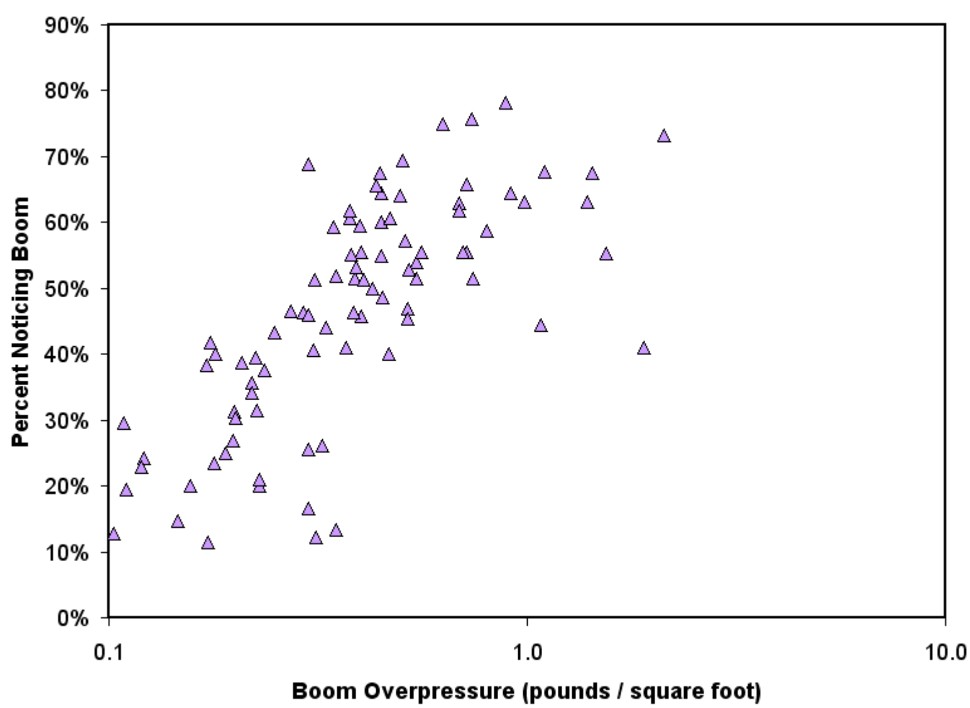

Figure 38: Percentages of at-home participants noticing sonic booms as a function of maximum boom overpressure (logarithmic scale)

