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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 181

Assessing Community Annoyance of Helicopter Noise

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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FOREWORD

By Joseph D. Navarrete
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ACRP Research Report 181 explores what is currently known about community annoyance of helicopter noise. It describes a protocol for conducting a large-scale community survey to quantify annoyance due to civil helicopter noise and presents the results of a test of the protocol which also helped improve understanding of the roles of acoustic and non-acoustic factors that influence community annoyance to civil helicopter noise. The report should be of particular interest to airport industry practitioners, community planners, and researchers who desire a better understanding of the factors affecting community annoyance with helicopter noise and possible differences between helicopter noise impacts and fixed-wing aircraft noise impacts.

Helicopter noise differs from fixed-wing aircraft noise in many ways. Helicopter operations and routes are more variable than those of fixed-wing aircraft and often occur at lower altitudes. In addition, the frequency content, sound level onset, decay rates, and overall duration of helicopter noise differ from those of fixed-wing aircraft. These differences may be associated with differences in how humans react to helicopter noise versus fixed-wing aircraft noise. There also may be factors affecting community response to helicopter noise, including audibility, safety, and privacy concerns. Although a 2004 FAA Report to Congress (*Nonmilitary Helicopter Urban Noise Study*) recommended that "additional development of models for characterizing the human response to helicopter noise should be pursued," to date, no such work had been undertaken. Research was therefore needed to better understand the factors affecting community annoyance to helicopter noise.

The research team, led by Landrum & Brown, began with a literature review. A set of hypotheses was developed from the review to explore whether helicopter noise was more annoying than noise from fixed-wing aircraft at comparable sound levels, and, if so, what factors might contribute to that greater annoyance. Also explored was how possible differences might be accounted for when predicting helicopter noise impacts. The team then developed a research protocol that included a large-scale social survey, noise monitoring, and noise modeling. The team next implemented the protocol in an effort to validate the approach and, if possible, obtain results to confirm their hypotheses. The surveys were conducted via telephone (both landline and wireless) in Long Beach, California; Las Vegas, Nevada; and Washington, D.C. About 2,300 respondents were interviewed. Survey results were analyzed and correlated to the noise monitor data and noise modeling output to draw conclusions.

In addition to the literature review, the report provides a detailed description of the research protocol and rationale, detailed survey results, and summary conclusions. While the project validated the protocol for conducting a large-scale study on community annoyance to helicopter noise, it could not conclusively identify any notable difference between community annoyance with light civil helicopter noise and the noise generated by fixed-wing aircraft at comparable sound exposure levels, nor could it conclusively identify any non-acoustic factors that might affect an individual's perception of helicopter noise.

CONTENTS

SUMMARY

Assessing Community Annoyance of Helicopter Noise

This report presents the findings of a study of the annoyance of helicopter and fixed-wing aircraft noise. This study developed and tested a series of hypotheses intended to determine whether helicopter noise is more annoying than fixed-wing noise. The request for proposal (RFP) cited a general lack of understanding of the relationship between helicopter noise and community response. In a 2004, FAA Report to Congress titled "Nonmilitary Helicopter Urban Noise Study," it was suggested that "additional development of models for characterizing the human response to helicopter noise be pursued." The RFP further raised the question of whether the assumed "excess" annoyance of helicopter noise was more appropriately attributed to purely acoustic factors, to nonacoustic factors, or to a combination of the two.

The study began with a review of the technical literature that identified annoyance as the primary noise effect of concern, distinguishing between the direct annoyance of airborne noise and the indirect annoyance of secondary emissions (vibration and rattling sounds) that may be induced in residences by helicopters. The review included an annotated bibliography of a score of prior publications on the annoyance of helicopter noise as well as tutorials on the nature and aerodynamic origins of helicopter noise emissions. It also included an analysis of the correlations among noise metrics commonly used as predictors of community response and a description of a systematic approach to accounting for nonacoustic influences on the annoyance of helicopter noise.

The literature review found inconclusive evidence from prior laboratory and field studies concerning half a dozen hypotheses about the origins of annoyance due to helicopter noise. The main point of agreement was that helicopter noise is much more variable and complex than fixed-wing aircraft noise. The main point of disagreement was the degree to which main rotor impulsive noise controls the annoyance of helicopter noise. Overall, the reviewed laboratory and field studies revealed little systematic, rigorous, or theory-based understanding of the annoyance of helicopter noise. Seven hypotheses were formed from the literature review about the origins of the annoyance of helicopter noise.

In simplified form, the hypotheses were:

1. The prevalence of annoyance due to helicopter noise exposure in a community is greater than that associated with comparable levels of exposure to noise produced by fixed-wing aircraft;
2. The prevalence of annoyance due to helicopter noise is most usefully predicted in units of A-weighted cumulative exposure;
3. The prevalence of annoyance due to helicopter noise is strongly influenced by its impulsive character, and thus requires an impulsiveness "correction" to A-weighted cumulative exposure;
4. The prevalence of annoyance due to helicopter noise is strongly influenced by indoor secondary emissions (rattle and vibration) due to its low-frequency content;

5. The prevalence of annoyance due to helicopter noise is appreciably influenced by non-acoustic factors;
6. The prevalence of annoyance due to helicopter noise is more usefully attributed to proximity to helicopter flight paths than to helicopter noise emissions per se; and
7. Complaints lodged about helicopter noise are more reliable predictors of the prevalence of annoyance than measures of exposure to helicopter noise or proximity to helicopter flight paths.

Telephone interviews were conducted with residents of three urban areas about their annoyance with exposure to helicopter noise. The interviewing sites were among those with the greatest concentrations of civil helicopter traffic in the United States. The range of helicopter-only cumulative noise exposure levels expressed in day-night average sound level (DNL) across the interviewing sites nonetheless ranged from about 27 dB $\leq L_{dn} \leq$ 53 dB.

A questionnaire consisting of 15 items was created to collect information relevant to these hypotheses in largely residential neighborhoods near three airports supporting fixed-wing and helicopter operations: Long Beach, CA [Long Beach Airport (LGB)]; Las Vegas, NV [McCarran International Airport (LAS)]; and Washington, D.C. [Ronald Reagan Washington National Airport (DCA)]. Interviewing sites were selected primarily for their substantial exposure—by civil aviation standards—to helicopter noise. A range of helicopter noise exposure levels was sought at each site, and when possible, a range of fixed-wing aircraft noise exposure as well. Because the primary site selection criterion was exposure to large numbers of daily civil helicopter flight operations, only one of the three interviewing sites (DCA) was exposed to appreciable levels of noise exposure produced by fixed-wing flight noise.

Modeling of these helicopter operations was undertaken to estimate the helicopter noise exposure. Representative random samples of both landline and wireless telephone-subscribing households at each site were then compiled into a sampling frame by first identifying geographic areas in proximity to helicopter flight tracks with similar noise exposure, and then by identifying households within them. Home addresses of wireless telephone subscribers were inferred from their billing addresses, or from address information associated with the wireless number in other proprietary databases.

Computer-assisted, live-agent telephone interviewing was then conducted over a period of at least 1 week in each of the neighborhoods. A total of 2,372 respondents completed the interview: 1,189 in Long Beach, 741 in Las Vegas, and 442 in Washington, D.C.

Field measurements to confirm the noise exposure predictions were conducted for a week prior to the start of interviewing and during interviewing at LGB and at LAS. Time series of sound pressure levels were collected at 1-second intervals, along with A-weighted 1-second equivalent continuous noise level (L_{eq}), C-weighted 1-second L_{eq}, and 1-second L_{eq} in each of the one-third octave bands from 6 Hz to 20 kHz. Both A-weighted and C-weighted 1-second time histories of L_{eq} values were also recorded. Due to high levels of fixed-wing aircraft noise in Washington, D.C., helicopter noise exposure levels were estimated by noise modeling alone. Helicopter flight operations at DCA were highly constrained by higher altitude fixed-wing approach and departure flight paths, and high-quality radar flight track information was available during the interviewing period.

All of the neighborhoods in which interviewing was conducted had stable residential populations. Large majorities of respondents in Long Beach and Las Vegas described their neighborhoods as quiet. Nearly half of the respondents in Washington did as well. However, nearly a quarter of the respondents in Long Beach described their neighborhood as noisy, and nearly a third of the respondents in Washington described their neighborhood as "quiet, except for aircraft noise."

Only small minorities of respondents reported noticing helicopters more than a few times a day at any of the three study sites even though the number of flights per day at one site was nearly 10 times the number of flights at the other two sites. The mean level of exposure to helicopter noise of respondents who were annoyed in any degree by it was 44 dB. The mean level of exposure to helicopter noise of respondents who were *not* annoyed in any degree was 42 dB. The difference in exposure levels of respondents who were and were not annoyed in any degree by helicopter noise was unlikely to have arisen by chance alone, but accounted for very little variance in the relationship between noise exposure and annoyance. Likewise, a weak but statistically significant relationship between exposure to helicopter noise and high annoyance (self-description by respondents as "very" or "extremely" annoyed by helicopter noise) was observed in the Long Beach interviewing area. No statistically significant relationship between helicopter noise levels and annoyance due to in-home vibration and rattling was observed at any of the three study areas.

Less than 3% of all respondents reported that they had ever registered complaints about helicopter noise. Among the 1,937 respondents who reported no annoyance with helicopter noise, 1.3% registered complaints; of the 330 respondents who reported at least slight annoyance by helicopter, 9.4% registered complaints. No statistically significant difference was observed in the helicopter-only DNL for respondents who did and did not complain.

At two of the three interviewing sites (Las Vegas and Washington), the prevalence of high annoyance with helicopter noise was statistically distinguishable from zero, but varied little with DNL. At the remaining site (Long Beach), the prevalence of high annoyance with helicopter noise was also non-zero and invariant with DNL at low exposure levels, but increased modestly at levels exceeding about $L_{dn} = 45$ dB.

The prevalence of annoyance with helicopter noise was not strongly related to noise exposure levels over the range of helicopter-only DNL values that were available for study. The present study could not determine whether respondents in the same communities differed in tolerance for fixed- and rotary-wing aircraft, because sites with comparable exposures to the two types of aircraft noise were not found. At the one interviewing site (Washington, D.C.) at which residents were exposed to both forms of aircraft noise, noise due to fixed-wing operations generated significantly higher annoyance, but the fixed-wing noise exposure was also considerably greater than noise exposure due to helicopter operations.

The majority of survey respondents were exposed to helicopter-only DNL values between roughly 30 and 45 dB. These absolute levels of exposure to helicopter noise were low with respect to typical urban noise exposure, so that most of the observed prevalence rates of high annoyance with helicopter noise were correspondingly low as well. It was observed that individuals highly annoyed by fixed-wing aircraft noise were fifteen times more likely to be highly annoyed by helicopter noise than those not highly annoyed by fixed-wing aircraft noise.

The relatively low levels of exposure to helicopter noise (with respect to other sources of cumulative urban noise exposure) are believed to be responsible for a general absence of strong helicopter noise effects in the current data set. The findings of the present study do not support construction of useful dosage-response relationships between exposure to helicopter-only noise and the prevalence of high annoyance. It also does not appear that further surveys along typical civil helicopter routes would prove to be any more useful in developing a dosage-response relationship. Additional study in communities with much higher helicopter DNL exposure values, such as around military facilities, might support development of a more definitive dosage-response relationship. However, such a relationship would be applicable primarily to heavy military helicopters whose impulsive noise signatures are more prominent than those of lighter civil helicopters.

Introduction

ACRP's RFP for Project 02-48 cited a general lack of understanding of the relationship between helicopter noise and community response and that in 2004, an FAA Report to Congress, "Nonmilitary Helicopter Urban Noise Study," recommended that "additional development of models for characterizing the human response to helicopter noise should be pursued." The solicitation raised the question of whether the assumed "excess" annoyance of helicopter noise was more usefully attributed to purely acoustic factors, or to nonacoustic factors, or to a combination of the two. This report presents the findings of a social survey on the annoyance of aircraft noise that was intended to seek evidence of the reasonableness of the underlying assumption of the RFP.

Chapter 1 reviews the technical literature on the annoyance of helicopter noise to aid in the design of questionnaire items and other aspects of field surveys regarding opinions about the annoyance of helicopter noise.

Chapter 2 develops hypotheses for field testing about the annoyance of exposure to helicopter noise. Not all hypotheses were testable at all sites, since individual site characteristics limited types and amounts of helicopter and fixed-wing aircraft noise exposure available for analysis.

Chapter 3 discusses criteria used to select survey sites, and identifies sites that satisfied selection criteria. The chapter also describes the questionnaire that was developed, along with the purposes that individual questionnaire items served in testing the hypothesis developed in Chapter 4.

Chapter 4 describes noise measurement and social survey methods and implementation.

Chapter 5 presents the analysis of survey findings including an interpretation of the results.

Chapter 6 provides conclusions and discussion.

Appendix A is a short tutorial on the sources and nature of helicopter noise emissions, and an analysis of the correlations among noise metrics commonly used as predictors of community response.

Appendix B is an annotated bibliography of relevant studies of the annoyance of helicopter noise, in both laboratory and field settings. It is intended as an interpretive guide to the technical literature on the annoyance of helicopter noise. The annotation focuses on the issue of the "excess" annoyance of rotary-wing aircraft noise, and on examining hypotheses of potential interest for empirical tests in the field study phase of ACRP Project 02-48.

Appendix C summarizes a modern approach to accounting for the potential excess annoyance of helicopter noise. The approach concentrates on estimating the *net* effect of all of the many potential nonacoustic factors on the prevalence of annoyance judgments in communities, rather than identifying individual factors.

Appendix D describes the noise measurement protocol for this study.

Superscripts in the text refer to Endnotes located at the end of this document.

CHAPTER 1

Literature Review

1.1 Introduction

The literature review performed by the research team initially identifies prior design and analysis approaches used for research on community response to aircraft noise. Review of these prior design and anaylsis approaches then leads to a discussion of hypotheses that merit consideration in field studies.[1] The review then identifies annoyance as the primary noise effect of concern and distinguishes between the direct annoyance of airborne noise and the indirect annoyance of secondary emissions (vibration and rattling sounds) that may be induced by helicopter acoustic emissions. A recent increase in concern with helicopter noise complaints is then discussed.

The next topics addressed are the potential influences of nonacoustic factors in community response to helicopters and the usefulness of laboratory and field findings about helicopter annoyance. The review concludes with a summary of prior findings.

1.2 Understanding of Helicopter Noise Versus Fixed-Wing Aircraft Noise

Community reaction to helicopter noise has been less studied and less well understood than community reaction to fixed-wing aircraft noise for a variety of reasons. Most obviously, exposure to helicopter noise remains a more geographically limited problem than exposure to fixed-wing aircraft noise, and affects far fewer people. For example, out of a total of 232,567 active aircraft in the domestic U.S. fleet of commercial and general aviation aircraft, only 11,245 are helicopters (FAA 2011). Despite the smaller numbers of people affected by exposure to helicopter noise than by exposure to noise from fixed-wing aircraft, helicopter noise can nonetheless be distinctive and highly annoying.

As described in Appendix A, noise emissions of helicopters are more complex, variable, and unpredictable than those of fixed-wing aircraft. (The appendix provides a brief tutorial on the sources and characteristics of helicopter noise in various flight regimes.) Helicopter noise emissions vary not only with flight regime, orientation with respect to the flight path, and speed, but also with manner of operation. A fixed-wing aircraft flyover characteristically produces a simple and familiar "haystack" temporal pattern. Fixed-wing aircraft noise increases more or less monotonically as an aircraft flies toward an observer, reaches a peak at about the time that the aircraft is directly overhead, and then monotonically decreases as it flies away from the observer. In areas within a few miles of runway ends, high-speed, fixed-wing aircraft usually follow predictable paths and distribute their noise emissions symmetrically with respect to the flight path.

In contrast, the spatial distribution of helicopter noise is more complex than that of fixed-wing aircraft because of source directivity, dependence of emissions on flight regime, and the operational flexibility of rotary-wing flight. High-speed impulsive (HSI) helicopter noise is concentrated in the plane of the rotor disk and in the direction of forward flight. Blade-vortex interaction (BVI) noise ("blade slap") is also impulsive sounding and is concentrated forward and downward, along the helicopter's flight path. Broadband emissions of rotary-wing aircraft are typically greater on the side of the aircraft with the counter-torque rotor. Helicopters may approach and depart a landing pad at low speeds, and to and from more than one direction. The flexibility of rotary-wing flight also means that the time pattern of helicopter noise intrusions is less predictable than that of fixed-wing aircraft. Helicopters typically operate at lower altitudes than fixed-wing aircraft and can orbit a location on the ground or hover in place for prolonged periods. These flight characteristics can render individual helicopter operations more audible, for longer periods of time, than fixed-wing aircraft overflights in urban ambient noise environments. Further, the low-frequency noise emissions of helicopters can excite more indoor rattle and vibration in residences than fixed-wing aircraft in flight at greater altitudes.

For all of these reasons, helicopter noise is often thought to be more annoying on a per-event basis than fixed-wing aircraft noise of comparable sound level. It is also commonly believed that the repetitive impulsive nature of helicopter noise is its most annoying characteristic. Neither of these interpretations is necessarily correct, nor the complete story. In particular, it remains unclear whether the supposed "excess" annoyance of helicopter noise (vis-à-vis that of fixed-wing aircraft noise) is acoustic or nonacoustic in origin.

1.3 Noise Effects of Concern

1.3.1 Annoyance

The Federal Interagency Committee on Noise (FICON) (1992) considers annoyance an attitude (that is, a covert mental process) as its preferred general indication of adverse aircraft noise impacts. In this context, annoyance is gauged by the self-reporting of opinions in community-wide social surveys, in response to questions such as "While you've been at home over the last (day/week/year), have you been not at all, slightly, moderately, very, or extremely annoyed by aircraft noise?" Schultz (1978) and his successors have produced several quantitative dosage-response relationships to predict the prevalence of a consequential degree of aircraft noise-induced annoyance attributable to cumulative noise exposure. Nearly all of the field studies from which such relationships have been inferred have dealt with annoyance produced by fixed- rather than rotary-wing aircraft operations.

Most dosage-response relationships attempt to predict the prevalence of aircraft noise-induced annoyance in communities from a single independent variable—cumulative noise exposure—as estimated either by direct measurement or by noise modeling. Such relationships account for less than half of the variance in the association between noise exposure and annoyance. Only in recent years has a practical, quantitative method emerged for incorporating an additional variable into predictions of annoyance prevalence rates. As described in Appendix C, the second predictor variable is the sum total of community-specific, *nonacoustic* influences on annoyance.[2]

Even if it is assumed that the annoyance of exposure to noise produced by helicopters is best understood in entirely acoustic terms, a further question remains: is that annoyance produced solely by the airborne acoustic energy that helicopters produce or by secondary emissions (rattling noises and vibration) induced by helicopter noise in residences.

1.3.2 Direct Annoyance of Airborne Noise Created by Helicopters

Figure 1-1 compares three dosage-response relationships between cumulative aircraft noise exposure and the prevalence of aircraft noise-induced annoyance in average communities.