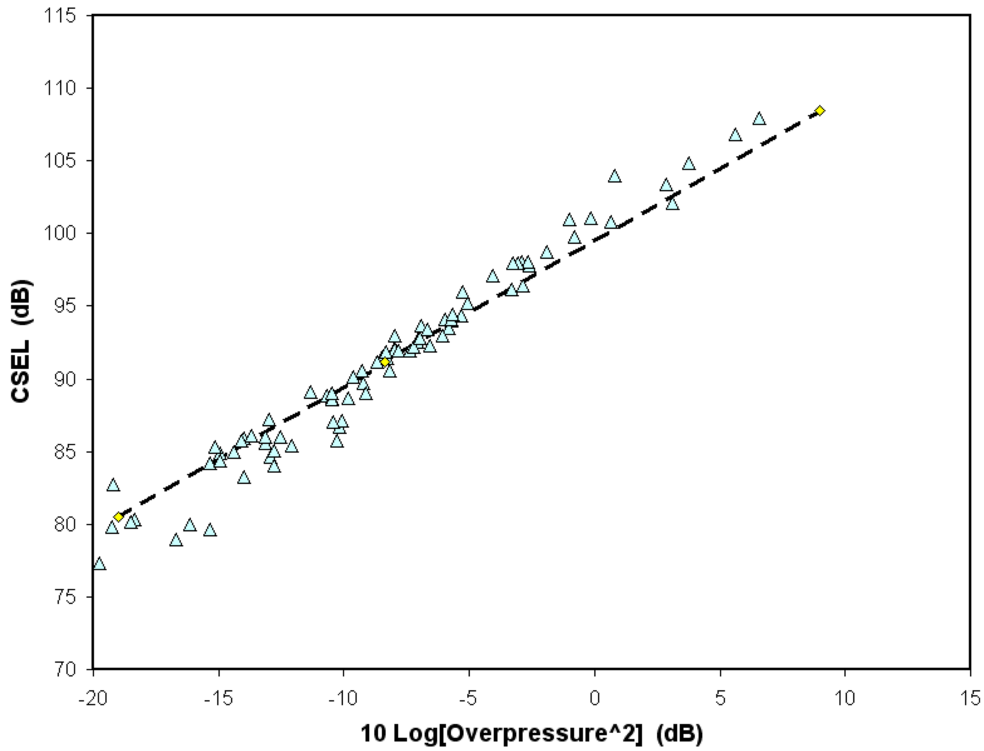

Figure 39: Observed relationship between C-weighted sound exposure level and square of maximum overpressure (dashed line is unity slope)

11.7 Analysis of responses to question about individually memorable booms

One question in the end-of-day interview asked "Was any one particular sonic boom that you noticed today much more annoying than any of the others?" The question was asked to investigate the contributions of individual booms to the annoyance of cumulative exposure, and whether annoyance judgments can be modeled as an energy integration process. It was also asked to investigate whether such a self-report could be associated with objective measures of single-event sound levels.

Figure 40 plots the percentage of respondents who answered "Yes" as a function of the day's C-weighted day-night average sound level exposure to sonic booms. Open circles identify percentages of respondents who reported hearing one or fewer booms, and thus were not asked if one boom was more annoying than others. This percentage declines with increasing CDNL, suggesting that days of higher CDNL may have included greater numbers of individually memorable booms in the present dataset.

Among respondents who reported noticing more than one boom, the percentages who believed that one boom was more annoying than others are plotted as solid red squares in Figure 40. This percentage tends to increase with CDNL.

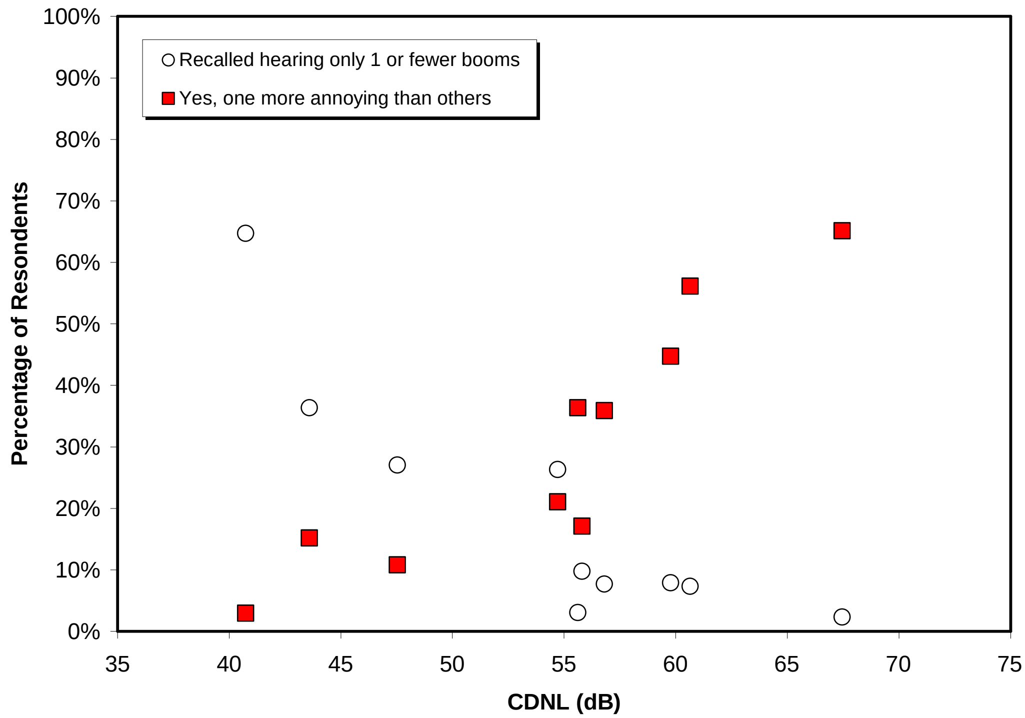

Figure 40: Relationship between percent of respondents reporting one boom to be louder than all others for the day and CDNL.

Figure 41 summarizes a more direct analysis of responses to the question. This figure plots the relationship between the percentage of respondents describing one boom as more annoying than all others (ordinate) and the CSEL difference between the highest and second highest boom (abscissa)[30, 31]. The responses seem to cluster into two sets: 1) those in the 1 to 2 decibel difference range, whose corresponding percentages exceed 15 percent, and 2) the remaining low CSEL difference points and those with CSEL differences greater than 2 decibels.

The high percentage data points in the 1 to 2 decibel range seem less than plausible if all respondents were exposed to all booms during the day. However, if some respondents were not at home for all booms, then perhaps of the booms they did hear, one stood out above the others. A more detailed analysis would be required at the individual event level to more fully understand this observation.

Figure 42 re-plots the data points of Figure 41 by showing as open plotting symbols the high-percentage / low CSEL difference points discussed above. The remaining filled plotting symbols form a trend of increasing percent of respondents noticing a single annoying boom with increasing CSEL difference between the two highest sound level booms. The slope of the relationship appears to be approximately 3 percent increase in noticeability per decibel of difference.

---

[30] The data points stack in a vertical straight line because the sound level data was reported to the nearest whole decibel.

[31] Note that from Figure 39 this relationship would differ little if the boom exposure were expressed in terms of boom overpressures.

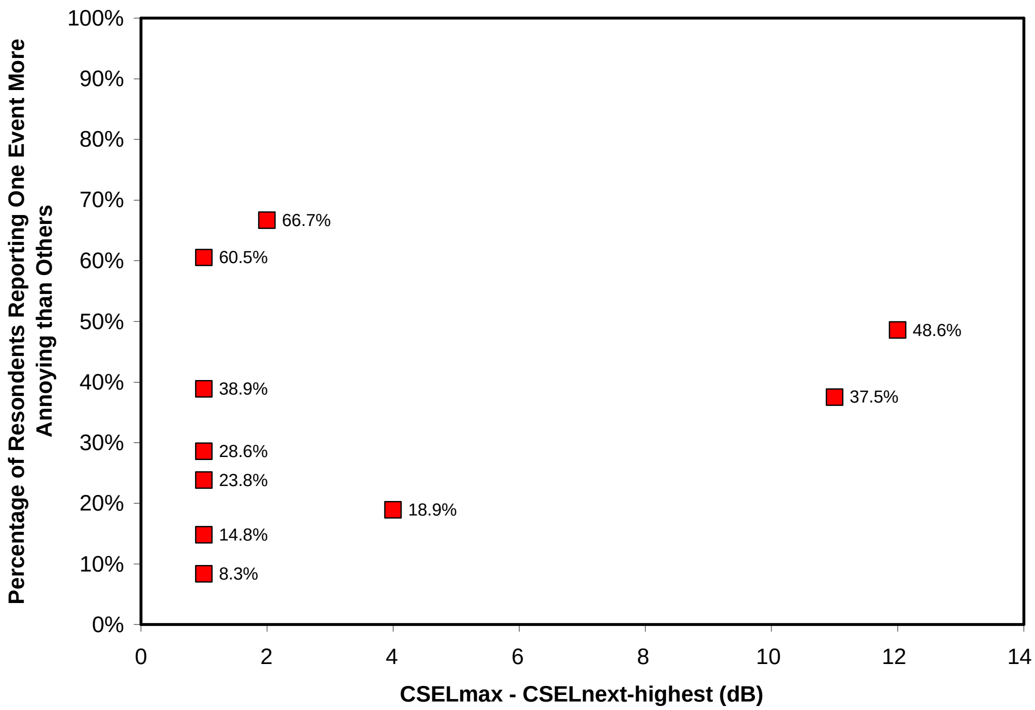

Figure 41: Relationship between percent of respondents reporting one boom louder than others and CSEL difference between loudest and next loudest boom.