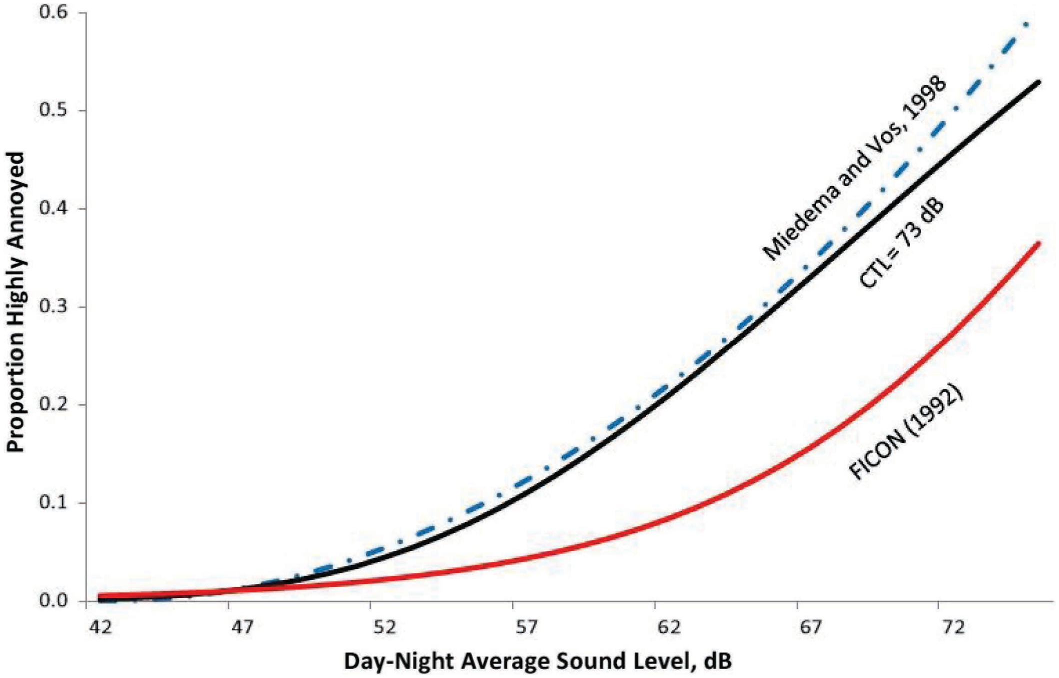


Figure 1-1. Comparison of revised ISO Standard 1996-1 dosage-response curves with earlier FICON curve.

The solid black line, the community tolerance level (CTL) relationship, is the one recommended in the 2016 revision of International Standards Organization (ISO) Standard 1996-1.[3] (Appendix C provides additional detail about the methods described in the latest revision of the ISO Standard.) If helicopter noise is more annoying, decibel-for-decibel, than fixed-wing aircraft noise, the CTL curve seen in Figure 1-1 (developed for fixed-wing aircraft) will be shifted toward the left side of the graph.

Figure 1-2 illustrates a family of dosage-response relationships corresponding to increases in the annoyance of helicopter noise exposure by amounts ranging from 3 to 10 dB. For example, if helicopter noise proves to be 3 dB more annoying than fixed-wing aircraft noise, analyses of survey data may be expected to produce a dosage-response relationship similar to the dashed curve to the left of the one seen in Figure 1-1. Note that the curves in Figure 1-2 differ both in positions on the abscissa, and in their slopes, for reasons discussed in Appendix C. The shapes of the curves are identical no matter where they are horizontally. However, the horizontal position affects the slope of a given curve at a particular dose (i.e., DNL value), and hence the rate at which annoyance grows with increasing dose at that level.

1.3.3 Annoyance Due to Secondary Emissions

The primary structural resonance in conventional wood frame construction for single-family detached dwellings is typically in the 10–25 Hz frequency region, the same frequency region as the fundamental (one per revolution) frequency of the main rotor system of many helicopters. This means that helicopter operations can easily induce noticeable vibration in homes near helipads and flight paths. Even modest levels of structural vibration, which might escape direct notice, can cause lightweight or suspended architectural elements (windows, doors, bric-a-brac on shelves, pictures on walls, crockery in cupboards, HVAC ducts, and other household paraphernalia) to

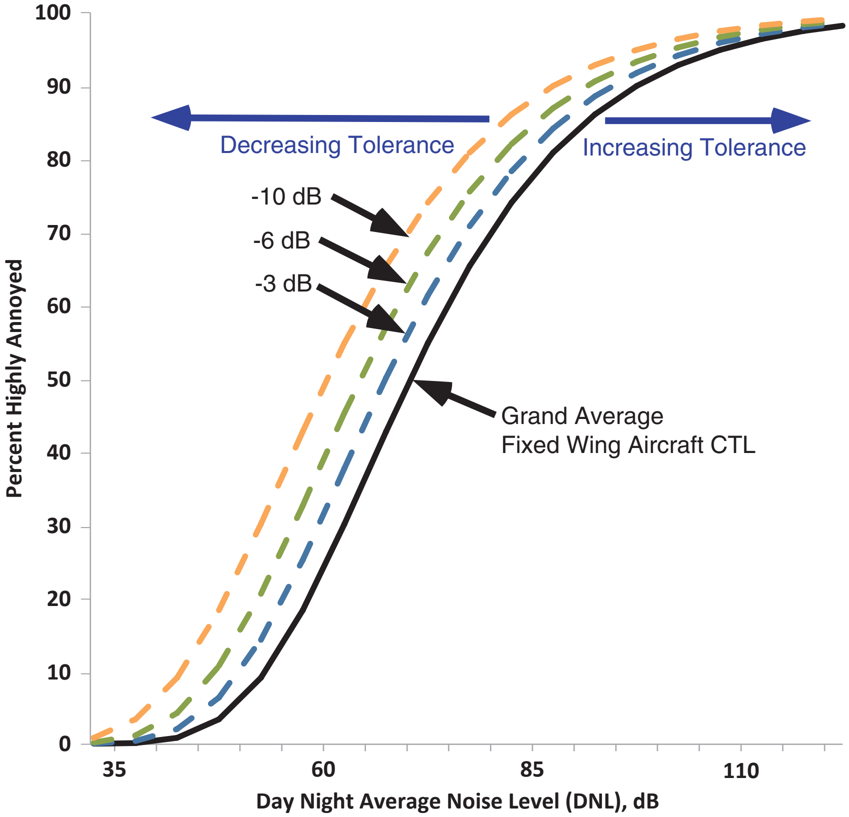


Figure 1-2. Family of hypothetical dosage-response curves for differing levels of community sensitivity.

rattle audibly. Such rattling noises can be annoying in their own right, whether or not accompanied by noticeable vibration, or by audible helicopter noise.

Figure 1-3, adapted from Fidell et al. (2002a), shows a relationship between the prevalence of annoyance due to aircraft noise-induced rattle and a single-event measure of low-frequency noise level. The measure, known as low frequency sound level (LFSL), is the sum of the sound exposure levels in the six one-third octave bands between 25 and 80 Hz.

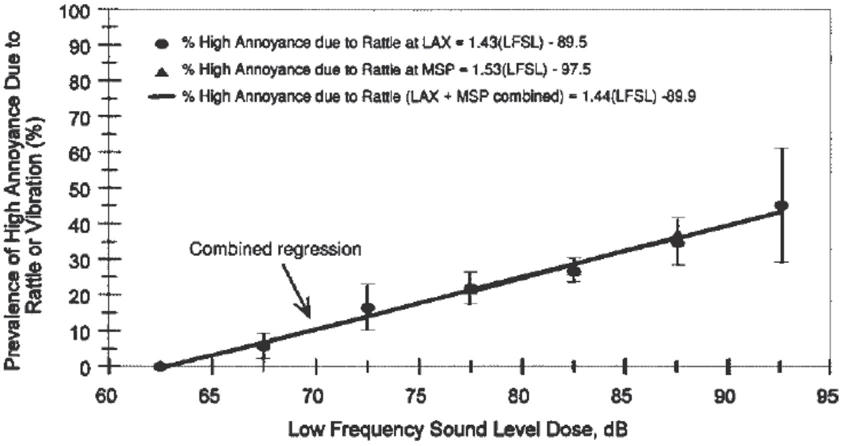


Figure 1-3. Relationship between LFSL and the prevalence of high annoyance with rattle. (Note: the % high annoyance due to rattle at MSP appears at 87.5 dB on the graph.)

1.3.4 Complaints

In July of 2013, the Washington, D.C., Court of Appeals found that helicopter noise could adversely affect a residential population at an A-weighted cumulative noise level more than 20 dB lower than FAA's customary criterion of "significant" noise impact (L_{dn} = 65 dB). The court ruled in Helicopter Association International, Inc. *v*. Federal Aviation Administration, Case No. 12-1335 (C.A. D.C., Jul. 12, 2013) that the FAA was justified in mandating compulsory compliance with an offshore flight route for helicopters,[4] even when the noise created by helicopter operations did not exceed L_{dn} = 45 dB at affected residences. The ruling seems to rely solely on a high number of noise complaints rather than any specific acoustic measure. Complaints, a behavior, are not the same quantity as annoyance, an attitude. A recent study has made some progress in suggesting a potential relation between the behavior and the attitude (Fidell et al. 2012). Note that the referenced study made a clear distinction between numbers of complaints, number of complainers and segregating complainers by numbers of complaints. Except for the most prolific complainers, a common pattern was observed leading to the conclusion that tracking the number of non-prolific complainers *may* provide an indication of community attitudes about noise. This is a topic about which more, and very possibly quite productive, research could be done.

The court's ruling implies an A-weighted difference on the order of 20 dB between the annoyance of helicopter and fixed-wing aircraft noise. Conventional analyses, such as those identified by ISO 1996 and discussed in Appendix C, however, "penalize" helicopter noise by less than 10 dB in an attempt to equalize predictions of the annoyance of rotary- and fixed-wing noise. The order of magnitude difference between the findings of the Court of Appeals and current (acoustically driven) noise impact evaluation methods suggests that metrics sensitive to acoustic factors alone may not be fully capable of predicting community response to helicopter noise.

1.4 Noise Metrics Useful for Quantifying Helicopter Noise

Two frequency weighting networks and families of noise metrics are commonly employed in the U.S. to express sound levels of both fixed- and rotary-wing aircraft. For aircraft noise certification purposes, the FAA has required frequency weighting, called the tone-corrected perceived noise level, abbreviated PNL(T), developed in the 1950s. For predicting and assessing environmental impacts of aircraft noise exposure, the FAA endorses the A-weighting network, developed in the 1930s.[5] Each metric supports a family of single-event and cumulative exposure metrics to deal with exposure that varies from instantaneous through annual time frames.[6]

Concern about noise metrics appropriate for predicting the annoyance of exposure to rotary-wing aircraft noise has peaked several times since the 1950s. As discussed in Appendix B, a 1982 literature review by Molino (1982) compares the findings of 34 earlier analyses of the annoyance of helicopter noise, the earliest of which date to the 1960s (cf. Crosse et al. 1960, Niese 1961, Robinson et al. 1961, and Pearsons 1967). The findings of these early studies are neither consistent nor definitive. These and other studies (e.g., Powell, 1981) do not fully support Molino's conclusion that there is "no need to measure helicopter noise any differently from other aircraft noise."

The common belief that rotary-wing aircraft noise causes more annoyance on a decibel-for-decibel basis than fixed-wing aircraft noise has led to the practice of imposing decibel-denominated "penalties" on A-weighted (but not PNL-weighted) measures of helicopter noise for purposes of assessing environmental impacts of helicopter noise. This may be an expedient way of accommodating the supposed excess annoyance of helicopter noise, but is not necessarily the most systematic or defensible way.

The tactic of assigning penalties treats the assumed excess of annoyance of helicopter noise as a simple problem of measurement, while ignoring the underlying causes of the supposed excess annoyance. Since the evidence supporting the assumption of excess annoyance is not definitive, the issue may not simply be one of physical measurement, however. The supposed excess could be attributable to operational factors (the characteristic shorter slant ranges and relatively longer duration of helicopter operations *vis-à-vis* fixed-wing aircraft operations) rather than inherent differences in noise-induced annoyance. The supposed excess could also be attributable to entirely nonacoustic factors. Although a good deal has been learned since Molino's 1982 review about the mechanisms that generate rotary-wing aircraft noise in different flight regimes, it is only recently that systematic means have become available to focus more closely on potential nonacoustic factors that influence annoyance judgments (Appendix C provides greater detail about these means).

To the extent that excess annoyance of helicopter noise is attributable to the annoyance of rattle and vibration (to which A-weighted noise metrics are insensitive), A-weighted noise metrics are unlikely to adequately predict the overall annoyance of helicopter overflights of residential populations, if the helicopter noise has strong low-frequency components as is the case for heavy military aircraft.

1.5 Nonacoustic Contributions to Community Reaction to Helicopter Noise

FAA (2004) summarized many operational, situational, and other nonacoustic factors that contribute to adverse community response to helicopter noise. These include low flight altitudes; long hover durations; times, numbers, and frequencies of operations; fear of crashes; and attitudes of misfeasance and malfeasance. Most of these factors similarly affect the annoyance of fixed-wing aircraft, but to lesser degrees. Perceptions of the necessity for flight operations can differ greatly for a range of rotary-wing missions. The necessity of medical evacuation, search and rescue, law enforcement, firefighting, and some heavy lift construction missions is widely acknowledged. The necessity for other rotary-wing flight operations is less apparent.

For example, large fixed-wing aircraft are self-evidently the most efficient mode of public transportation for regularly scheduled, long-haul carriage of hundreds of passengers per flight. As such, their necessity is generally taken for granted. In contrast, short-haul private transportation of individuals by helicopter is widely viewed as a luxurious choice (or "a rich man's toy," in the words of FAA's 2004 Report to Congress) rather than a practical necessity. Similarly, the limited ground visibility from fixed-wing airplanes and high flight speeds and altitudes pose little threat to domestic privacy. Helicopters hovering over residences are a different matter. Few would consider long duration hovering to permit paparazzi to photograph private events to be truly necessary.

Likewise, fixed-wing aircraft in the vicinity of airports necessarily approach and depart runways on flight paths corresponding to runway alignments. The motivation and necessity for non-emergency (e.g., air tour), small rotorcraft operations are not as apparent. Given their flexibility of flight, why must helicopters approach a particular house so closely on their way to and from landing pads? Why must multiple news gathering helicopters orbit the same traffic accident?

1.6 Laboratory Versus Field Studies of Helicopter Annoyance

Studies of the annoyance of rotary-wing aircraft noise have been conducted under both laboratory and field conditions. Laboratory studies offer greater precision of control over listening conditions than field studies, but lack the residential context of field studies. It is also difficult to accurately reproduce recorded or helicopter-like synthetic sounds under laboratory conditions while also preserving crest factor (ratio of peak value to average value of sound wave—important with impulsive noise), phase relationships (whether two sound waves are synchronized or shifted in time), low frequency, and other dynamics of rotorcraft noise emissions. On the other hand, while field studies provide the appropriate residential context for annoyance judgments, they lack the precision of control over acoustic conditions of laboratory studies.

It follows that questions about potential nonacoustic influences on the "excess" annoyance of helicopter noise are not readily answered in laboratory studies and that questions about the detailed acoustic origin of excess annoyance are not readily answered in field settings.

1.7 Summary of Findings of Literature Review

This literature review was conducted to identify pragmatically useful—that is, testable and relevant—hypotheses about the origins of annoyance with exposure to helicopter noise as a preliminary aid to the design of subsequent field research. The current review, as well as prior literature reviews such as those conducted by Molino (1982), Ollerhead (1985), and FAA (2004) document research undertaken in the last half-century to quantify and predict the individual and community annoyance of rotary-wing aircraft noise.

Whether conducted under laboratory or field conditions, much of this research was intended, directly or indirectly, to inform decisions about aircraft noise regulatory policy. Understandably, the early research sought out low-hanging fruit: "magic bullet" noise metrics; non-systematic (*ad hoc*, regression-based) dosage-response relationships; evidence that demographic and socio-economic factors could account for non-trivial amounts of variance in a predictively useful manner, and so on. The reviewed literature provided little systematic, rigorous, or theory-based understanding of the annoyance of helicopter noise.

Given what has been learned over the decades, some of the earlier exploratory research goals, hypotheses tested, study designs, and analysis approaches are not as relevant or appropriate today as they once may have been. For example, individual-level analyses intended to identify covariates that might arguably improve prediction of helicopter annoyance prevalence rates are now outdated. Individual differences such as demographic (sex, age, gender, nationality, etc.) account for relatively little variance in the relationship between noise exposure and annoyance, and are of little practical regulatory utility. Attitudinal differences (fear, suspected malfeasance, sense of necessity, etc.) as measured on a community-wide basis have significant effects on annoyance. Systematic means have recently become available for efficiently taking into consideration the net effects, rather than individual influences, of all of the nonacoustic factors that may affect the annoyance of helicopter noise exposure.

The findings of individual studies on the annoyance of helicopter noise disagree about as often as they agree. The main point of agreement in the technical literature is that helicopter noise is much more variable and complex than fixed-wing aircraft noise. This variability and complexity make it more difficult to accurately and credibly model helicopter noise exposure (other than under idealized conditions[7]), particularly in the vicinity of helipads. It follows, in turn, that predictions of the prevalence of annoyance of exposure to helicopter noise are likely to be more uncertain than predictions of the annoyance of exposure to fixed-wing aircraft noise.

A main point of disagreement is the degree to which main rotor impulsive noise controls the annoyance of helicopter noise. Many believe that impulsiveness "corrections" are appropriate for predicting the annoyance of exposure to helicopter noise; others believe that conventional A-weighted noise measurements suffice for predicting the annoyance of helicopter noise.

Table 1-1 summarizes the laboratory (controlled listening) and field (social survey) evidence for and against hypotheses about the origins of the supposed excess annoyance of helicopter noise. (Annotation is provided in Appendix B for only some of the cited sources.) The empty cells in Table 1-1 reflect the incomplete nature of understanding of the origins of annoyance with helicopter noise.

Some of the implications of the findings of this literature review for the design of field studies include the following:

- Neighborhood opinions about the annoyance of helicopter noise and fixed-wing aircraft noise exposure are likely to differ for nonacoustic reasons. Unless analytic means are employed to account for such community-specific differences, it may not be possible to reliably identify differences in opinions about fixed- and rotary-wing annoyance per se.

Table 1-1. Evidence relevant to hypotheses about the annoyance of rotary-wing noise exposure.

HYPOTHESIS	EVIDENCE OR ASSERTION CONSISTENT WITH HYPOTHESIS	MARGINAL OR INCONCLUSIVE EVIDENCE OR ASSERTION	EVIDENCE INCONSISTENT WITH HYPOTHESIS
Decibel for decibel, rotary-wing aircraft noise is more annoying than fixed-wing aircraft noise	No reliable, large-scale comparisons reported in peer-reviewed field studies	More (2011); several other controlled-listening tests, which may not have controlled for confounding factors; tone-corrected effective perceived noise level [EPNL(T)] is a less consistent predictor of annoyance for rotary- than fixed-wing aircraft noise (Ollerhead 1982)	Ollerhead, 1982 (2 dB average effect in effective perceived noise level, in direction opposite to predicted direction)
Main rotor impulsive noise controls the annoyance of helicopter noise (and hence requires an impulsive noise "correction" to A-weighted measurements)	Sternfeld and Doyle (1978); Man-Acoustics & Noise, Inc. (1976); Lawton (1976); Wright and Damongeot (1977); Galanter et al. (1977); Klump and Schmidt (1978)	Fields and Powell (1987) (weak evidence at best); More (2011); Schomer and Wagner (1996); Magliozzi et al. (1975); Munch and King (1974)	Patterson et al. 1977; Powell 1981; Ollerhead 1982—also ICAO, 1981 [no impulse correction needed for EPNL(T); effect of impulsiveness is confounded with level and duration]; Passchier-Vermeer, 1994; Ohshima and Yamada, 1993; Gjestland, 1994; Bisio et al., 1999
A-weighted noise measurements are inadequate for predicting the annoyance of rotary-wing aircraft noise	Patterson et al. (1977); Schomer et al. (1991); Schomer and Neathammer (1987); Sternfeld et al. (1995); Edwards, (2002); Ollerhead (1982)	More (2011)	Molino, 1982
The annoyance of helicopter noise is strongly influenced by nonacoustic factors	Leverton (2014); Ollerhead (1982); FAA (2004); Atkins et al. (1983)		
Situational and operational factors account for much of the annoyance of helicopter noise	Ollerhead and Jones (1994); FAA (2004) Anecdotal evidence from popular press		
Cumulative noise metrics usefully predict the annoyance of exposure to helicopter noise	Fields and Powell (1987) ("broad consistency"); Atkins et al. (1983)		
Secondary emissions (rattle) induced by helicopter noise strongly influence its annoyance	Schomer and Neathammer (1987)		
The annoyance of helicopter noise is strongly influenced by its noticeability rather than its level per se	Schomer and Wagner (1996)		
Annoyance is better predicted by time-integrated proximity to flight tracks than by acoustic measures			

- The flexibility of low-speed, rotary-wing flight lends itself to much more complex flight paths than those of fixed-wing aircraft. These complex flight paths cause the helicopter to accelerate/decelerate along the flight path and can dramatically change blade vortex interaction (BVI) impulsive noise level. The directivity of helicopter noise emissions further complicates noise exposure predictions based on flight tracks alone. Selecting sites with comprehensive flight track radar coverage and using sections of level flight rather than climbing and descending segments, the aircraft performance information will aid prediction, measurement, and interpretation of helicopter noise exposure, minimizing the uncertainty of the dosage portion of the dosage-response analysis. In other words, differences of as little as 2 or 3 dB between the annoyance of rotary- and fixed-wing aircraft may be difficult to discern on the basis of social surveys undertaken in a limited number of communities.
- Extensive efforts to confirm the utility of impulsive noise adjustments have yielded contradictory and inconclusive results.
- Correlation analyses have shown that most of the noise metrics commonly used to quantify helicopter noise are so highly correlated with one another that no one metric differs meaningfully from others in its ability to predict the prevalence of annoyance of helicopter noise (Mestre et al. 2011).
- Operational factors can also affect the annoyance of helicopter noise, but their effects may or may not be accounted for by integrated energy noise metrics.
- Questions about potential nonacoustic influences on the "excess" annoyance of helicopter noise are not readily answered in laboratory studies, while questions about the detailed acoustic origin of excess annoyance are not readily answered in field settings.