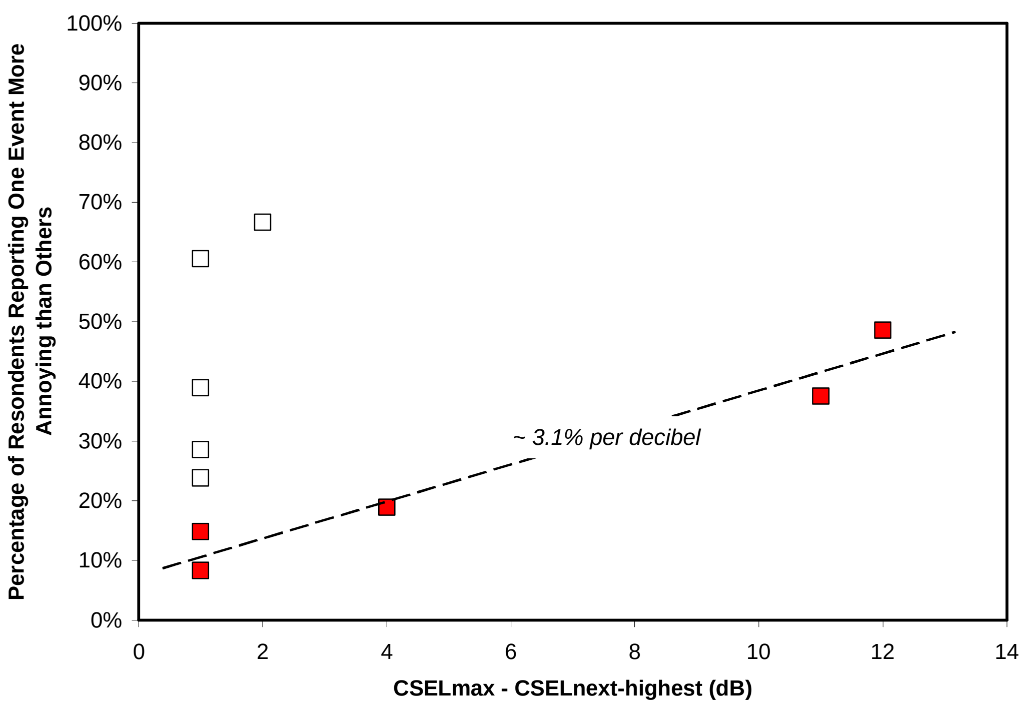

Figure 42: Relationship between percent of respondents reporting one boom louder than others and CSEL difference between loudest and next loudest boom (with fit line).

Figure 43 shows the data of Figure 42 in a slightly different manner. The ordinate is the same in both figures, as are the percentages for each plotting symbol. However, the abscissa in Figure 43 plots the energy difference between the boom of highest CSEL and that of all other booms combined by subtracting the CDNL of all but the highest level boom from that of the highest. The same days shown with open plotting symbols in Figure 42 are also shown as open plotting symbols in this figure. In other words, the open plotting symbols in Figure 43 also indicate days on which there was very little difference in single event levels between the highest and second highest booms. A similar trend, also of approximately 3 percent per decibel slope, is evident. Visually, the residuals about the trend lines in the two figures seem indistinguishable from one another, so it is not clear from this limited data set whether one predictor performs better than the other.

Taken together, the patterns apparent in Figure 40 through Figure 43 suggest that people are sensitive to unusually annoying individual booms, even if they do not occur in close temporal proximity to other booms. This, in turn, suggests the possibility of tailoring exposure schedules in future studies to permit investigations of the manner in which people integrate the annoyance of individual booms into their estimates of the annoyance of cumulative exposure.