CHAPTER 2

Development of Hypotheses

2.1 Introduction

The literature review contained in Appendix B, and described in Chapter 1, identified hypotheses about the absolute and relative annoyances of fixed- and rotary-wing aircraft and examined the published evidence in favor of and contrary to the various hypotheses. Much of the historical evidence about these hypotheses proved to be either contradictory or ambiguous. As a practical matter, the hypotheses may be expressed in terms of the ability of various factors to explain variance in the relationship between helicopter noise exposure and the prevalence of a consequential degree of annoyance in communities. The nine hypotheses described in Table 1-1 were summarized and restated in seven hypotheses that were tested in this study. The nonacoustic hypotheses (general nonacoustic, noticeability, and situational awareness) were combined into one, and A-weighted and cumulative hypotheses were considered in combination.

Loosely stated in simplified form, the hypotheses are:

1. The prevalence of annoyance due to helicopter noise in a community is greater than that associated with comparable levels of exposure to noise produced by fixed-wing aircraft;
2. The prevalence of annoyance due to helicopter noise is most appropriately predicted in units of A-weighted cumulative exposure;
3. The prevalence of annoyance due to helicopter noise is strongly influenced by its impulsive character, and thus requires an impulsiveness “correction” to A-weighted cumulative exposure (cumulative helicopter noise exposure corrections may be different for different helicopters at different exposure points on the ground);
4. The prevalence of annoyance due to helicopter noise is strongly influenced by indoor secondary emissions (rattle and vibration) due to its low-frequency content;
5. The prevalence of annoyance due to helicopter noise is appreciably influenced by nonacoustic factors;
6. The prevalence of annoyance due to helicopter noise is appreciably influenced by proximity to helicopter flight paths; and
7. Complaints lodged about helicopter noise are more reliable predictors of the prevalence of annoyance than measures of exposure to helicopter noise or proximity to helicopter flight paths.

The following sections describe some of the factors that complicate the testing of these hypotheses. These issues are discussed next in considerable detail, including the nature and relative amounts of exposure to fixed- and rotary-wing aircraft noise, population and sample size requirements, methods for quantifying nonacoustic influences on annoyance, magnitudes of expected effects, site selection criteria, and content and method of questionnaire administration.

2.2 Factors Complicating Hypothesis Testing

Both general and site-specific factors complicate hypothesis testing and interpretations of social survey findings. For example, some of the hypotheses are not mutually exclusive. It is possible that an impulsiveness correction may improve the ability of A-weighted measurements to predict the prevalence of annoyance created by helicopters, at least in flight regimes that produce conspicuous blade slap. It is also possible, however, that audible blade slap, rattle, and vibration are sufficiently correlated with one another that any of these factors could provide equally plausible explanations. Likewise, simple proximity to helicopter flight paths is highly correlated with most measures of noise exposure, even if the predominant cause of annoyance (e.g., fear of a crash) is not necessarily audible airborne sound.

In the abstract, the field research techniques that can produce evidence in favor or contrary to these hypotheses are clear. Opinion surveys can be conducted with representative samples of people in neighborhoods exposed to varying amounts of helicopter (and potentially fixed-wing) noise. Field measurements of aircraft noise exposure can be made prior to and during the interviewing process, in areas with large residential populations living within geographically distinct areas with well-defined boundaries with homogenous exposure to noise produced by similar amounts of rotary- and fixed-wing aircraft operations, little seasonal variability, and a wide range of aircraft types and exposure levels.

Many factors can reduce the reliability and generalizability of social survey findings, compromise the ability to make confirming field measurements of actual noise exposure, increase interviewing costs, or make it difficult to delineate geographic areas eligible for interview. The following are among the factors that complicate or even preclude conduct of a social survey of relative reactions to fixed- and rotary-wing noise exposure at any site:

- Geographic disparities between areas with high helicopter noise exposure and areas with sufficiently large residential populations;
- Greatly disparate amounts of noise exposure due to fixed- and rotary-wing aircraft operations;
- Narrow ranges of exposure levels created by helicopter noise[8];
- Small numbers of operations in particular flight modes (cruise, hover, rapid ascent and/or descent, taxiing, etc.);
- Insufficient numbers of respondents to yield a sample large enough to document small differences in annoyance prevalence rates;
- Unavailability of reliable radar/transponder information about actual rotorcraft flight paths;
- Unreliability of noise modeling due to variability, complexity, seasonality, or sketchy knowledge of operations;
- Excessively high ambient neighborhood noise levels;
- Unavailability of complaint records; and
- Large proportions of non-English speaking residents (for reasons of cost).

The consequence of all of these complications is that few sites are likely to be appropriate for testing all hypotheses. In particular, it may not be possible to test many of the other hypotheses if priority in site selection is given to a direct test of the basic hypothesis that helicopter noise is more annoying than fixed-wing aircraft noise. A major goal of site selection is to identify a set of sites that allows testing for as many hypotheses as feasible.

2.3 Some General Constraints on Hypothesis Testing

2.3.1 Geographic Disparities Between Areas with High Helicopter Noise Exposure and Areas with Sufficiently Large Residential Populations

Helicopter noise exposure levels are generally greatest in geographic areas near terminal operating areas and in close proximity to flight routes. Good land use and flight route planning tend to minimize residential populations in such areas. Thus, to avoid overflights of residential areas, helipads are often located near shorelines, and approach and departure routes to them often overfly bodies of water rather than residential neighborhoods. Heliports are also often located in commercial and industrial areas with relatively few residences as well as in very high-density business districts with elevated ambient noise levels and urban canyons.

The net effect of good planning practice is to minimize the exposure of residential areas with low ambient noise levels to very high levels of helicopter noise exposure. This, in turn, makes it difficult to identify interviewing sites in which opinions about effects of high levels of helicopter noise can be solicited from suitably large numbers of households.

2.3.2 Disparate Exposures to Fixed- and Rotary-Wing Aircraft Operations

Areas of high exposure to fixed-wing aircraft noise are concentrated around runway ends and in approach and departure corridors along extended runway centerlines. For air traffic safety reasons, these are precisely the areas from which helicopter operations are excluded. It was difficult to locate interviewing sites with high levels of exposure to *both* fixed- and rotary-wing aircraft noise.

It may be less difficult to locate residential areas exposed to intermediate or low levels of both types of aircraft noise, but these are unlikely to be areas in which the greatest differences in the annoyance of rotary- and fixed-wing aircraft noise are likely to be observed. Smaller differences between the annoyance of the two types of aircraft noise require larger sample sizes to discern, and hence, larger residential populations from which to draw such samples.

By definition, the areal extents of low-density residential areas (i.e., those with low outdoor ambient noise levels) are greater than those of high-population density areas. Aircraft noise levels across these greater areas are likely to vary considerably, perhaps by ± 10 dB or more.[9] In turn, this implies that sub-populations in low-population density areas with similar noise exposure levels may be quite small. It may therefore be impractical to stratify samples in low-population density areas into geographic zones within narrow exposure ranges (say, ± 1.5 dB).

If it is not possible to identify large enough sample strata with reasonably homogeneous noise exposure that span a wide enough exposure range, it will be necessary to model exposure levels of individual survey respondents. Because nominal integrated noise model (INM) flight tracks are often assumption-based rather than empirical, credible inferences of helicopter noise exposure levels may be limited to those at sites for which high-quality radar data are available. In practice, this may restrict interviewing sites to those near major airports with good radar coverage. INM was used because the study began before the Aviation Environmental Design Tool (AEDT) was released. INM Version 7.0d and AEDT Version 2b make identical noise predictions in any event.

2.3.3 Narrow Ranges of Exposure Levels Created by Helicopter Noise and/or Small Numbers of Operations in Particular Flight Modes

A narrow range in exposure levels within a given community implies that the *shape* of the dosage-response curve cannot be well defined empirically, regardless of the number of respondents.[10] While the findings of this study will be analyzed in part with respect to a fixed-shape dosage-response curve that translates laterally depending on local community tolerance to aircraft noise sources, it is highly desirable to verify the fixed-shape assumption within communities. A narrow exposure range can preclude this possibility.

Furthermore, helicopter sound level emissions can differ markedly between flight modes (in addition to differences in helicopter types). These flight modes can change rapidly along a flight corridor. For example, if a helicopter is descending rapidly, then the BVI may create significant amounts of blade slap, which can affect both its A-weighted sound level as well as any impulsiveness adjustments. On the other hand, if the aircraft goes into a very shallow decent or level flight, blade slap can cease very quickly. Consistency of operation along any given flight corridor would benefit site selection, but such consistency cannot be expected from one flight to the next at sites with differing types of helicopters and modes of operation. Of greatest concern is the ability to estimate when high sound level modes of operation occur, since even a small percentage of high sound level events may control annoyance responses.

2.3.4 Unavailability of Reliable Radar Flight Performance Information About Actual Rotorcraft Flight Paths and Procedures

Reliable radar information is essential for modeling noise levels over the interviewing area. Helicopters almost always operate as visual flight rules (VFR) flights, and hence do not usually file flight plans or transmit a unique transponder code. Helicopter radar tracks must therefore be distinguished from fixed-wing aircraft radar tracks based on unique level flight segments at low altitude, origin or destination at specific heliport locations, or tracks within a known and exclusive helicopter corridor.

A test program is in progress in Los Angeles in which VFR helicopter flights will not use 1200 as their squawk code, but will be assigned unique helicopter codes. This simplifies identification of helicopter tracks. Radar data is a regularly acquired data set at airports with modern airport noise monitoring systems. It is also possible to obtain radar data from FAA. Radar data will be available only within reasonable distances of aircraft surveillance radar (ASR) sites that will be located near airports, and for which no terrain or building obstructions intervene between the ASR sensor and the helicopter paths. Because helicopter tracks are lower and farther from the airport than those of fixed-wing aircraft, this may limit survey sites to those near (within 20 nm and without obstructions) ASR sites. Although helicopter tracks can be distinguished from fixed-wing aircraft tracks by speed, the study sites selected all had programs in place for unique helicopter squawk codes. As noted later, LAS and DCA also assign unique call signs to helicopters.

2.3.5 Questionable Reliability of Noise Modeling Due to Operational Variability, Complexity, Seasonality, or Sketchy Knowledge of Operations

INM-based noise modeling for civil airports is conventionally conducted on an “average annual day” basis. If helicopter flight activity at a potential interviewing site is concentrated in one season of the year, but interviewing is conducted in a different season, standard noise modeling contours may not work well for stratifying samples by noise exposure. Such noise modeling errors could bias observed dosage-response relationships. Likewise, as with any model, generalizations and simplifications are made regarding flight paths.

Noise modeling at the block or individual residence level is preferable for estimating respondents’ noise doses. The modeling procedure can also be adjusted to reflect sound level measurements made at various sites within the interviewing area. Hence, the combined uncertainty in both measurements and modeling will be reflected in the computed doses. Dose uncertainty is ultimately determined by the less reliable form of estimation, whether measurement or modeling. Selection of interviewing sites should be based in part on the complexity of operations to estimate the size of a difference in exposure that can be attributed to aircraft type. All of these considerations underscore the need to measure, model, and ask attitudinal questions about identical time frames to maximize the strength of association between dose and response.

2.3.6 Excessively High Ambient Neighborhood Noise Levels

Excessively high ambient sound levels in the vicinity of heliports pose several complications for present purposes. In extreme cases, such as heliports in very high population density areas, or in areas with high levels of highway traffic noise, extraneous noise sources may mask the noise of some helicopter operations. High ambient noise levels also complicate estimation of individual noise event levels, and thus may influence differing attitudes toward aircraft noise in urban, suburban and rural areas. Since low-frequency noise level measurements are susceptible to large pseudo-noise artifacts in windy conditions (such as wind interacting with the microphone), one criterion for survey site selection may be typical wind speeds. Areas expected to have high wind speeds and high turbulence levels were avoided. Nonetheless, two unseasonable weather fronts moved through Long Beach during the field data collection period.

2.3.7 Unavailability of Complaint Records

Many airports collect detailed complaint records. This may not be true at all heliports. Availability of complaint records was considered in site selection.

2.3.8 Large Proportions of Residents Ineligible or Unavailable for Interview

Unless the expense of translating the survey instrument (questionnaire) into other languages is affordable, response rates may be low in areas with large proportions of non-English speakers. A highly transient population (for example, of students, as in the vicinity of a helicopter-served hospital or at a major university) can also be difficult to contact.

2.4 Discussion of Potential Tests of Hypotheses

Several of the hypotheses summarized in Table 1-1 can be tested via analyses of responses to individual questionnaire items about the annoyance of aircraft noise. Several other hypotheses are testable by comparing responses across sites chosen for the present study, or by less direct means described below. The suggested form of closed response category annoyance items is:

> "While you've been at home during (*time period of interest*), have you been bothered or annoyed by (*noise source*)?"

and if yes,

> "Would you say that you've been slightly, moderately, very, or extremely annoyed by aircraft noise while you've been at home during (*time period of interest*)?"

The time period of interest can be either (or both) the week prior to interview—during which extensive empirical noise measurements were made at field sites—or the year prior to interview, over which exposure estimates may be made from modeling of annual average day exposure.

Hypothesis 1: Decibel for decibel, rotary-wing aircraft noise is more annoying than fixed-wing aircraft noise.

The most basic of the hypotheses holds that exposure to noise produced by rotary-wing aircraft is more annoying than exposure to an equivalent amount of noise produced by fixed-wing aircraft. The hypothesis does not specify *why* one type of aircraft noise may be more annoying than another—for example, because of spectral differences in emissions, indoor vibration or rattle excited by rotary-wing aircraft, greater noticeability of helicopter noise in some ambient noise environments, and so forth. Thus, even if the hypothesis can be empirically confirmed, it would not necessarily yield enough understanding to be useful for improved explanatory, regulatory, or policy purposes.

As discussed in Section 1.2 in general terms, and Appendix A in greater detail, the complex and varied nature of rotary-wing operations can make it difficult to fully test this hypothesis. Helicopter noise may vary relatively little from fixed-wing aircraft noise at some locations and in some flight regimes (e.g., at off-track, long-range, sideline locations during straight and level cruise) but can vary greatly from that of fixed-wing aircraft in other flight regimes (e.g., in duration, level, audibility, predictability, and impulsiveness during low-altitude maneuvering). The most useful tests of this hypothesis must be able to characterize not just exposure levels, but also the nature of helicopter noise emissions. It may be necessary to test this hypothesis at more than one site, since no one site may include all of the helicopter flight regimes of potential interest.

The most direct test of this hypothesis would compare the annoyance judgments of the same interview respondents to very similar levels of fixed- and rotary-wing aircraft noise. If it is possible to conduct interviews at sites with sufficient numbers of respondents who are exposed to comparable levels of fixed- and rotary-wing aircraft noise, the general form of questionnaire items that could test this hypothesis would be:

> "While you were at home last week, did helicopter noise bother or annoy you?"
>
> "Would you say you were not at all, slightly, moderately, very, or extremely annoyed by noise from helicopters while you were at home last week?"
>
> "While you were at home last week, did noise from aircraft *other* than helicopters bother or annoy you?"
>
> "Would you say you were not at all, slightly, moderately, very, or extremely annoyed by noise from aircraft other than helicopters while you were at home last week?"

It could also be helpful to include a questionnaire item seeking a direct comparison of the annoyance of fixed- and rotary-wing aircraft noise, of the general form as follows:

> "While you were at home last week, were you annoyed more greatly by noise made by helicopters or noise made by other types of aircraft?"

As noted earlier, it may not be possible to identify sites at which sufficient numbers of eligible respondents are exposed to similar amounts of *both* forms of aircraft noise. A less direct test of the hypothesis is still possible if this should prove to be the case. The opinions of respondents about helicopter noise could be compared with the opinions about fixed-wing aircraft noise of 75,000 respondents to prior surveys about the annoyance of aircraft noise (Fidell et al. 2011). Annoyance prevalence rates measured in the planned study could then be compared with previously measured annoyance prevalence rates at as many as hundreds of sites with similar noise exposure levels at which respondents had been queried about their annoyance with exposure to fixed-wing aircraft noise.

Hypothesis 2: The prevalence of annoyance due to rotary-wing noise is most appropriately predicted in units of A-weighted cumulative exposure.

No specific questionnaire items are required to test this hypothesis. The utility of the A-weighting network for predicting the annoyance of helicopter noise can be gauged instead via simple calculations of variance accounted for in the relationship between various measures of noise exposure and the prevalence of a consequential degree of annoyance at interviewing sites. All that is required is that noise measurements accompanying interviewing be conducted in such a manner that alternative frequency weightings and other adjustments can be calculated. This can be accomplished by capturing raw acoustic waveforms and post-processing them with reference to radar-confirmed helicopter flight operations.

As in the case of testing Hypothesis 1, a fully generalizable test of Hypothesis 2 requires both social and acoustic measurements of helicopter noise produced in varying flight regimes.

Hypotheses 3 and 4: Main rotor impulsive noise controls the annoyance of helicopter noise (and hence requires an impulsive noise "correction" to A-weighted measurements); the prevalence of annoyance due to helicopter noise is strongly influenced by indoor secondary emissions (rattle and vibration) due to its low-frequency content.

Hypotheses 3 and 4 are most appropriately tested at sites exposed to considerable amounts of BVI (or "blade slap") noise. Due to the highly directional nature of blade slap noise, this constraint may limit testing of these hypotheses to sites exposed to landing noise in the immediate vicinity of helipads, or to cruise noise in the direction of flight and directly beneath helicopter flight paths.

Questionnaire items of interest for testing Hypothesis 3 require a "yes" response to a prior question about annoyance with helicopter noise.[11] Respondents who report some degree of annoyance with helicopter noise can then be asked questions of the form:

> "Have you been not at all, slightly, moderately, very, or extremely annoyed by repeated pounding or slapping noises made by helicopter rotors?"
>
> "Have you been not at all, slightly, moderately, very, or extremely annoyed by droning noises made by helicopters?"
>
> "Have you been slightly, moderately, very, or extremely annoyed by whining noises made by helicopters?"
>
> "What sort of helicopter noise annoys you most?"

Questionnaire items of interest for testing Hypothesis 4 also require a "yes" response to a prior question about annoyance with helicopter noise. Respondents who express some degree of annoyance with helicopter noise can then be asked previously tested (Fidell et al., 1999, 2002a) questions of the form:

> "Do helicopters make vibrations or rattling sounds in your home?"
>
> "Are you bothered or annoyed by these vibrations or rattling sounds in your home?"
>
> "Would you say that you are slightly annoyed, moderately annoyed, very annoyed, or extremely annoyed by vibrations or rattling sounds in your home?"
>
> "About how often do you notice vibrations or rattling sounds in your home made by helicopters?"

Hypothesis 5: The prevalence of annoyance due to helicopter noise is heavily influenced by nonacoustic factors.

The most direct test of this hypothesis would require soliciting annoyance judgments from respondents in two or more communities with very similar helicopter noise exposure but very different tolerances for helicopter noise. It is not yet apparent whether such pairs of communities can be found.

An alternative test of this hypothesis could be conducted, however, with reference to the database of observations of annoyance prevalence rates for fixed-wing aircraft in more than 500 communities worldwide. The survey instrument itself would not need any items other than the customary ones described in the discussion of Hypothesis 1.

Hypothesis 6: The prevalence of annoyance due to helicopter noise is heavily influenced by proximity to helicopter flight paths.

This hypothesis is most readily tested at sites along well-defined and heavily trafficked helicopter routes. Geographic information system (GIS) methods can be used to estimate how long helicopters flew within varying distances of respondents' homes over the course of the week prior to interview. Since proximity to flight paths and noise exposure levels are highly correlated, it would be necessary to conduct ancillary GIS-based analyses of complaint rates to distinguish between exposure and proximity as determinants of annoyance and complaints, such as those described below.

Figure 2-1 and Figure 2-2 show spatial complaint densities in the vicinity of Seattle-Tacoma International Airport (SEA) before and after the opening of a new runway. Both the numbers and westward shift of complaints are consistent with a small but abrupt shift in aircraft noise

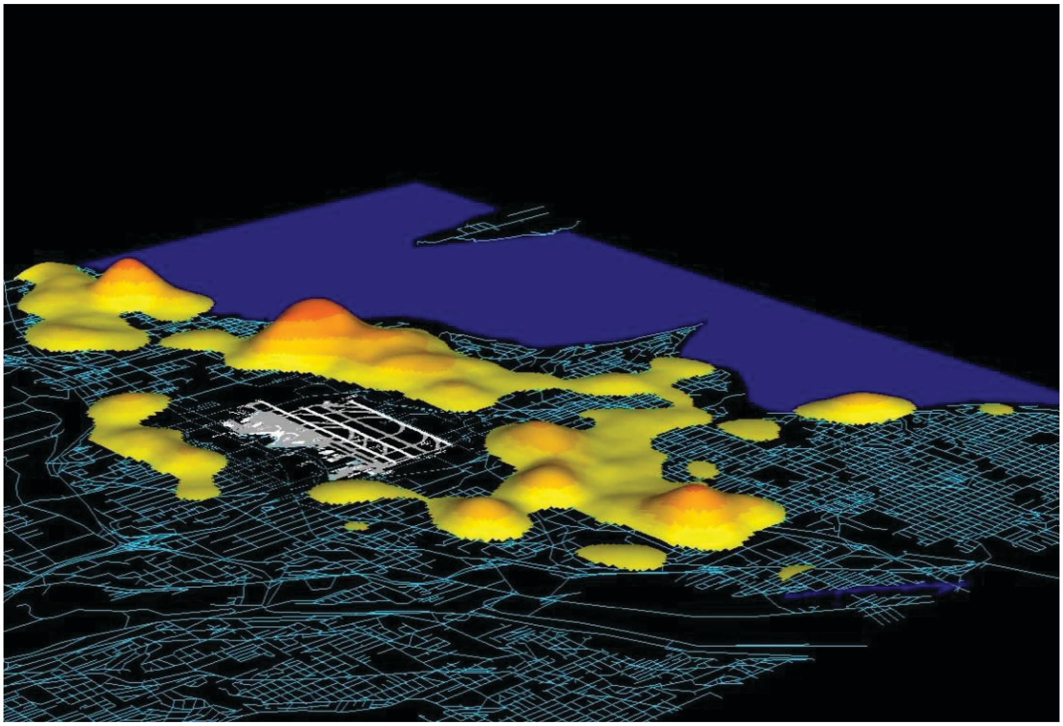


Figure 2-1. Three-dimensional spatial density representation (viewed obliquely) of complaints in 12 months prior to the start of operations on third runway.

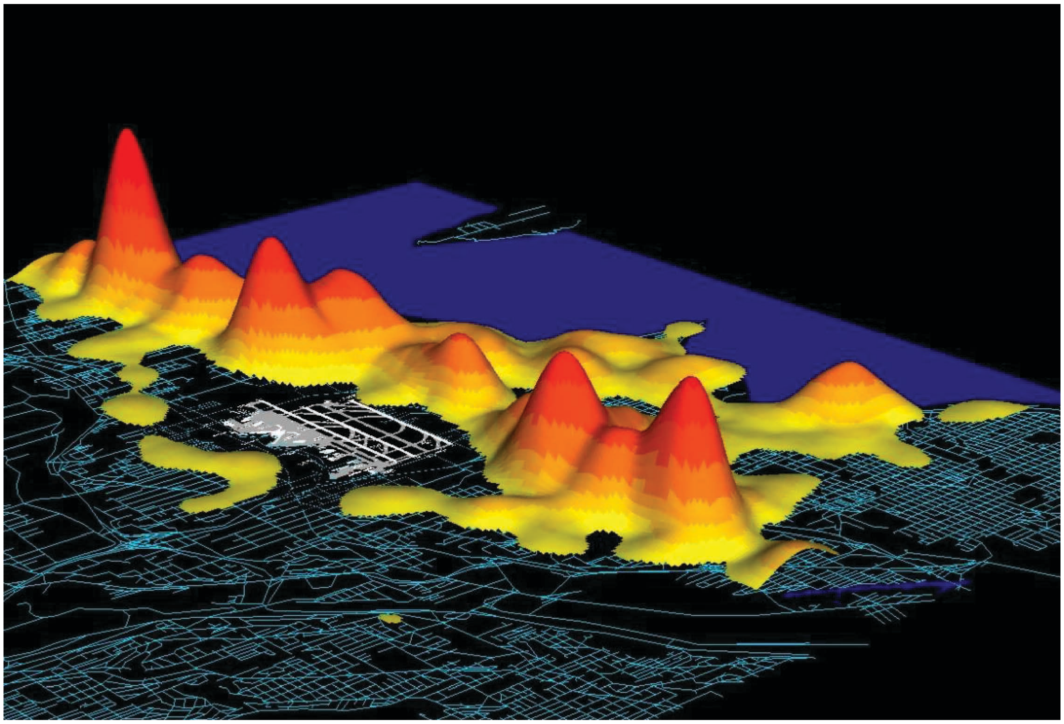


Figure 2-2. Three-dimensional spatial density representation (viewed obliquely) of complaints in 12 months following the start of operations on third runway.

exposure levels in the immediate vicinity of the airport. Actual changes in the geographic distribution of complaints were closely contained in the vicinity of changes in flight paths associated with the runway opening. The actual change in DNL was minor. Even though the change received widespread media coverage, the pattern of changes in complaints could not be attributed to the media coverage per se. Rather than reflecting a community-wide response to media coverage, the changes in spatial density of complaints were limited to the vicinity of changed flight tracks.

Hypothesis 7: Complaints lodged about helicopter noise are more reliable predictors of the prevalence of annoyance than measures of exposure to helicopter noise or proximity to helicopter flight paths.

One or more questionnaire items inquiring whether social survey respondents had lodged single or multiple complaints about helicopter noise might be a useful predictor of the prevalence of annoyance with helicopter noise. It is conceivable that responses to such items might predict actual annoyance prevalence rates as well as measures of exposure, per se, or measures of proximity to helicopter flight paths.

If access is available to helicopter noise complaints at airports with appreciable numbers of helicopter operations, it might be possible to compare empirical measurements of annoyance prevalence rates with total numbers of complaints and numbers of complaints per complainant, in the manner described by Fidell et al. (2012). The latter reference demonstrated that the number of complaints per complainant at half a dozen airports closely followed a power law relationship known as Zipf's Law.

CHAPTER 3

Site Selection and Opinion Survey Methods

3.1 Introduction

This chapter describes site selection and measurement methods. Section 3.2 discusses the survey site selection process. Criteria used to assess the suitability of survey sites are presented along with the sites considered and a recommendation for survey sites for the study. Section 3.3 describes the questionnaire along with discussions of its form and organization as well as of interviewing methods.

Section 3.4 is a general discussion of the role of sample size in social survey design. Noise measurement methods are described in Section 3.7, along with specific discussion of sample size concerns.

3.2 Survey Site Evaluation

3.2.1 Overview of Survey Site Selection Process

Survey site selection is complicated by the fact that there is no such thing as generic "helicopter noise." Acoustic emissions of helicopters vary much more with flight regime than do those of fixed-wing aircraft. Sites exposed to sideline noise from straight and level flight have considerably different acoustical experiences than those near landing pads that can experience prominent blade slap from steeply descending helicopters. Sites on either side of the flight path can experience different acoustical exposures due to the directionality of BVI impulsive noise and tail rotor noise. Some sites may be exposed to relatively short overflights, while others may experience prolonged exposures from hovering, orbiting, or otherwise maneuvering helicopters. The selected sites should provide as wide a range of aircraft noise exposures as possible.

The primary consideration for survey sites is that the residents must be exposed to appreciable amounts of civil helicopter noise and, where possible, fixed-wing aircraft noise. If only a small portion of an exposed population is annoyed by aircraft noise, or is only slightly annoyed by it, then unreasonably large numbers of interviews may be necessary to demonstrate that population proportions of annoyance differ significantly from zero. Further, it may not be possible to perform a credible dosage-response analysis if annoyance prevalence rates are low.

As a generality, a large number of survey responses over as wide a range of helicopter flight regimes and nonmilitary noise levels is preferred. To maximize the potential for responses, thousands of households should be eligible for interviews at a site. Further, individual sites should be exposed to as great a variety of aircraft types as possible. If a site is overflown only by a small number of aircraft types, such as a small tour helicopter or a large military rotorcraft, it may be difficult to generalize any findings beyond those aircraft types.

One of the primary goals of the project is to determine the relative annoyance of exposure to rotary- and fixed-wing aircraft. Residents eligible for interview would ideally be exposed to noise from both forms of aircraft, if possible. Further, the magnitude of residential noise exposure levels of the two forms of aircraft noise should be roughly comparable to support straightforward analyses and inferences.

In addition to the characteristics described above, the survey sites should preferably lack any features that preclude or complicate collection and processing of interview and acoustic information. For example, unambiguous aircraft noise exposure measurements require that non-aircraft noise levels at measurement sites not approach or exceed aircraft noise levels. To facilitate valid measurement of cumulative (average annual day) exposure metrics, aircraft operations should have little seasonal variability. Neighborhoods with large proportions of non-English speaking households can increase the cost and complexity of administering questionnaires. Detailed radar data and helicopter performance state data will be needed to provide an accurate basis for noise modeling.

The following sections describe the site selection process. The primary, secondary, and survey optimization criteria used to select sites are discussed in Section 3.2.2. Section 3.2.3 presents the locations that were considered and discusses sites that satisfy the primary survey site criterion. A comparison of the potential survey sites relative to the selection criteria is presented in Section 3.2.4. Finally, Section 3.2.5 presents the recommended sites along with a discussion of the rationale for selecting them.

3.2.2 Survey Site Selection Criteria

Selection of survey sites was accomplished in several steps. The primary criterion—sufficient civil helicopter overflights of residential neighborhoods—was used to develop an initial list of potentially acceptable sites. Secondary criteria were used to evaluate the acceptability of these potential sites to provide high quality data required for the analysis. Sites that were clearly unable to meet the secondary criteria were not considered further. The sites that were at least minimally acceptable were then compared and summarized in Table 3-1.

The primary criterion for selection of survey sites was sufficient rotary-wing aircraft overflight of residential land. Four general types of areas were believed likely to satisfy the primary selection criterion: those near commercial airports, neighborhoods near military airfields that are also exposed to noise from civil aircraft operations, neighborhoods near hospitals, and areas near civil heliports.

3.2.2.1 Secondary Criteria for Selecting Interviewing Sites

Secondary criteria were used to further appraise the sites satisfying the primary criterion. Table 3-1 contains a list of the secondary criteria along with their relative importance and a summary discussion of each. The following paragraphs discuss secondary selection criteria in greater detail.

The first of the secondary site selection criteria is the absence of any conditions that would unnecessarily increase the cost or complexity of data collection. Increased sampling, interviewing, and acoustic measurement costs required for sites outside the contiguous 48 states were considered unjustifiable.

While noise measurements were made concurrently with interviewing, noise modeling was required to quantify noise exposures at each site. The noise measurements were used to validate and improve the accuracy of modeled noise levels. Reliable radar data for aircraft operations in the week before and during interviewing was also needed and acquired.

Table 3-1. Secondary criteria for site selection, ranked by importance.

CRITERION	IMPORTANCE	DISCUSSION
Survey Feasibility/Cost	Very High	Survey sites must be suitable for both noise measurement and interviewing. Higher costs for sites outside the continental United States are not justifiable.
Availability of Radar Data and Performance State Data	Very High	Radar data is essential for accurate and meaningful noise modeling. Performance state will be based on noise model profiles.
Aircraft Noise Exposure Levels	High	Low noise exposures are likely to produce small annoyance prevalence rates and require larger sample sizes.
Background Noise Levels	High	Aircraft noise should not be masked by other community sources.
Fleet Mix	Moderate	Small variability in the fleet of aircraft limits the generalizability of the findings.
Seasonality	Moderate	Highly seasonal operations may result in misleading cumulative (average annual day) exposure metrics and constrain schedules.
Availability of Complaint Records	Moderate	Complaint information can be helpful for analytic purposes. (A recent D.C. Court of Appeals ruling on regulation of helicopter noise was largely based on complaints.)
Predominant Language	Moderate	Neighborhoods with predominantly non-English speaking households increase complexity and cost of social surveys.

The noise exposure levels from aircraft overflights must engender measureable annoyance prevalence rates. Both the absolute level of the exposure from single overflights and numbers of overflights are important. In addition, each site must have sufficient aircraft noise exposure to result in an annoyance prevalence rate that can be detected by a reasonable number of interviews.

Similarly, background noise levels (those due to non-aircraft noise sources) must not be so great that they mask single-event aircraft noise levels. Readily generalizable findings of the social survey require exposure to a variety of aircraft types and flight regimes. Sites with little variability in types of aircraft overflights were thus undesirable.

Sites with high seasonal variability in aircraft operations and noise exposures were also undesirable. Such sites would result in misleading cumulative (annual average day) noise exposure metrics. Further, high seasonal variability could unreasonably constrain interviewing schedules. Likewise, special events such as parades and large sporting events with extensive helicopter activity provide only short exposures and are not the focus of this study.

3.2.2.2 Optimizing Social Survey Design

Potential survey sites that satisfied both the primary and secondary selection criteria were then compared with respect to criteria for optimizing the design of the social survey. These criteria are listed in Table 3-2 along with their relative importance and a brief summary.

3.2.3 Sites Considered

The primary criterion for selection of interviewing sites was sufficient rotary-wing aircraft overflights of populated areas. Areas that satisfy this basic requirement are typically found around civil airports, military airfields, heliports, and hospitals. Table 3-3 lists facilities that satisfy the primary criterion.

Table 3-2. Survey optimization criteria by importance.

CRITERION	IMPORTANCE	RATIONALE FOR CRITERION
Mix of Exposure Levels	Very High	Wider range of noise exposures provides more defensible, credible, and generalizable dose-effect relationships.
Mix of Helicopter Type and Operational Regimes	High	Helicopter noise is highly variable in character and dependent on both helicopter type and flight regime. The greater the range in these factors, the more generalizable the results.
Mix of rotary-wing and fixed-wing aircraft	High	Sites exposed to both fixed-wing and helicopter overflights will allow for a direct comparison of annoyance rates.
Relative rotary-wing and fixed-wing exposure levels	Moderate/High	Smaller disparities between rotary- and fixed-wing aircraft noise exposures simplify study design and reduce the need for statistical measures to compensate for large disparities.
Use of unique transponder (XPNDR) Codes	Moderate	The use of unique XPNDR codes facilitates identification of aircraft type.

3.2.3.1 Civil Airports

Figures 3-1 through Figure 3-4 show published helicopter routes for Van Nuys Airport, Torrance Airport, Long Beach Airport, and Las Vegas Airport. Actual helicopter routes for Las Vegas, derived from radar tracking, are shown in Figure 3-5. The Long Beach and Las Vegas figures also show residential land uses (red-shaded) in the areas around the airport. Published helicopter routes in the region around Reagan National Airport are shown in Figure 3-6.

Heliports reviewed include the numerous heliports in the Washington, D.C., area, Manhattan, New York, and Paulus Hook, New Jersey. Figure 3-6 and Figure 3-7 show heliports and published helicopter routes in the Washington, D.C., area. Figure 3-7 shows the Georgetown/Northern Arlington area in detail. This area of D.C. is exposed to helicopter operations over the river as well as fixed-wing aircraft from DCA that also fly over the river, albeit at higher altitudes. Residential land uses are shaded in red. Mixed-use land uses that include residential uses are shaded in orange. Figure 3-8 shows radar tracks for aircraft operations in this area. The aircraft altitudes are shown to distinguish helicopter operations from fixed-wing aircraft approaching and departing from Reagan National Airport. Aircraft at altitudes below 600 feet in Figure 3-8 are helicopters, while those above 600 feet are fixed-wing aircraft.

Table 3-3. Initial list of sites considered.

CIVIL AIRPORTS	MILITARY FIELDS	HOSPITALS*	HELIPORTS
Van Nuys, CA (VNY) Long Beach, CA (LGB) Torrance, CA (TOR) Las Vegas, NV (LAS) Reagan National, D.C. (DCA) Anchorage, AK (ANC) Kahului, Maui, HI (OGG) Hilo, Hawaii, HI (ITO) Lihue, Kauai, HI (LIH)	Camp Pendleton MCAB, CA Miramar MCAS, CA Ft. Rucker, AL Ft. Eustis, VA Edgewood Arsenal, MD 29 Palms MCB (Joshua Tree), CA	San Francisco General, CA UCLA Medical Center, CA Massachusetts General, MA	Manhattan, NY East 34th Street, NY MetLife Building, NY West 30th St., NY Paulus Hook (Jersey City), NJ Hamptons, NY Boston Harbor, MA Washington, D.C., heliports

*Additional hospitals with helicopter noise issues were reviewed for consideration but excluded because they had less than one flight per day on average. The three hospitals noted have near-daily operations

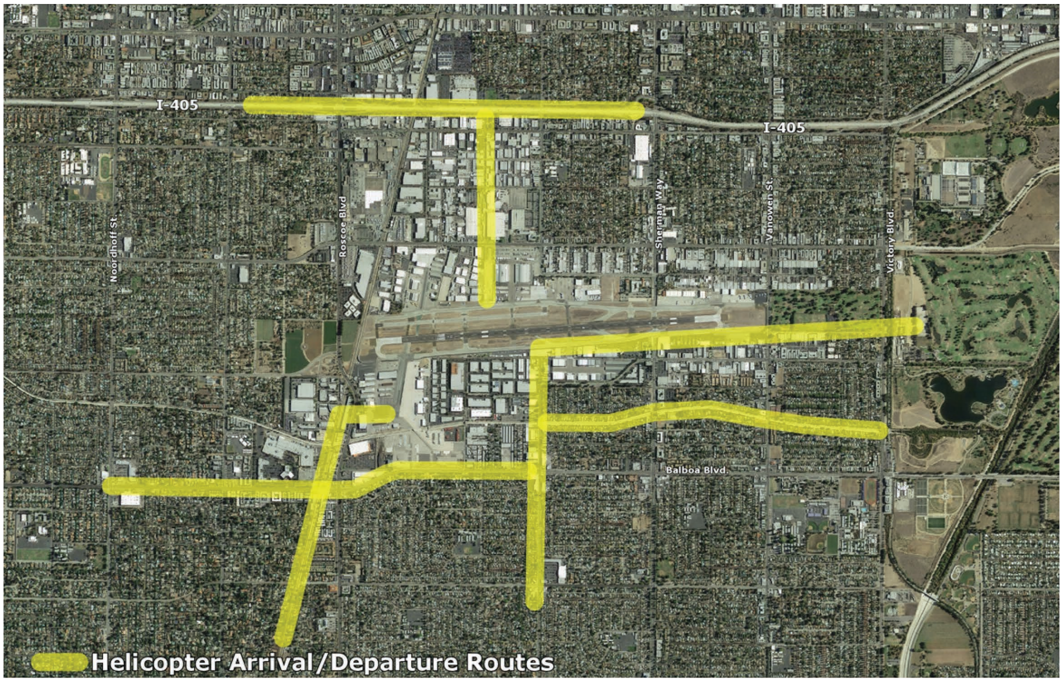


Figure 3-1. Van Nuys Airport.