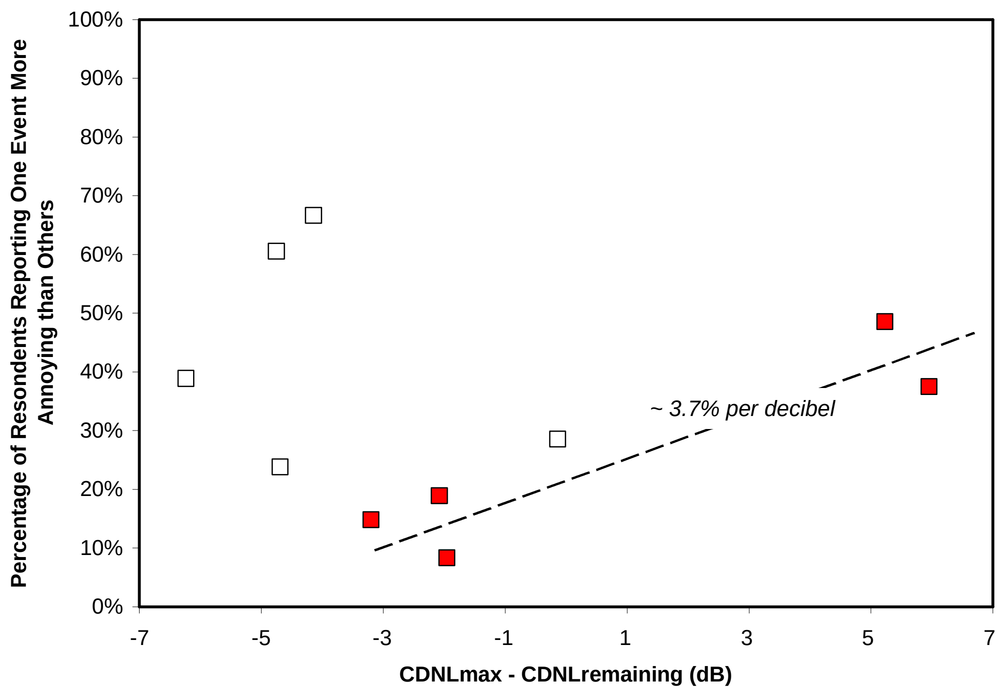

Figure 43: Relationship between percent of respondents reporting one boom to be louder than all others for the day and the difference in CDNLs between that of the loudest boom and all the rest (with fit line).

11.8 Reports of annoyance of individual sonic boom events as functions of sound levels

Figure 44 illustrates the degrees of annoyance associated with CSEL values for individual booms. In general, greater percentages of test participants describe themselves as at least slightly annoyed at lower CSEL values than the percentages of those who describe themselves as at least moderately annoyed. Conversely, higher CSEL values are generally required for test participants to describe themselves as "very" or "extremely" ("highly") annoyed than for test participants to describe themselves as at least moderately annoyed by sonic booms.