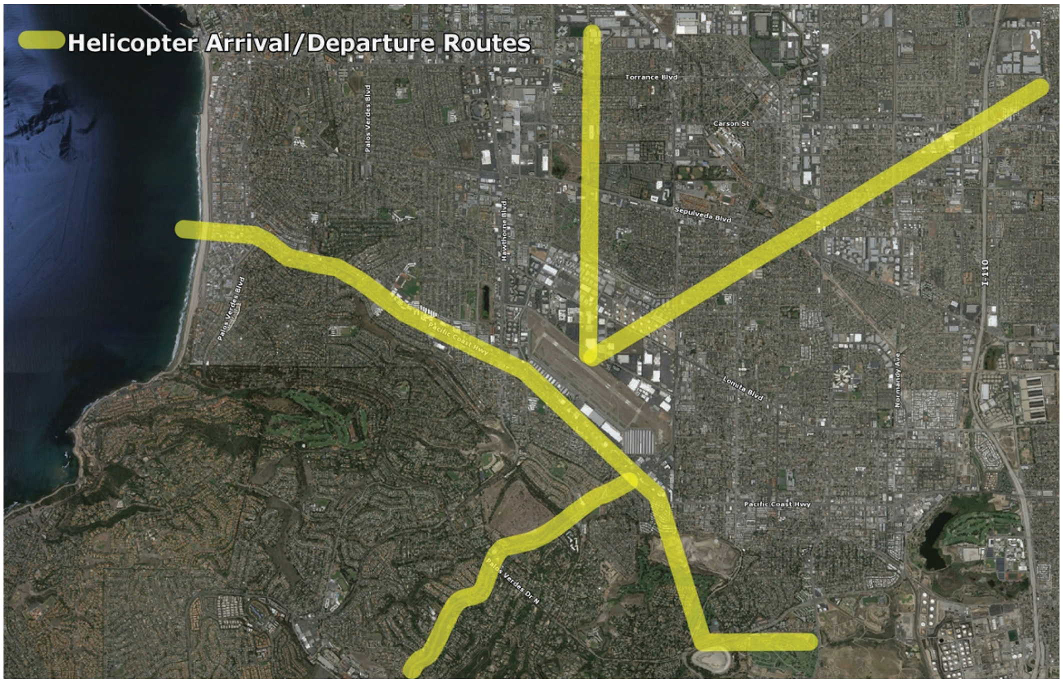


Figure 3-2. Torrance Airport.

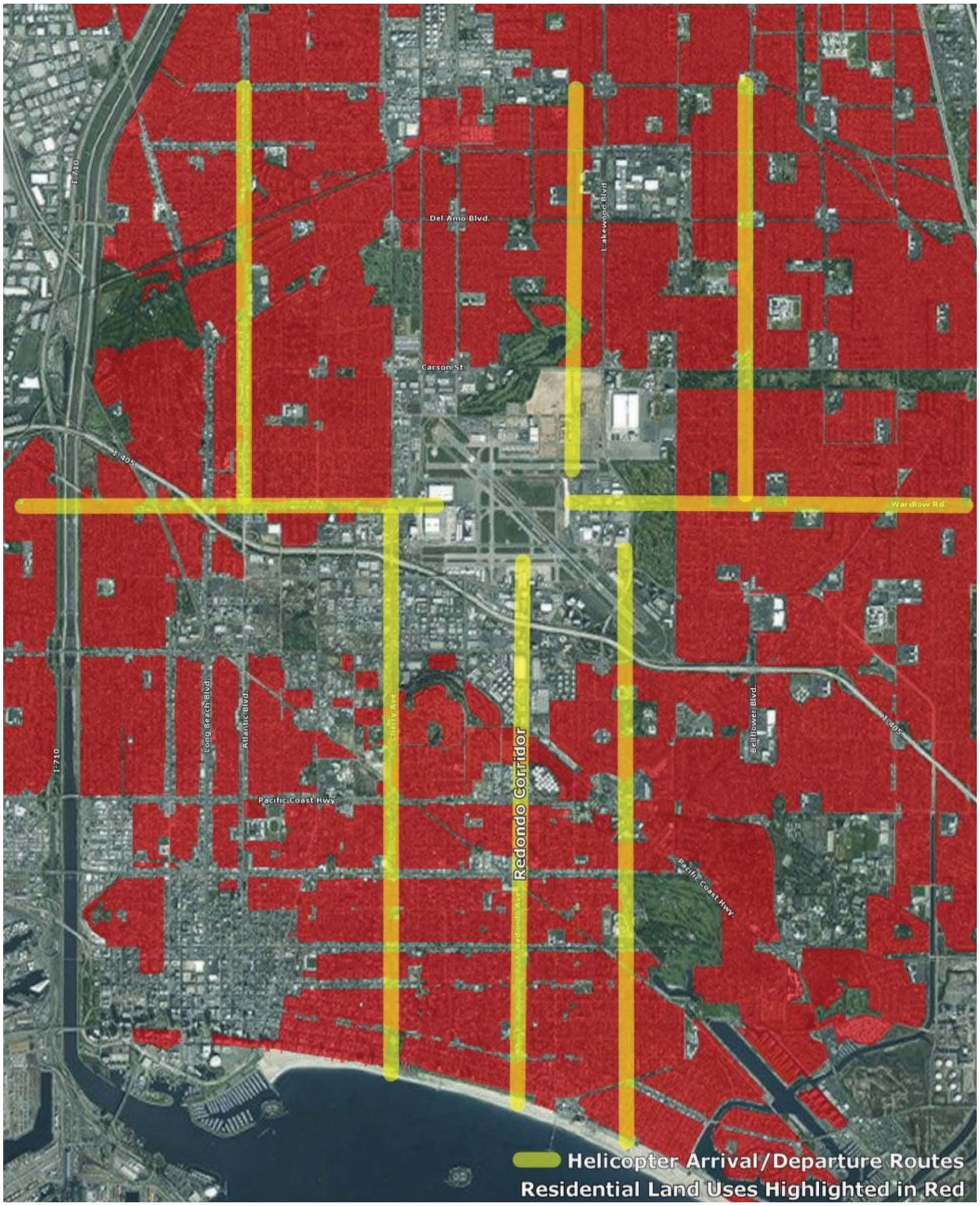


Figure 3-3. Long Beach Airport.

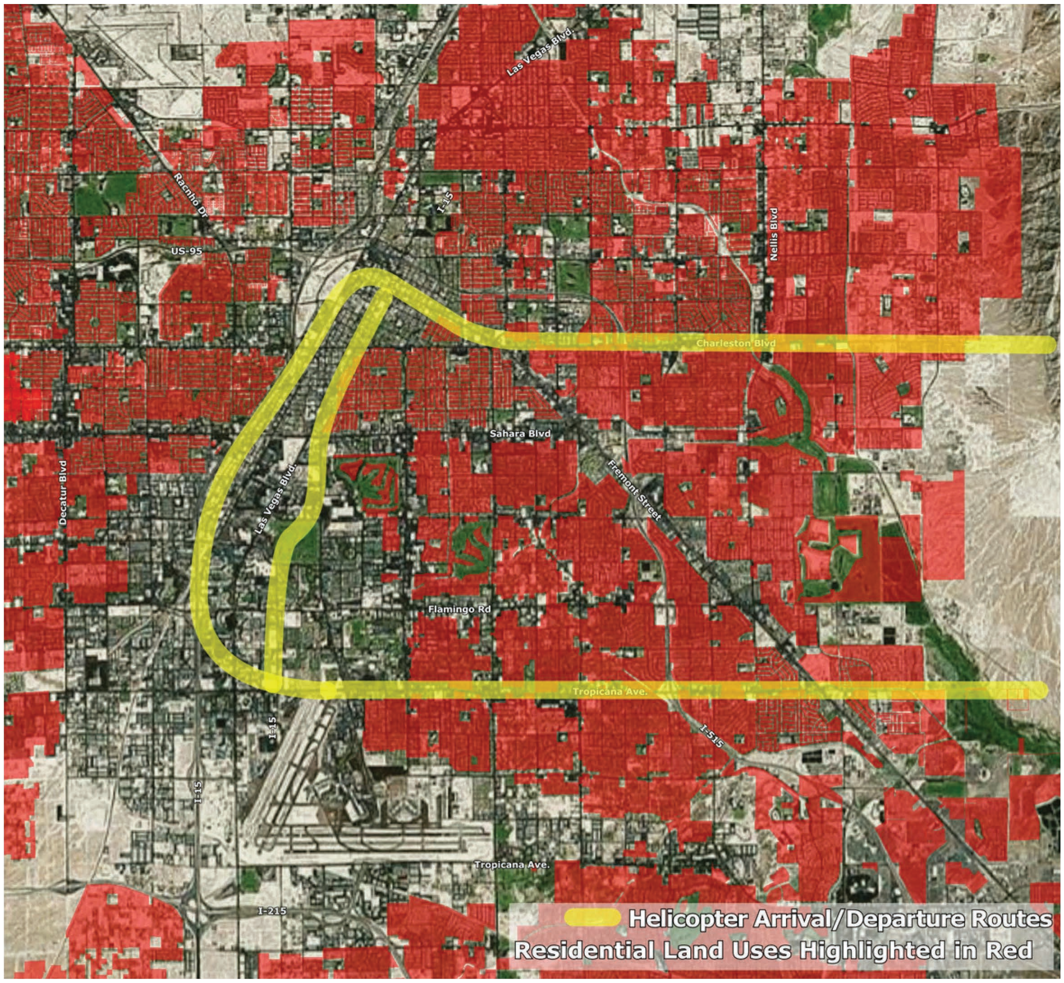


Figure 3-4. Las Vegas International Airport.

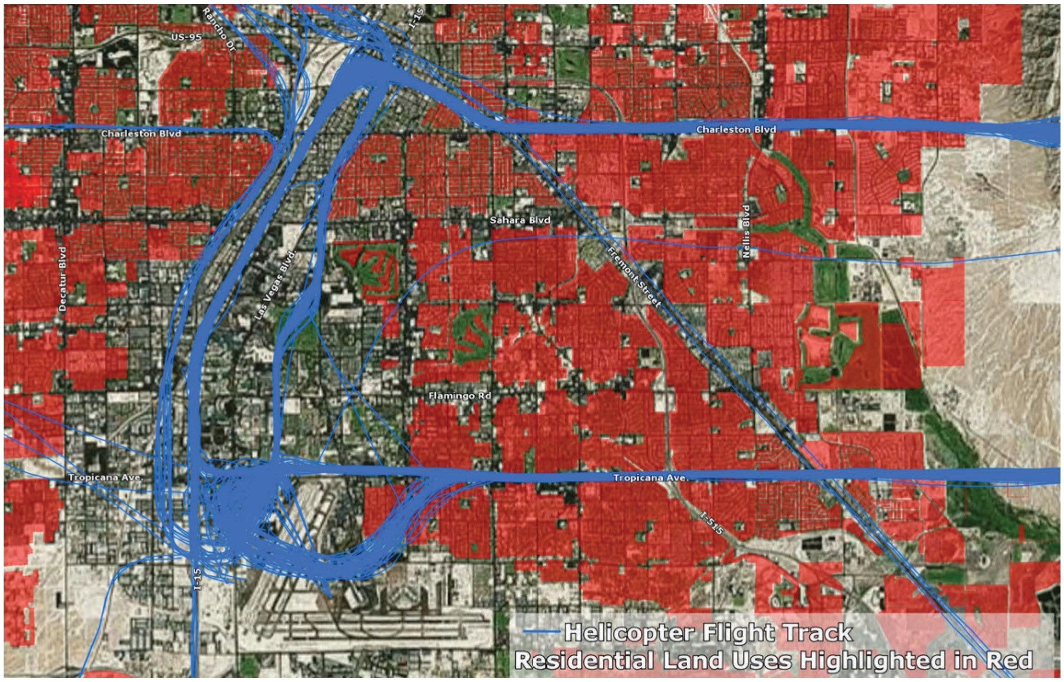


Figure 3-5. Las Vegas helicopter radar tracks.

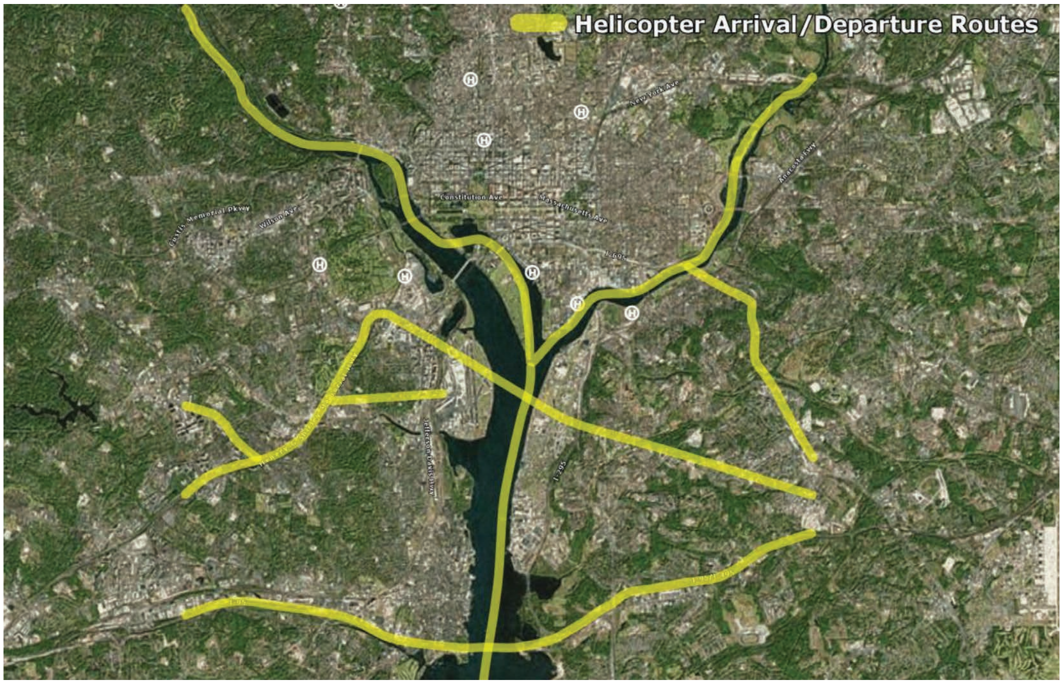


Figure 3-6. Greater Washington, D.C., helicopter routes.

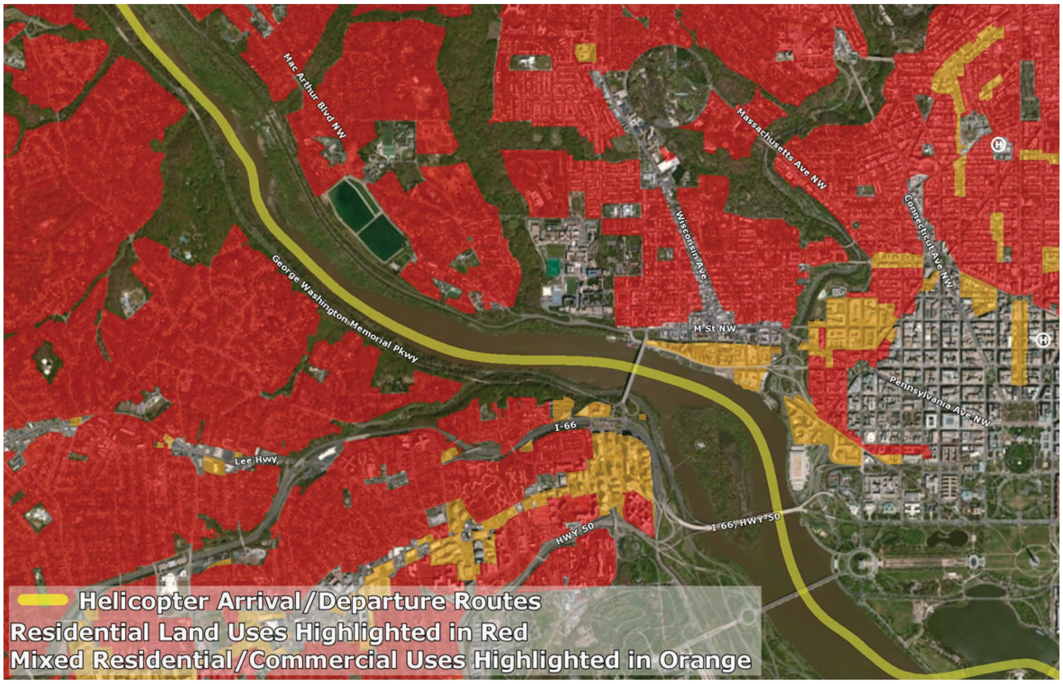


Figure 3-7. Georgetown, Washington D.C.

Figure 3-8. Georgetown, Washington, D.C., radar flight tracks.

Figure 3-9 and Figure 3-10 show the published helicopter routes and nearby land uses in the immediate vicinity of the Manhattan and Paulus Hook helistops. Residential land uses are shaded in red. Mixed-use land uses that include residential uses are shaded in orange.

3.2.4 Site Evaluation

Table 3-4 summarizes the considered sites' characteristics relative to the selection criteria. The type of facility is presented along with information relevant to the primary, secondary, and

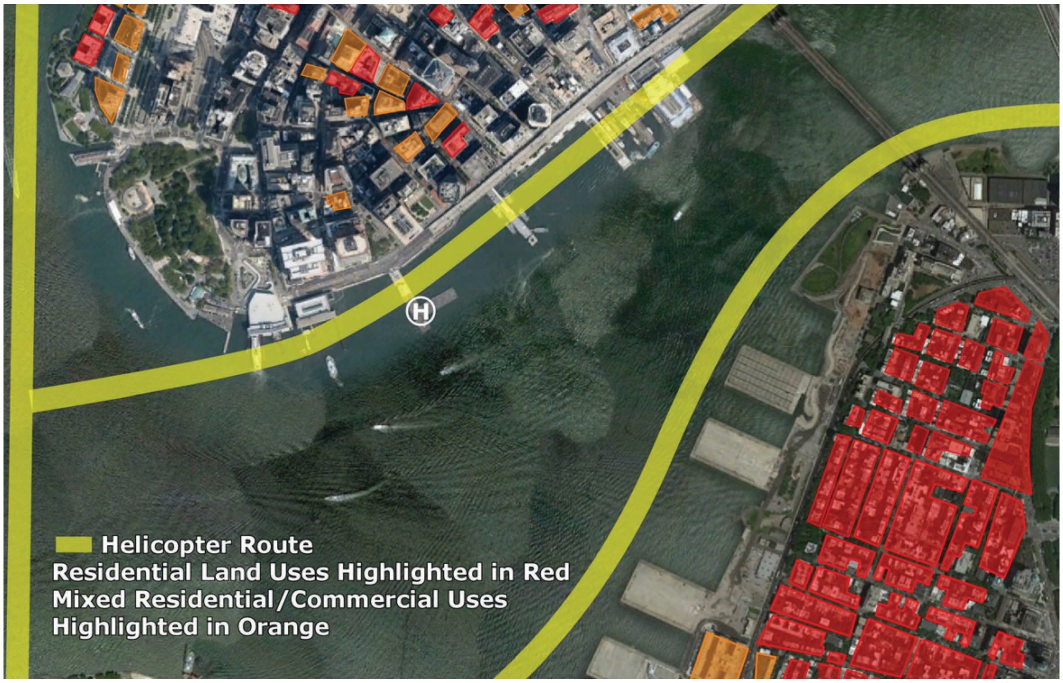


Figure 3-9. Manhattan heliport.

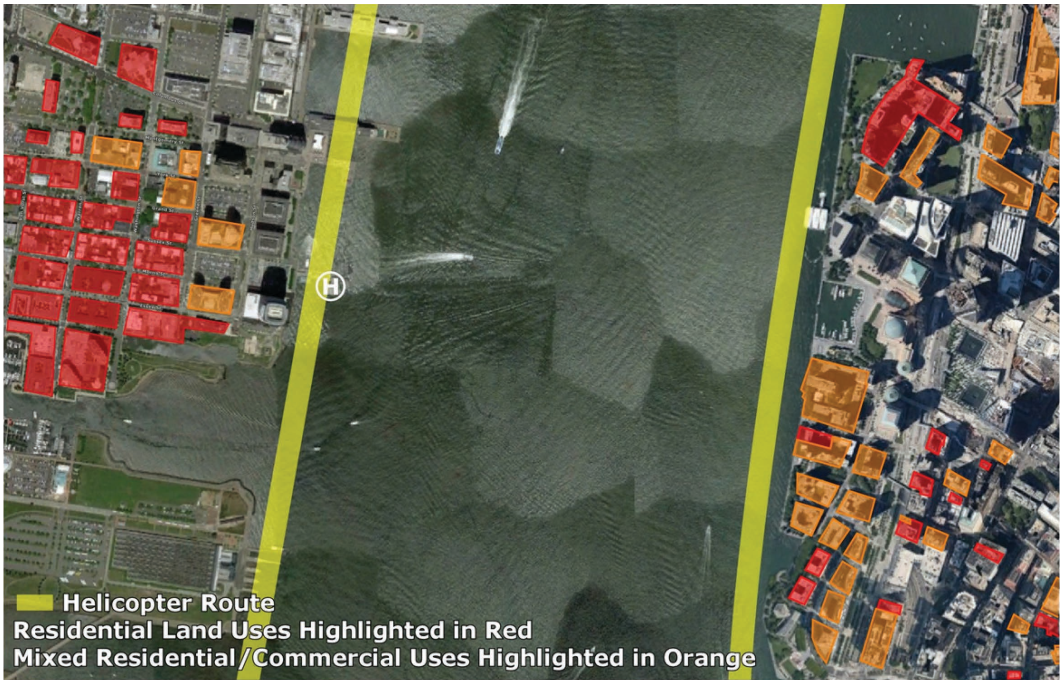


Figure 3-10. Paulus Hook heliport.

Table 3-4. Survey site evaluation summary matrix.

		PRIMARY CRITERIA		SECONDARY CRITERIA		OPTIMIZATION CRITERIA		
SITE	FACILITY TYPE	NUMBER OF DAILY OPERATIONS	RESIDENTIAL OVERFLIGHTS	RADAR TRACK AVAILABILITY	BACKGROUND NOISE	MIX OF AIRCRAFT TYPE	UNIQUE XPNDR CODE	RECOMMENDED FOR FURTHER CONSIDERATION
Van Nuys, CA (VNY)	Airport	Unknown	Yes	Yes	Acceptable	Good	Yes	Yes
Long Beach, CA (LGB)	Airport	34	Yes	Yes	Acceptable	Good	Yes	Yes
Reagan National, D.C. (DCA)	Airport	~35	Yes	Yes	Acceptable	Excellent	Yes	Yes
Las Vegas, NV (LAS)	Airport	237	Yes	Yes	Acceptable	Very Good	Yes	Yes
Kahului, Maui, HI (OGG)[1]	Airport	Unknown	Yes	Yes	Acceptable	Poor	No	No
Hilo, Hawaii, HI (ITO)[1]	Airport	Unknown	Yes	Yes	Acceptable	Poor	No	No
Lihue, Kauai, HI (LIH)[1]	Airport	Unknown	Yes	Yes	Acceptable	Poor	No	No
Anchorage, AK (ANC)[1]	Airport	Unknown	Yes	Yes	Acceptable	Poor	No	No
Torrance, CA (TOR)	Airport	Unknown	Yes	Yes	Acceptable	Poor	Yes	Yes
Camp Pendleton MCB, CA	Military	Unknown	No	Unknown	Acceptable	Poor	No	No
Miramar MCAS, CA	Military	Unknown	Yes	Yes	Acceptable	Poor	No	No
Ft. Rucker, AL	Military	Unknown	Yes	Unknown	Acceptable	Poor	No	No
Ft. Eustis, VA	Military	Unknown	Yes	Unknown	Acceptable	Poor	No	No
Edgewood Arsenal, MD	Military	Unknown	Yes	Unknown	Acceptable	Poor	No	No
29 Palms MCB (Joshua Tree), CA	Military	Unknown	No	Unknown	Acceptable	Poor	No	No
San Francisco General[2]	Heliport	None	No	Yes	Excessive	Good	No	No
UCLA Medical Center	Heliport	Low	Yes	Yes	Excessive	Good	Yes	No
Massachusetts General	Heliport	Low	Yes	Yes	Excessive	Good	No	No
Manhattan	Heliport	Unknown	No		Excessive			No
East 34th Street	Heliport	Unknown	Yes		Excessive			No
MetLife Building	Heliport	Unknown	Yes		Excessive			No
Hamptons	Heliport	Unknown	Yes	No	Acceptable	Good	No	No
Paulus Hook (Jersey City)	Heliport	0[3]	No	n/a	Excessive	n/a	n/a	No
Boston Harbor	Heliport	Unknown	Yes		High			No

[1] Eliminated from consideration due to travel costs.
[2] Conditional Use Permit for heliport not approved.
[3] The helipad owner has recently ceased all operations at this facility. It is not known if, or when, they will resume.

optimization criteria. The table shows approximate number of daily helicopter operations, along with information about the presence or absence of overflights of residential neighborhoods. The availability of radar tracks and a characterization of the background noise levels in the vicinity of the site are also shown. A characterization of the mix of aircraft types at each location, and the use of unique XPNDR codes, is used to evaluate the optimization criteria. The final column of Table 3-4 indicates whether further consideration was warranted for each of the sites considered.

3.2.5 Site Recommendations

Site visits were conducted at Long Beach, Las Vegas, Washington, D.C., Van Nuys, and Torrance. Of these, Long Beach, Las Vegas, and Washington, D.C., were selected for the social surveys.

3.3 Questionnaire

The social survey was intended to test as many of the hypotheses as feasible, as described in Chapter 2 about the annoyance of helicopter noise at three interviewing sites. The hypotheses concern community reactions to various aspects of helicopter noise exposure and required detailed acoustic and aircraft position (“radar”) information for testing. Some hypotheses required analyses of explicit questions about the nature of annoyance with helicopter noise. Other hypotheses could be evaluated simply by comparing dosage-effect relationships constructed with different noise metrics, or other variables, as independent (predictor) variables.

3.3.1 Form and Organization of Questionnaire

An ISO Technical Specification (15666:2003 "Acoustics—Assessment of noise annoyance by means of social and socio-acoustic surveys") offers general recommendations for the order and wording of transportation noise annoyance questionnaire items. The recommendations are intended to facilitate meta-analysis and interpretation of survey findings, not to further specific research goals.

All of the Technical Specification's recommendations are merely informative, and are qualified by provisions that they not conflict with survey goals. The ISO specification explicitly states, "specific requirements and protocols of some social and socio-acoustic studies may not permit the use of some or all of the present specifications. This Technical Specification in no way lessens the merit, value or validity of such research studies." The suggested organization of the present questionnaire follows that of many prior studies of the prevalence of annoyance with aircraft noise exposure in airport neighborhoods.

3.3.2 Questions for All Interviewing Sites

Table 3-5 shows the complete questionnaire. Instructions to interviewers that are not posed to respondents are shown in italic blue or red: questions posed to respondents are in black. The interview was introduced as a study of neighborhood living conditions, not as one of the annoyance of exposure to helicopter noise. This approach reduces the likelihood that respondents will either grant or refuse an interview, or bias their responses to questionnaire items, based on foreknowledge of the purpose of the study.

Item 1 was intended to confirm eligibility for interview. Respondents who did not confirm residence at the household street address (e.g., guests, relatives, household employees, etc.) were not eligible for interview, but were asked whether and when an adult resident would be available for interview. The response coding provides information for a test of a potential relationship between duration of residence and degree of annoyance with aircraft noise—an indirect measure of adaptation.

Items 2 and 3 were included for the sake of consistency with the introduction of the study as one of neighborhood living conditions. They also provided an opportunity, prior to any mention of noise-related concerns, for spontaneous mention of helicopter noise as the least-favored aspect of neighborhood living.

Items 4 and 4A introduced respondents to the closed category absolute judgment scale used in all subsequent items for expressing degrees of annoyance with noise exposure. Item 5 was the first explicit mention of noise as a neighborhood living condition of interest.

Items 6 and 6A sought information about the frequency of notice of helicopter noise in the week preceding interview. Items 7 and 7A inquired about the degree of annoyance of helicopter noise.

Several variant sets of questionnaire items could follow Item 7A, depending on the suitability of noise exposure and other site-specific circumstances. These included:

- Variant 1: Assessment of relative annoyance of exposure to fixed- and rotary-wing aircraft noise, intended for administration at sites exposed to both types of flight operations.
- Variant 2: Assessment of relative contributions of different aspects of helicopter noise for sites exposed to BVI ("blade slap"), thickness, blade-wake interaction, and ducted fan tail rotor noise, intended for administration at sites exposed to noise of diverse helicopter operations.

Table 3-5. List of questionnaire items.

Item 1	How long have you lived at (street address)?
Response/Coding Categories: don't live at this address (0, *ask to speak with resident, schedule a callback, or terminate interview*), less than 1 year (1), at least 1 year but less than 2 years (2), 2 to 5 years (3), 5 to 10 years (4), more than 10 years (5), don't know (6), refused (7)	
Item 2	What do you like best about living conditions in your neighborhood?
Record verbatim response (coding per optional post hoc content analysis)	
Item 3	What do you like least about living conditions in your neighborhood?
Record verbatim response, code as "aircraft noise-related" (1) or "non-aircraft noise-related" (2)	
Item 4	Would you say that your neighborhood is quiet or noisy?
Response/Coding Categories: quiet (0), quiet except for aircraft (of any kind) (1), noisy (2), don't know (5), refused (6), skipped (7)	
If respondent answers "noisy," ask Item 4A; if any other response to Item 4, ask Item 5 next	
Item 4A	Would you say that your neighborhood is slightly, moderately, very , or extremely noisy?
Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don't know (5), refused (6) , skipped (7)	
Item 5	While you're at home, are you bothered or annoyed by street traffic noise in your neighborhood?
Response/Coding Categories: no (0), yes (1), don't know (5), refused (6)	
If respondent answers yes to Item 5, ask Item 5A; if any other response to Item 5, ask Item 6 next	
Item 5A	Would you say that you are slightly, moderately, very, or extremely annoyed by street traffic noise in your neighborhood?
Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don't know (5), refused (6), skipped (7)	
Item 6	While you were at home last week, did you notice noise made by helicopters?
Response/Coding Categories: no (0), yes (1), don't know (5), refused (6)	
If respondent answers yes to Item 6, ask Item 6A; if any other response to Item 6, ask Item 7 next	
Item 6A	About how often did you notice noise made by helicopters while you were at home last week? Would you say you noticed noise made by helicopters less than once a day, about once a day, a few times a day, or at least several times an hour while you were at home last week?
Response/Coding Categories: less than once a day (1), a few times a day (2), several times or more per hour (3), don't know (5), refused (6), skipped (7)	
Item 7	While you were at home last week, did noise made by helicopters bother or annoy you?
Response/Coding Categories: no (0), yes (1), don't know (5), refused (6)	
If respondent answers yes to Item 7, ask Item 7A; if any other response to Item 7, ask Item 8 next	
Item 7A	Would you say that you were slightly, moderately, very, or extremely annoyed by noise made by helicopters while you were at home last week?
Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don't know (5), refused (6), skipped (7)	
Item 8	While you were at home last week, did you notice noise made by aircraft other than helicopters?
Response/Coding Categories: no (0), yes (1), don't know (5), refused (6)	
If respondent answers to Item 8, ask Item 8A; if any other response to Item 8, ask Item 9 next	
Item 8A	About how often did you notice noise made by aircraft other than helicopters while you were at home last week? Would you say you noticed noise made by aircraft other than helicopters less than once a day, about once a day, a few times a day, or at least several times an hour?
Response/Coding Categories: less than once a day (0), once a day (1), a few times a day (2), several times an hour or more (3), don't know (5), refused (6), skipped (7)	

(continued on next page)

Table 3-5. (Continued).

<table>
<tr><td>Item 9</td><td>While you were at home last week, did noise made by aircraft <i>other</i> than helicopters bother or annoy you?</td></tr>
<tr><td colspan="2">Response/Coding Categories: no (0), not home last week (1), yes (2), don’t know (5), refused (6)</td></tr>
<tr><td colspan="2"><i>If respondent answers yes to Item 9, ask Item 9A; if any other response to Item 9, ask Item 10 next</i></td></tr>
<tr><td>Item 9A</td><td>Would you say you were slightly, moderately, very, or extremely annoyed by noise made by aircraft <i>other</i> than helicopters while you were at home last week?</td></tr>
<tr><td colspan="2">Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td>Item 10:</td><td>While you were at home last week, did you notice repeated pounding or slapping noises made by helicopters?</td></tr>
<tr><td colspan="2">Response/Coding Categories: no (0), not home last week (1), yes (2), don’t know (5), refused (6)</td></tr>
<tr><td colspan="2"><i>If respondent answers yes to Item 10, ask Item 10A; if any other response to Item 10, ask Item 11 next</i></td></tr>
<tr><td>Item 10A</td><td>Would you say that you were slightly, moderately, very, or extremely annoyed by thumping or slapping noises made by helicopters while you were at home last week?</td></tr>
<tr><td colspan="2">Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td>Item 11</td><td>While you were at home last week, did you notice buzzing noises made by helicopters?</td></tr>
<tr><td colspan="2">Response/Coding Categories: no (0), not home last week (1), yes (2), don’t know (5), refused (6) don’t know, refused</td></tr>
<tr><td colspan="2"><i>If respondent answers yes to Item 11, ask Item 11A; if any other response to Item 11, ask Item 12 next</i></td></tr>
<tr><td>Item 11A</td><td>Would you say you were not at all, slightly, moderately, very, or extremely annoyed by buzzing noises made by helicopters while you were at home last week?</td></tr>
<tr><td colspan="2">Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td>Item 12:</td><td>While you were at home last week, did you notice whining or tonal noises made by helicopters?</td></tr>
<tr><td colspan="2">Response/Coding Categories: no (0), not home last week (1), yes (2), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td colspan="2"><i>If respondent answers yes to Item 12, ask Item 12A; if any other response to Item 12, ask Item 13 next</i></td></tr>
<tr><td>Item 12A</td><td>Would you say you were not at all, slightly, moderately, very, or extremely annoyed by whining or tonal noises made by helicopters while you were at home last week?</td></tr>
<tr><td colspan="2">Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td>Item 13</td><td>Did helicopters make vibrations or rattling noises in your home last week?</td></tr>
<tr><td colspan="2">Response/Coding Categories: no (0), not home last week (1), yes (2), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td colspan="2"><i>If yes to Item 13, ask Item 13A; if any other response to Item 13, ask Item 14 next</i></td></tr>
<tr><td>Item 13A</td><td>Would you say that you are slightly, moderately, very, or extremely annoyed by vibrations or rattling noises in your home that are made by helicopters?</td></tr>
<tr><td colspan="2">Response/Coding Categories: slightly (1), moderately (2), very (3), extremely (4), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td>Item 14</td><td>About how often do you notice vibrations or rattling noises in your home that are made by helicopters? Do you notice vibrations or rattling noises about once a week, once a day, or several times a day?</td></tr>
<tr><td colspan="2">Response/Coding Categories: once a week or less (0), once a day (1), several times a day (2), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td>Item 15</td><td>Has any member of your household ever called or written to the airport to complain about noise made by helicopters?</td></tr>
<tr><td colspan="2">Response/Coding Categories: no (0), yes (1), don’t know (5), refused (6), skipped (7)</td></tr>
<tr><td colspan="2"><i>If yes to Item 15, ask Item 15A; if any other response to Item 15, terminate interview</i></td></tr>
<tr><td>Item 15A</td><td>About how many times has a member of your household complained about helicopter noise in the last year? Has someone in your household complained just once, a few times, or many times over the last year?</td></tr>
<tr><td colspan="2">Response/Coding Categories: once (1), a few times (2), many times (3), don’t know (5), refused (6), skipped (7)</td></tr>
</table>

- Variant 3: Assessment of annoyance due to secondary emissions (vibration and rattle) excited by BVI noise.
- Variant 4: Assessment of predictability of annoyance from complaint information, particularly for sites with reliable complaint databases.

3.4 Description of Questions

3.4.1 Questions for Direct Comparison of Relative Annoyance of Exposure to Fixed- and Rotary-Wing Noise

At sites for which it was possible to directly compare the relative annoyance of exposure to fixed- and rotary-wing aircraft, Items 8 and 9 follow the initial several items. Items 8 and 8A sought respondents' opinions about the frequency of notice of exposure to noise of fixed-wing aircraft operations. The term "aircraft other than helicopters" was preferred because it would be easier for some respondents to understand than "fixed-wing" aircraft. The wording and coding of these items parallel those of Items 6 and 6A. Likewise, Items 9 and 9A parallel Items 7 and 7A. The similarity of wording and coding of these items were intended to support comparisons of the frequency of notice and degree of annoyance of fixed- and rotary-wing aircraft noise.

3.4.2 Questions for Assessing Relative Annoyance of Exposure to Various Forms of Helicopter Noise

Items 10 through 12 were posed to respondents at sites exposed to noise from helicopter operations that generate more than one form of noise, and/or to operations of a mixed fleet of helicopters that includes some equipped with shrouded rotors (Fenestron) and some with open counter-torque rotors.

3.4.3 Questions for Assessing Annoyance of Helicopter-Induced Rattle and Vibration

Items 13 and 14 were posed to respondents at sites exposed to blade slap noise.

3.4.4 Questions for Assessing Relationship Between Helicopter Noise Complaints and Annoyance

Items 15 and 15A were intended to reveal potential relationships between helicopter annoyance prevalence and complaint rates, as well as potential relationships between helicopter complaint rates and noise exposure levels.

3.4.5 Target Population and Preparation of Sampling Frames

The survey was intended to provide unbiased information about the relative annoyance of exposure to nonmilitary, fixed- and rotary-wing aircraft noise in adult residential populations. In practice, the population of interest is confined to geographic areas within relatively short ranges of aircraft flight routes and civil helipads. Opinions of the general population exposed only to occasional overflights and/or to low levels of fixed- and rotary-wing aircraft noise were of secondary interest.

By definition, an unbiased sample of any target population requires that each member of the target population have an equal opportunity of contributing opinions to the survey. This means, among other things, that respondents cannot self-select for participation in the survey. It also means that inexpensive methods for compiling a sampling frame (an exhaustive and current enumeration of every person eligible for interview) are inappropriate for present purposes. These include constructing sampling frames from citywide voter registration, countywide tax assessor information, and other wide-area public records, not to mention random digit dialing of all numbers within a telephone exchange.

Reverse telephone directories were common sources of sampling frames in the era when landline telephone subscription was effectively universal. In recent years, rates of unlisted telephone numbers have become so high, and cell phone-only telephone subscription so widespread, that it has become difficult to rely on public information for such purposes.[12] The Telephone Consumer Protection Act of 1991, as amended, further complicates and increases the cost of telephone-based interviewing.

3.5 Potential Interviewing Methods

Three common methods of conducting interviews about opinions and reactions to aircraft noise exposure are by telephone, mail, and in person (face to face).[13] As summarized in Table 3-6, each method is characterized by unique sets of advantages and disadvantages. These must be balanced against study goals. The questionnaire was administered by telephone to a sample of landline and cell phone subscriber households located within areas defined by the vertices of

Table 3-6. Comparison of relative advantages and disadvantages of alternate interviewing methods.