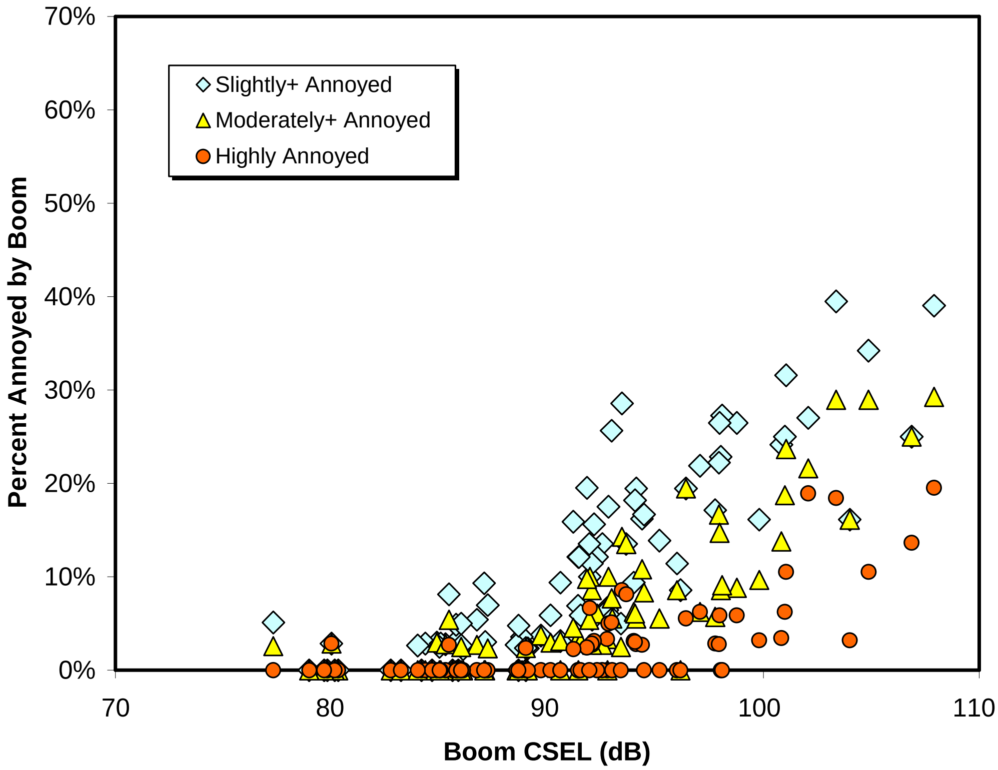

Figure 44: Percentages of at-home test participants reporting three different degrees of annoyance to sonic booms as a function of C-weighted sound exposure level.

11.9 Reports of startle associated with individual sonic boom events as functions of sound levels

Figure 45 shows a clear trend of increasing percentages of test participants reporting startle with increasing sound exposure levels of sonic booms. Reports of notice of rattle associated with individual sonic boom events as functions of sound levels.

Figure 46 shows a clear trend of increasing percentages of test participants reporting notice of rattle with increasing sound exposure levels of sonic booms.

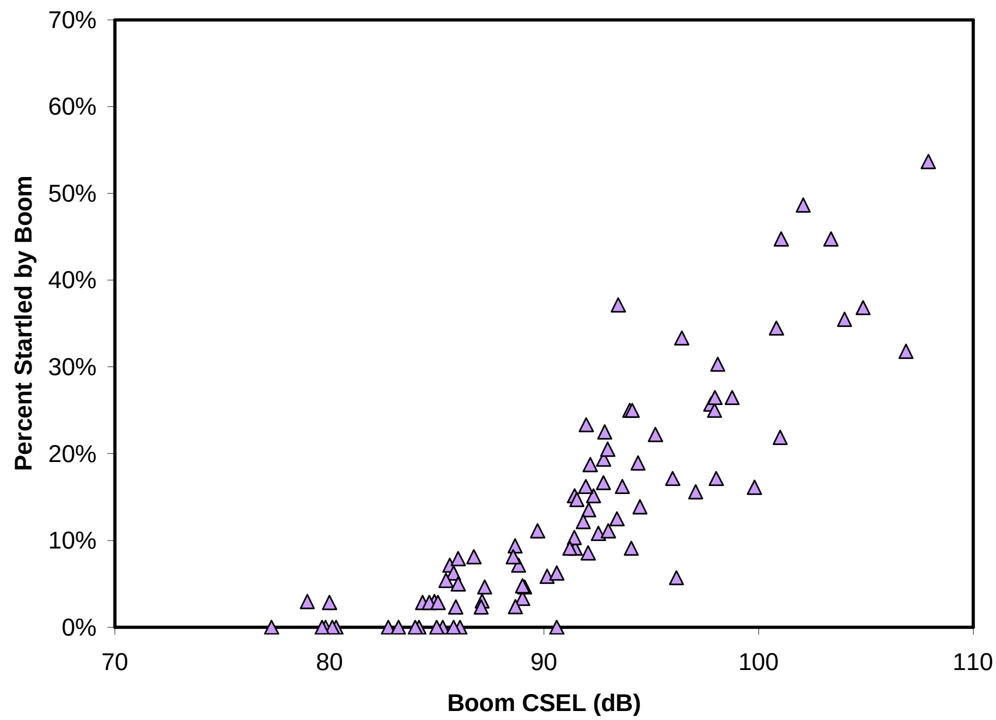

Figure 45: Percentages of at-home test participants reporting startle to sonic booms as a function of C-weighted sound exposure level.