Feature	PERSONAL (FACE TO FACE)	POSTAL	TELEPHONE
Interview Completion Rate	High	Low	Historically high; recently low
Relative Cost of Data Collection	High	Low to moderate, depending on follow-up methods for nonresponse	Intermediate (depends on sample incidence rate and numbers of callbacks)
Duration of Data Collection	Moderate (at least several days, dependent on field logistics)	Long (weeks), vulnerable to shifts in opinions due to external events (e.g., aircraft crashes, current events)	Short (several hours per day over the course of 3 or 4 days, depending on callback scheduling)
Efficiency of Data Collection (Cost per Interview, Including Data Entry)	Greatest in high population density settings	Independent of population density	Independent of population density
Common Limitations	High training costs, limited field supervision, costly to administer over wide areas	No knowledge of respondent identity; loss of control over order of questioning; biased toward more literate respondents	Questionable representation of younger, single, lower socioeconomic and less educated respondents, possible ethnic and racial biases
Most Appropriate for…	Administration of lengthy interviews to relatively small numbers of respondents in small, densely populated geographic areas about complex or sensitive matters	Settings in which duration, temporal specificity, confirmation of the identity of respondents, and supervision of the interviewing process is not critical	Representing residential response to noise exposure in large populations in short, well-defined time periods, with tight control over data collection
Difficulty of Constructing a Sampling Frame	Low (for example, field workers may be instructed to flip a coin or solicit interviews at every nth door or floor in an apartment building, or at every nth street address in an area of dense single-family detached dwellings)	Moderate (currency of sampling frame is difficult to maintain in high-turnover rental areas)	Moderate (workarounds required for high rates of unlisted telephone numbers and for cell phone-only users)
Interview Quality Control	Low (little effective real-time field supervision; slow tracking of response rates and callback success; difficulty in managing release of sub-samples and scheduling additional interviews)	None; lengthy delays in administration and tracking of survey progress	High (real-time supervision of interviewing possible; immediate tracking of sample incidence and refusal rates and scheduling of callbacks; possibility of conversion of refusals)
Knowledge of Respondent Identity	High	None	Intermediate
Control Over Order of Questioning	Complete	None	Complete

polygons enclosing geographic areas with reasonably homogeneous aircraft noise exposure. The selection of telephone interviewing was based on the following factors:

1. The costs of making field measurements for prolonged periods to correspond with the period of questionnaire items ("While you've been at home during the past *week*. . . .");
2. The need to control the order of presentation of questionnaire items;
3. The lack of necessity for lengthy and/or sensitive personal information; and
4. Overall data collection costs, except possibly at some (urban, high-density residential) sites, at which in-person (face-to-face) interviewing might be cost-effective.

3.6 General Discussion of Sample Size Constraints

This section presents background information about the role of sample size in social survey design. A more specific discussion of sample sizes required to test the hypotheses of current interest is included in the mock data analysis section.

The size of the population exposed to rotary-wing aircraft noise is a basic issue affecting study design and site selection. Larger sample sizes reduce the uncertainty of estimates of annoyance prevalence of rates for a given cumulative sound level exposure. They also reduce uncertainty about equivalent shifts, in decibels, of the dose-response curve that reflect nonacoustic influences on annoyance prevalence rates. Smaller uncertainties, in turn, permit more reliable estimates of smaller differences in community tolerance to a noise source.

Smaller sample sizes have the opposite effect. A basic decision must be made before final site selection regarding the minimal magnitude of effect of current interest, since it may not be realistic to seek evidence of small differences in annoyance rates at some sites. As a generality, surprisingly few (50–100) interviews may suffice to detect large differences between the annoyance of exposure to fixed- and rotary-wing aircraft, while surprisingly many (several hundred, if not more) interviews may be needed to detect small differences.

In practice, the number of respondents and the size of expected differences in annoyance prevalence rates are the major factors affecting site selection. Annoyance prevalence rates may be expected to change by about 1% (near asymptotes of dosage-response relationships) to 3% (in the linear portion of dosage-response relationships) per decibel of noise exposure. If differences in annoyance prevalence rates between interviewing sites with exposures differing by only 3 to 5 dB must be detected, then 95% confidence intervals of about 2% to 3% are required.

About 200 to 300 completed interviews are usually sufficient to achieve such confidence intervals. Roughly estimated, about half of the households in a sampling frame are likely to have unlisted telephone numbers, or cannot be reached with reasonable numbers of callbacks. Another half of the eligible respondents with listed telephone numbers may refuse to grant interviews. Working backward from confidence intervals of the desired widths, several thousand households must be eligible for interview by address-based landline telephone at a given interviewing site.

Residential neighborhoods with uniform low-density housing (e.g., single-family detached dwellings on large lots) may therefore not be optimal as interviewing sites. Levels of exposure to helicopter noise may vary considerably across such sites, unless they extend for distances as great as miles parallel to well-defined helicopter flight corridors.

3.6.1 Size of Expected Differences in Annoyance Prevalence Rates due to Rotary- and Fixed-Wing Aircraft Noise

Figure 3-11 shows a set of dosage-response relationships between cumulative noise exposure levels and percentages of respondents describing themselves as highly annoyed by aircraft

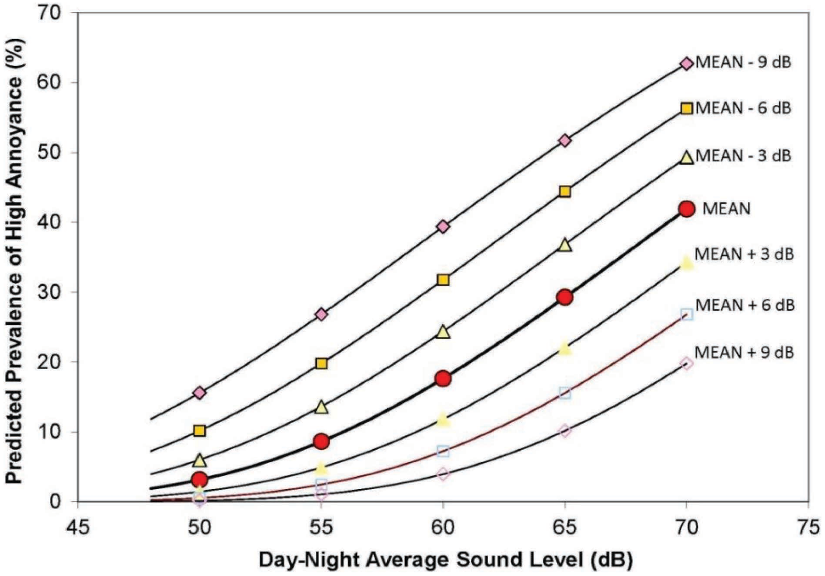


Figure 3-11. Hypothetical differences in annoyance prevalence rates in communities with greater or lesser degrees of tolerance for noise exposure due to fixed- and rotary-wing aircraft.

noise exposure. These curves are derived from the assumption that annoyance is most effectively predicted from the "effective" (duration-adjusted) loudness of noise exposure, as described by Fidell et al. (2011) and Schomer et al. (2012). The separations between dosage-response curves reflect varying degrees of community tolerance for noise exposure. For example, at a noise exposure level of $L_{dn} = 65$ dB in a community 6 dB less tolerant of helicopter than fixed-wing aircraft noise, an additional 15% of the population may be highly annoyed by helicopter noise than by fixed-wing aircraft noise.

The curve reflecting the grand mean of annoyance judgments made by 75,000 social survey respondents at about 540 interviewing sites is the one in the middle (shown with filled red circle plotting symbols). The other curves are for communities that are either more or less tolerant than average of aircraft noise exposure. If helicopter noise is truly more annoying than fixed-wing aircraft noise on a decibel-for-decibel basis, then the annoyance of helicopter noise should be displaced from the mean curve shown in Figure 3-11. The amount of displacement from the mean curve is a decibel-denominated measure of the size of the effect of differential tolerance for the noise of fixed- and rotary-wing aircraft noise.

3.6.2 General Examples of Sample Size Requirements

Figure 3-12 illustrates the effects of sample size (number of completed interviews) on the precision of estimation of the prevalence of high annoyance. Precision of measurement of a binomial proportion, such as the proportion of a population highly annoyed by rotary-wing aircraft noise, is expressed in Figure 3-12 in terms of the widths of confidence intervals constructed around observed proportions. For moderate or greater sample sizes, the upper bound of the 95% confidence interval is the observed proportion plus $1.96(pq/n)^{1/2}$, while the lower bound of the 95% confidence interval is the observed proportion minus $1.96(pq/n)^{1/2}$, where p is the percent highly annoyed, q is the percent not highly annoyed, and n is the number of completed interviews.[14]

Figure 3-12 shows that over the range of annoyance prevalence rates of present interest, confidence intervals for estimates of proportions of respondents highly annoyed are smaller than 1%,

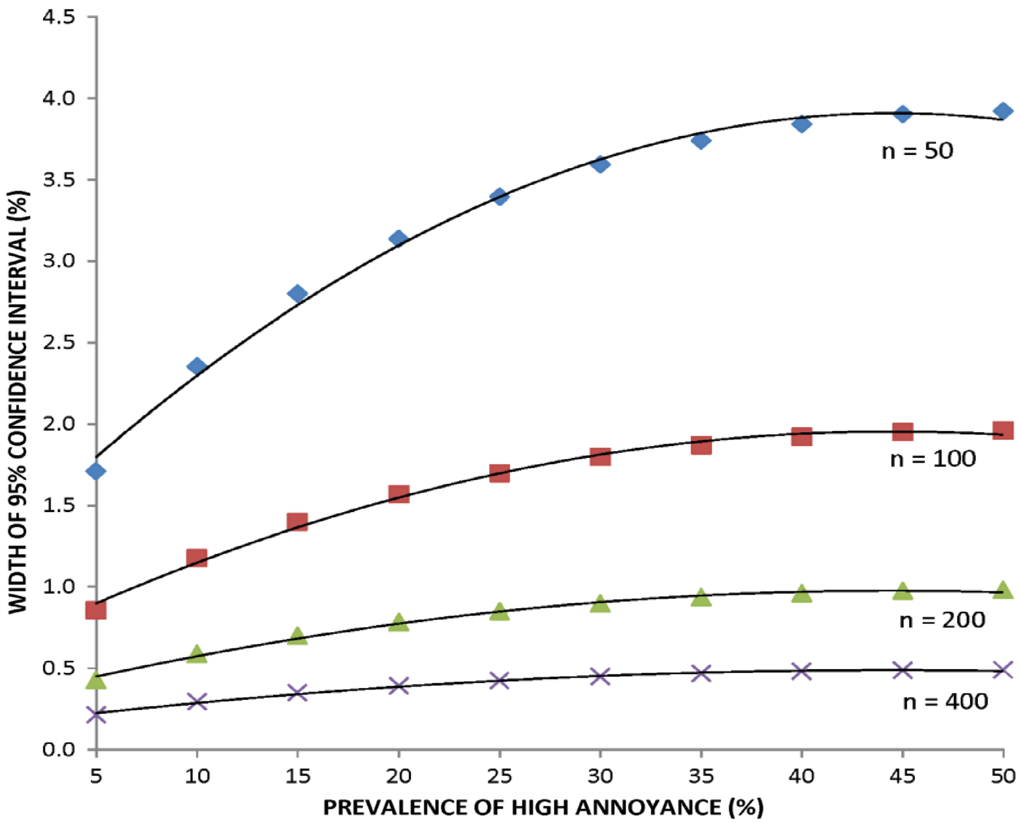


Figure 3-12. Widths of 95% confidence intervals around a range of binomial proportions, as a function of sample size.

for samples of n = 200 and greater. The figure also shows that a point of diminishing returns in reduction in confidence interval width is reached at a sample size of about 200. Since the precision of measurement is proportional to the square root of the sample size, further doublings of sample sizes yield only a factor of the square root of 2 (~1.4) improvements. In other words, impractically larger sample sizes would be required to reduce the widths of confidence intervals by useful amounts.

It is therefore apparent that interviewing sub-sites would preferably be able to yield at least 200 completed interviews. Since not every household at a potential interviewing site can be contacted, nor is necessarily willing to grant an interview, a useful interviewing site must contain at least several multiples of 200 households. If the sample incidence rate is as great as 50% (that is, if half of the sampling frame can be reached and is willing to grant an interview), then the minimum number of households at a site should be 400. If the sample incidence rate is lower, the minimum number of households at a site must be correspondingly greater.

3.7 Noise Measurement Methods

The social survey was accompanied by field noise measurements and INM estimates of helicopter noise levels. Noise measurements and recording of aircraft flight tracks started 1 week prior to the first date of interviewing and continued for the remainder of interviewing. The duration of interviewing was expected to be 3 to 4 days, but was extended in some cases to permit additional callbacks to yield adequate numbers of completed interviews.

Table 3-7. Noise metrics simultaneously measured.

FREQUENCY WEIGHTING	TIME AVERAGING			
	SLOW	FAST	IMPULSE	L_{eq}
A	X	X	X	X
C	X	X	X	X
1/3 Octave (12.5 to 20 kHz)				X
Audio (24 bit, 44.1 kHz)	Not Applicable			

The basic noise measurement instrumentation was the Larson Davis 824 precision Class 1 sound level meter. [Class 1 refers to the International Electrotechnical Commission's (2005) highest specification for precision sound level meters 2005]. Broadband audio recordings were made with a Zoom H2 digital recorder connected to the Direct Output of the L-D 824. The audio recorders use SD memory cards to store the audio signal in a standard audio WAV file format. The broadband audio files stored 24-bit samples at a rate of 44.1 kHz.

The goal of the field measurements was to continuously document simultaneous measurement of sound pressure levels in A- and C-weighted decibel units, along with one-third octave band sound pressure levels, and broadband audio for the duration of the measurements. The broadband audio recordings allowed for manual identification of noise sources and also preserved the noise environment near respondents' homes for further analysis. Table 3-7 identifies the noise metrics recorded during the measurement survey.

The acoustic measurements for Long Beach and Las Vegas were made simultaneously at four monitoring sites spaced throughout the survey area. The measurement sites were selected to collect data as nearly directly beneath the flight tracks and to the sideline of the corridors.

Field measurements of actual noise exposure were calibrated and supplemented INM-based estimates of aircraft noise exposure. The noise measurement data were used to calibrate INM predictions so that exposure predictions could be generated for each household that completed an interview. This was done by using INM to create a grid of points or INM "location points" for each noise metric of interest. The field measurements were used to create a decibel differential between predicted and measured values at the four measurement points and at INM grid or location points. This grid was used to estimate noise exposures at the homes of the social survey respondents. The longitude and latitudes of respondents' homes were coded in the sampling frame.

CHAPTER 4

Noise Exposure Estimation and Interviewing Methods

This chapter describes the conduct of noise measurements and interviews during July and September of 2015 in the cities of Long Beach, CA, and Las Vegas, NV, and during June of 2016 in Georgetown and North Arlington, VA, in the Washington, D.C., area.

4.1 Interviewing Areas, Helicopter Routes, and Noise Measurement Sites

Figures 4-1 through 4-3 show nominal helicopter flight routes and noise measurement sites for the three interviewing areas.

4.1.1 Description of Long Beach Study Area

The Long Beach study area was adjacent to the Redondo Avenue helicopter corridor, a voluntary route shown on aeronautical charts for the area. The route extends from LGB, just north of the study area, to the coast. Upon reaching the coast, helicopters turn east or west to follow it further. The route supports two-way traffic for both approaches and departures.

Overflown neighborhoods contain mostly single-family dwellings, with some small apartment buildings dispersed throughout the neighborhood. Redondo Avenue is a commercial street for the most part, with a few small commercial buildings scattered elsewhere throughout the study area. Homes in the study area range from classic California cottages built in the 1920s and 1930s, to mid-century small apartment buildings. Housing on streets nearer the coast is more expensive than elsewhere in the study area, while areas to the north of the study area contain more modestly priced homes.

The Redondo route is used for helicopter training, executive transport, tourism, and public safety flights. About fifteen overflights per day occur in the Redondo Avenue corridor, split about evenly between northbound and southbound flights.

For the sake of completeness, Figure 4-1 also shows the more lightly used Cherry Avenue corridor, which supports only about two overflights per day. Helicopter operations on both routes are generally flown at or about 500 feet above ground level (AGL) to avoid conflicts with nearby airport traffic.

Noise measurement sites for the Long Beach interviewing area were selected with the assistance of airport staff knowledgeable about nearby airspace uses.

4.1.2 Description of Las Vegas Study Area

The Las Vegas study area is composed largely of single-family homes constructed since the 1950s. The neighborhoods are typical low-density residential areas with a few condominiums

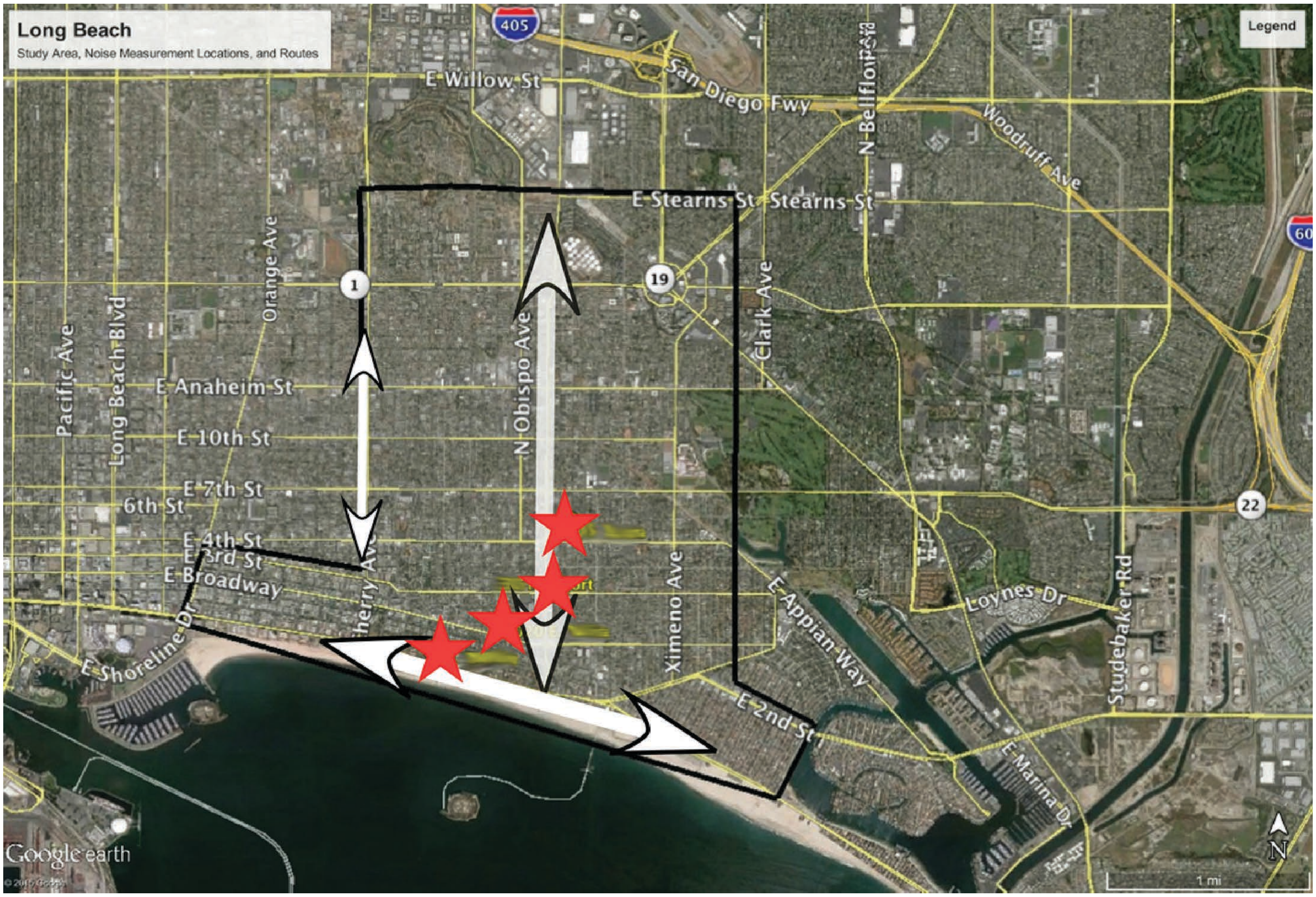


Figure 4-1. Helicopter routes (white double-ended arrows) and noise measurement sites (red stars) in Long Beach study area.

Figure 4-1a. Location of noise measurement sites at the Long Beach study area.