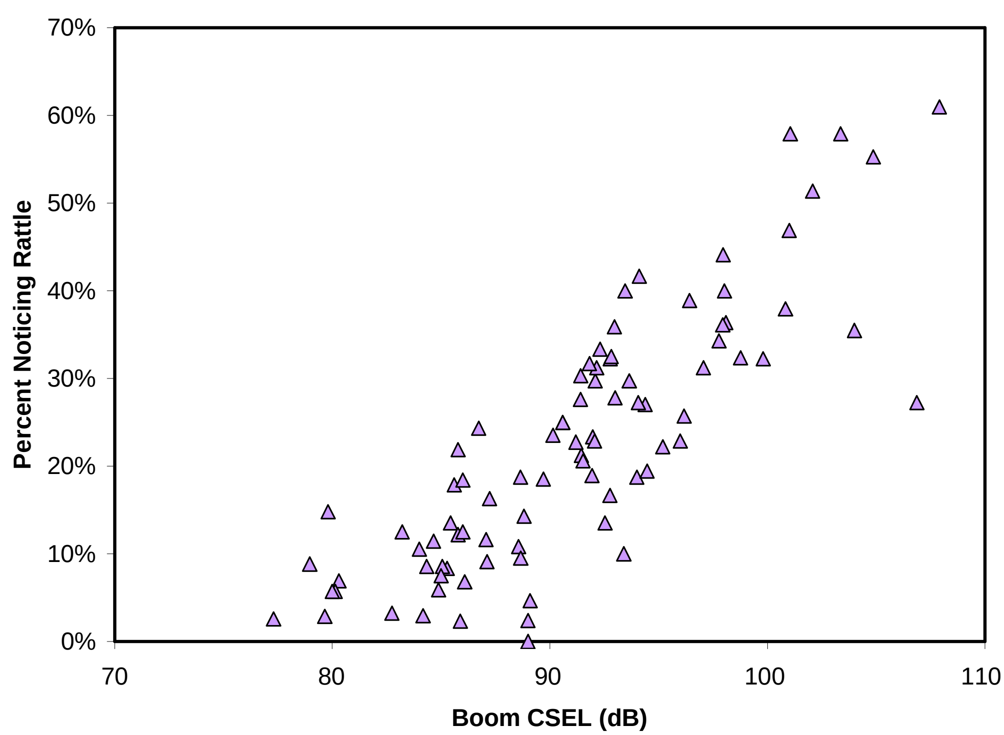

Figure 46: Percentages of at-home test participants noticing rattle as a function of C-weighted sound exposure level.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*: 01- 09 - 2012

2. REPORT TYPE: Contractor Report

3. DATES COVERED *(From - To)*:

4. TITLE AND SUBTITLE
Pilot Test of a Novel Method for Assessing Community Response to Low-Amplitude Sonic Booms

5a. CONTRACT NUMBER: NNL10AA19C

5b. GRANT NUMBER:

5c. PROGRAM ELEMENT NUMBER:

6. AUTHOR(S)
Fidell, Sanford; Horonjeff, Richard D.; Harris, Michael

5d. PROJECT NUMBER:

5e. TASK NUMBER:

5f. WORK UNIT NUMBER: 984754.02.07.07.18.03

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, Virginia 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER:

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S): NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S): NASA/CR-2012-217767

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 71
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

Langley Technical Monitor: Kevin P. Shepherd

14. ABSTRACT
A pilot test of a novel method for assessing residents' annoyance to sonic booms was performed. During a two-week period, residents of the base housing area at Edwards Air Force Base provided data on their reactions to sonic booms using Smartphone-based interviews. Noise measurements were conducted at the same time. The report presents information about data collection methods and about test participants' reactions to low-amplitude sonic booms. The latter information should not be viewed as definitive for several reasons. It may not be reliably generalized to the wider U.S. residential population (because it was not derived from a representative random sample) and the sample itself was not large.

15. SUBJECT TERMS
Aircraft Noise; Community Response; Sonic Boom

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER ***(Include area code)***
U	U	U	UU	72	(443) 757-5802