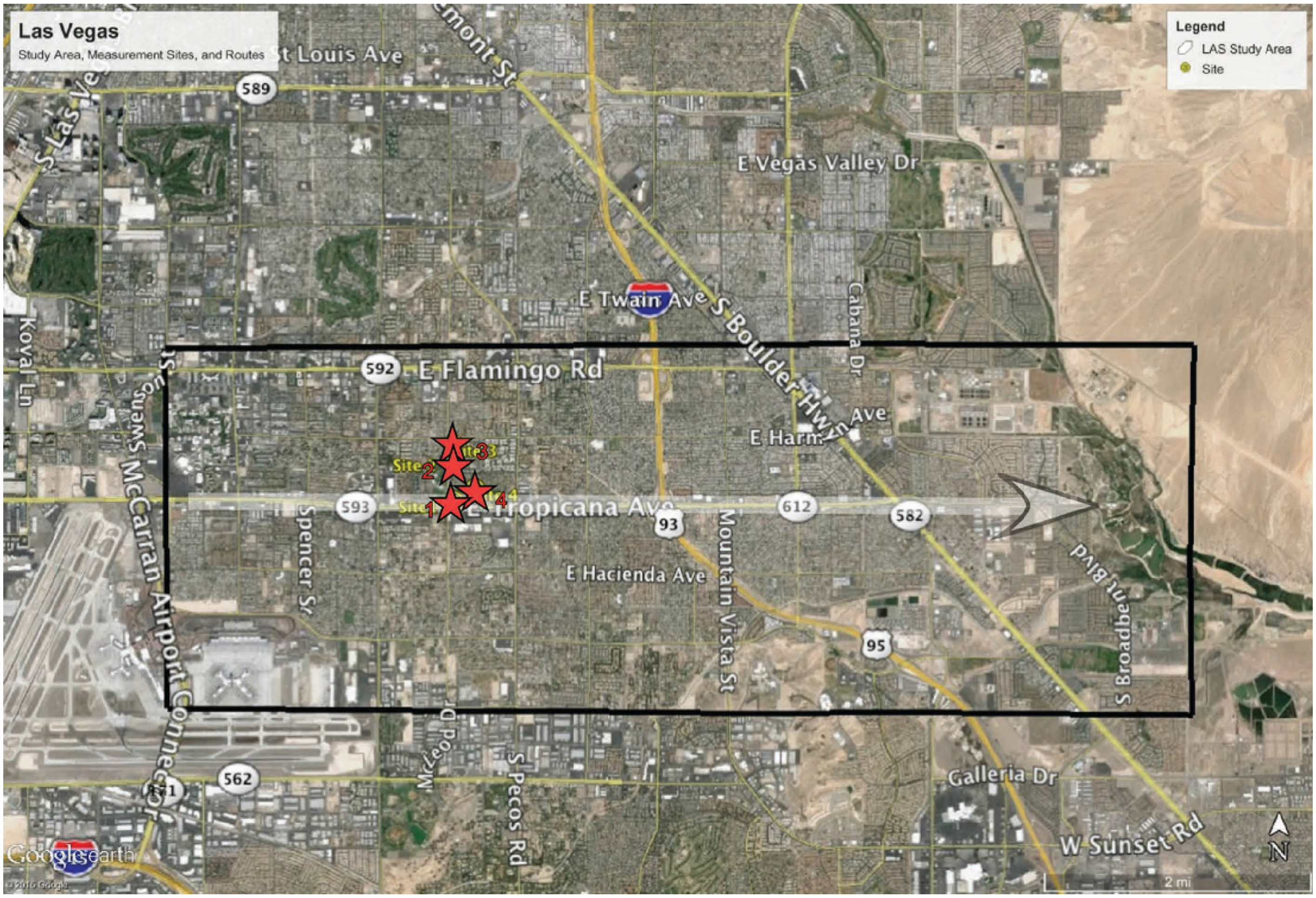


Figure 4-2. Helicopter route (white arrow) and noise measurement sites (red stars) in Las Vegas study area.

Figure 4-2a. Location of noise measurement sites at the Las Vegas study area.

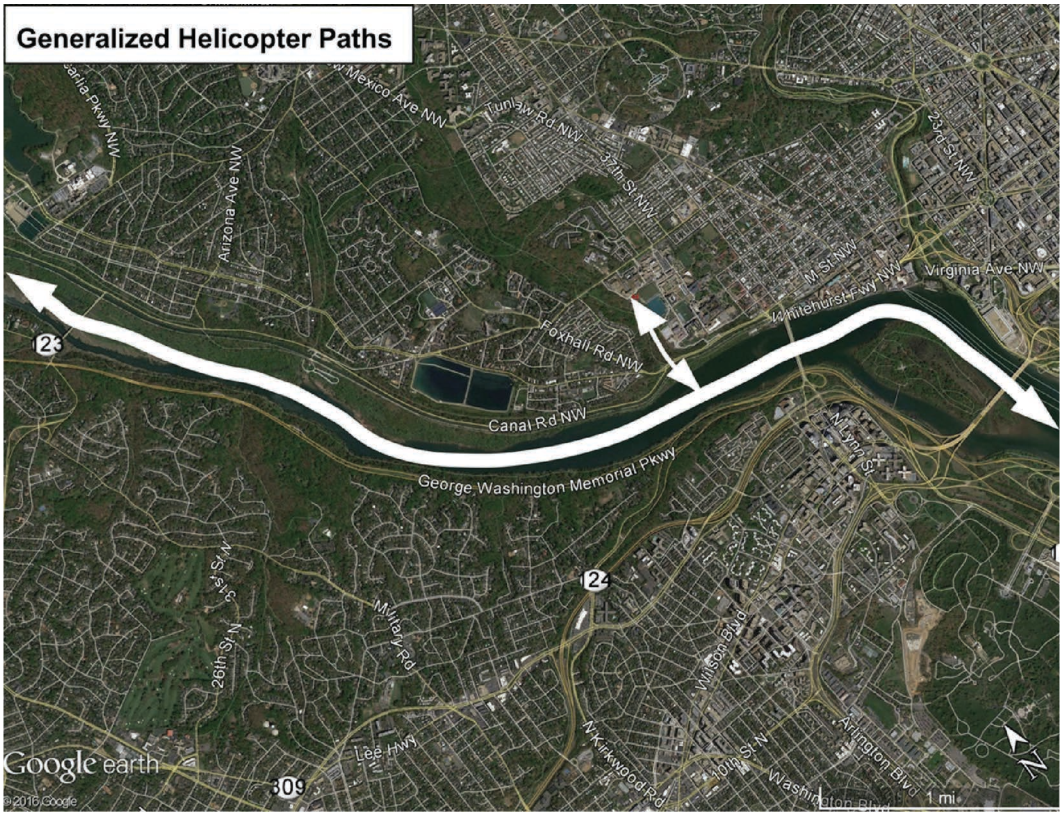


Figure 4-3. Washington, D.C., study area.

and no distinctive features. Ground elevations on the west side of the study area are essentially the same as the airport elevation, but the terrain drops considerably on the east side of the study area. The area along Tropicana Avenue is generally commercial, with homes located behind commercial development.

Interviews were conducted with residents of homes along the Tropicana Avenue helicopter corridor. The corridor is immediately to the east of LAS and the Las Vegas strip, as shown in Figure 4-2. It is a one-way departure corridor used primarily by air tour operators and some public safety helicopters. The corridor supports approximately 150 overflights daily. The helicopter flight route is at an elevation of about 1,000 feet AGL in the western portion of the study area, but at greater altitudes AGL in the eastern portion (due to falling terrain). Residential land uses in the interviewing area are dominated by single-family detached dwellings, mixed with a smaller number of condominiums.

Noise measurement sites were selected by door-to-door canvassing in a single-family residential area adjacent to Tropicana Avenue. The neighborhood includes many fenced private yards, in which noise monitors could be securely installed and operated 24 hours per day.

4.1.3 Description of Washington, D.C., Study Area

The Washington, D.C., study area was composed primarily of single-family homes dating from the 1950s to newer homes located in Northern Arlington and Georgetown adjacent to the Potomac River. The study area is shown in Figure 4-3. The neighborhoods in Northern Arlington have the appearance of suburban neighborhoods, without distinctive or unique features. A few condominiums and apartment buildings are also found in the study area. The Georgetown interviewing area included a mix of retail uses, a university with a hospital heliport, and party wall (row) and single-family houses.

Interviews were conducted within an area paralleling the Potomac helicopter corridor above the river. The helicopter flight paths are at an elevation of about 500 feet AGL to avoid airspace used by fixed-wing arrivals at DCA and a departure route from DCA that also follows the river.

Helicopter noise exposure estimates were made by modeling rather than by direct measurement. Since the helicopter corridor is beneath heavily used departure and arrival corridors to DCA, any attempt to measure helicopter noise exclusively would be complicated by fixed-wing overflight noise. One of the unresolved issues is how well INM models BVI noise. As described in Chapter 5, aircraft noise exposure generated by fixed-wing traffic (primarily air carrier jets) at DCA exceeds noise exposure created by helicopters by about an order of magnitude in the interviewing area.

4.2 Noise Measurement Protocol

Two sets of sound level meters were installed at each of the noise monitoring sites in both Long Beach and Las Vegas. The primary measurements were made using four Larson Davis 831 noise monitors. These meters continuously archived a time series of sound pressure levels at one-second intervals. The metrics collected by the 831 monitors included A-weighted 1 second L_{eq}, C-weighted 1 second L_{eq}, and 1 second L_{eq} for each of the one-third octave bands from 6 Hz to 20 kHz. In addition, Larson Davis Model 824 meters at each site collected 1-second time histories of A-weighted and C-weighted L_{eq} values.

High-resolution digital audio recorders were attached to the audio outputs of the sound meters at each monitoring site. All meters were calibrated periodically before, during, and after the measurement period. Appendix D contains a more complete description of the measurement equipment, calibration, and measurement protocols.

4.3 Noise Modeling Methods

4.3.1 Long Beach

DNL contours and DNL values at each respondent's home were developed with INM 7.0d,[15] using radar flight tracks obtained from each airport. At Long Beach, all flight tracks were obtained and then filtered based on altitude and passage through the study area. Although FAA has instituted unique radar squawk codes for helicopters operating in the LA basin, these were inconsistently used during the time of the survey. An observer was therefore stationed at the south end of the Redondo corridor from 7:00 AM to 7:00 PM every day. The observer photographed and logged every visible helicopter overflight. Helicopter types were determined from these photographs, and used to assign types to each helicopter flight track database entry. Figure 4-4 shows the Long Beach radar tracks, while Figure 4-8 shows the INM modeled tracks.

4.3.2 Las Vegas

In Las Vegas, helicopter operators have voluntarily agreed to use unique squawk codes. Due to high compliance by operators, LAS was able to provide helicopter-only flight tracks for just the helicopters using the Tropicana corridor. Since the Las Vegas flight track database included the helicopter registration number, this was used to look up the helicopter type and update the flight track database with each helicopter type.

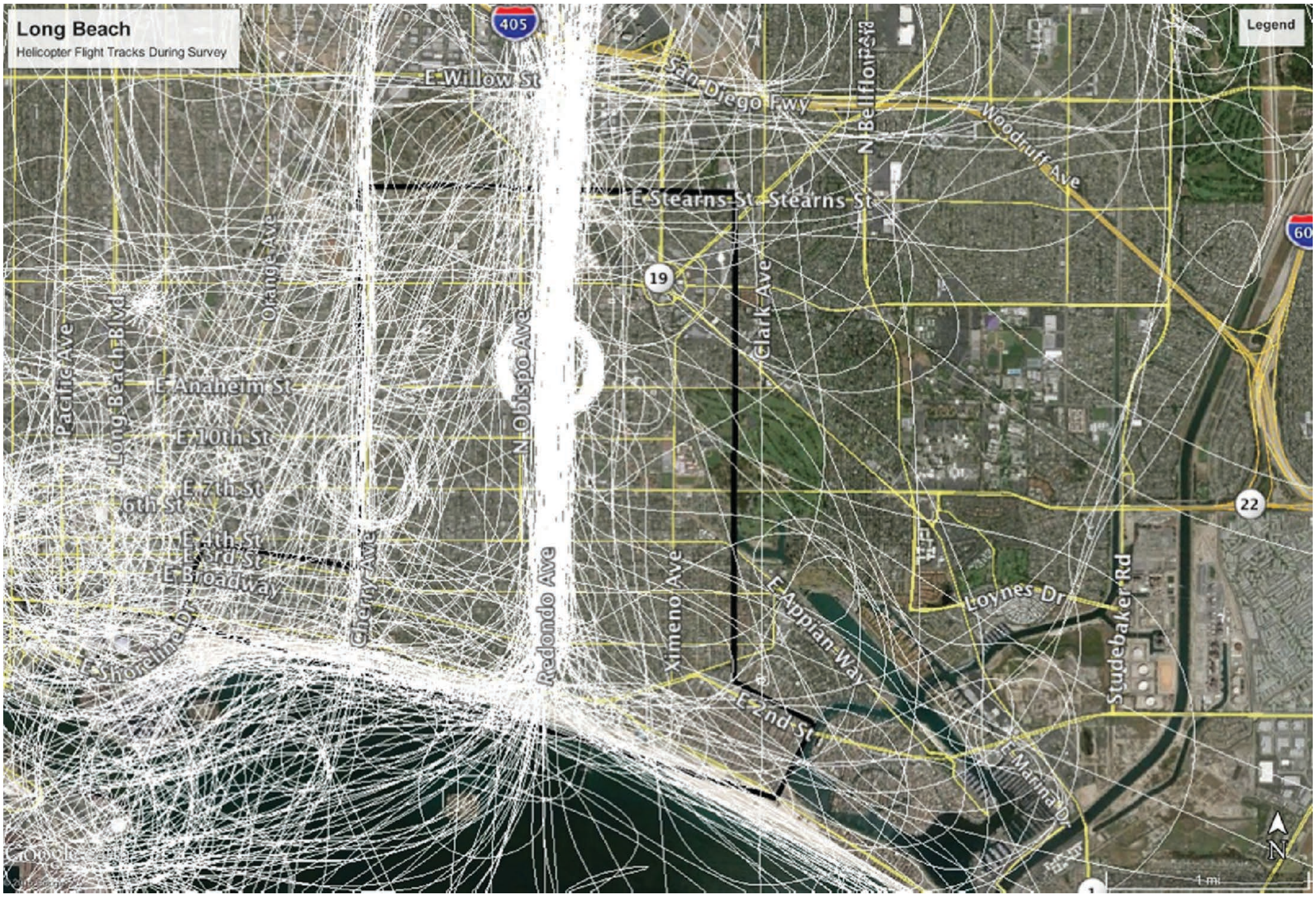


Figure 4-4. Radar flight tracks for 1 week prior to and during Long Beach survey.

4.3.3 Washington, D.C.

The DCA noise contours were generated using the INM study files previously developed for the "Runway Safety Area Improvements for Runways 15-33 and 04-22 Environmental Assessment." FAA's 2010 environmental assessment included year 2010 contours (based on actual operations) as well as a forecast contour for the year 2016. The 2016 contours for fixed-wing operations were used for current purposes. While a comparison of actual to forecast operations was not done as part of this effort, forecasting over such a short period is common. No major changes in fleet mix or other operating conditions affected the 2016 forecast. A doubling or halving of the operations would be required to change DNL by 3 dB. A 40% increase in operations would only cause a 1.5 dB increase in DNL. The 60 DNL contour closed just short of the study area, so the flight tracks over the Potomac used in the model were compared with the more recent flight tracks. This was done both because the study area was outside the focus of the EA and because it was unclear what changes in tracks occurred with the recent change due to NextGen procedures. The tracks along the Potomac were slightly modified for this study to better conform to the radar data observed during the study period. The change was minor, but aligned the helicopter model flight tracks to conform better to the radar tracks.

4.3.4 Modeling Process

The flight track databases, updated with aircraft type, were used to determine the number of operations by helicopter type, by time of day, and by the location of backbone flight tracks. Sub-track locations were developed from this information to model helicopter noise. Figures 4-4 and 4-5 show the radar flight tracks for Long Beach and Las Vegas, while Figures 4-6 and 4-7 show the helicopter tracks along the Potomac River and fixed-wing radar tracks for DCA, respectively. Figures 4-8, 4-9, and 4-10 show noise modeled backbone and sub-tracks for each helicopter noise model run. The fixed-wing INM noise model run was done using the year 2016 INM Study that Ricondo and Associates undertook as part of the EA for the Runway Safety Area project for Metropolitan Washington Airport Authority (MWAA).

The vertical profiles used for the helicopter modeling were based on the altitudes actually flown. The variations in average altitude for each study area were small. The altitudes were 550 feet AGL for LGB, 500 feet for DCA, and 1,037 feet for LAS. The profiles were the standard INM departure profiles, modified only to reflect level flight at the above altitudes and at the speeds given in the standard profiles for level flight.

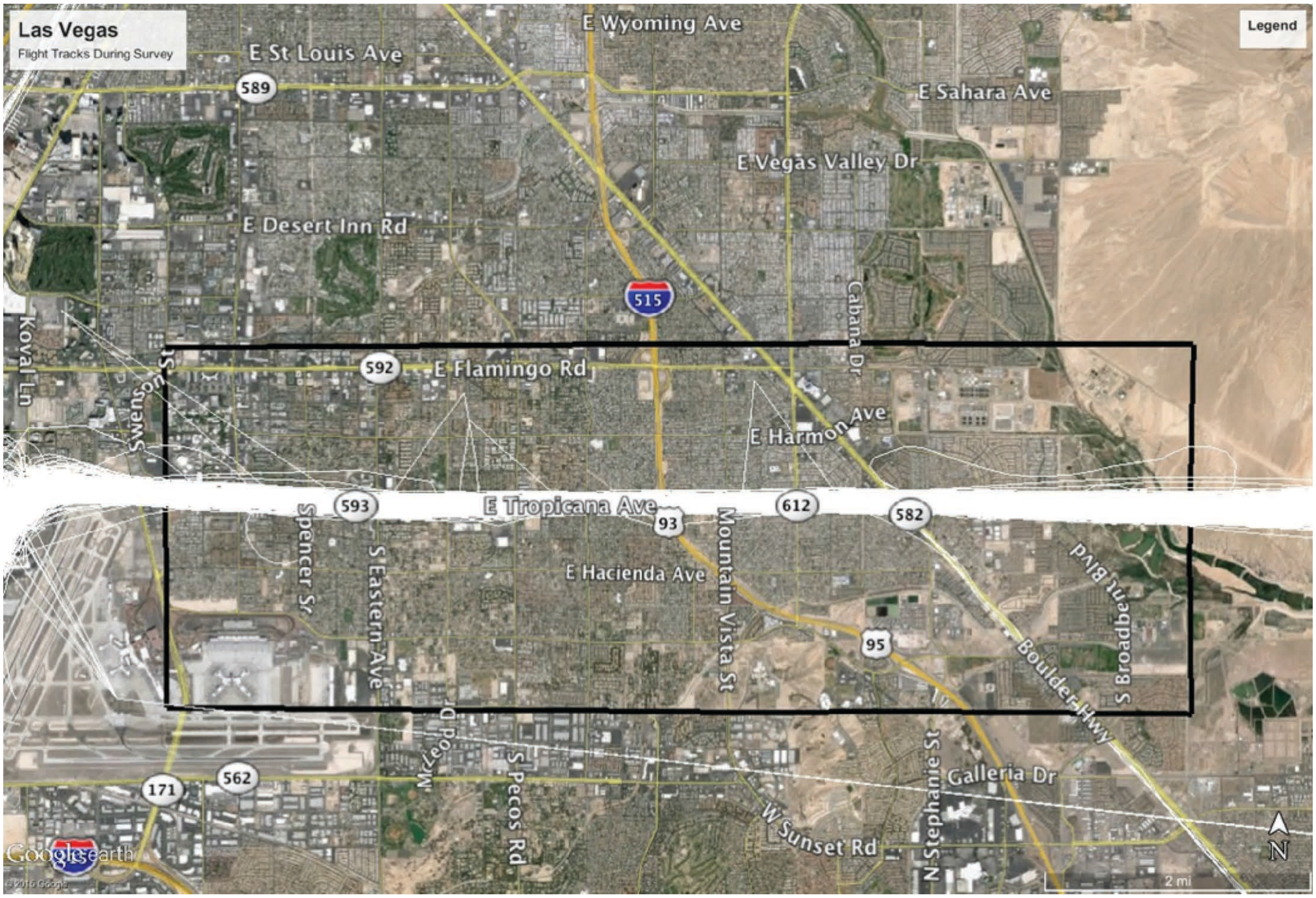


Figure 4-5. ***Radar flight tracks for 1 week prior to and during Las Vegas survey.***

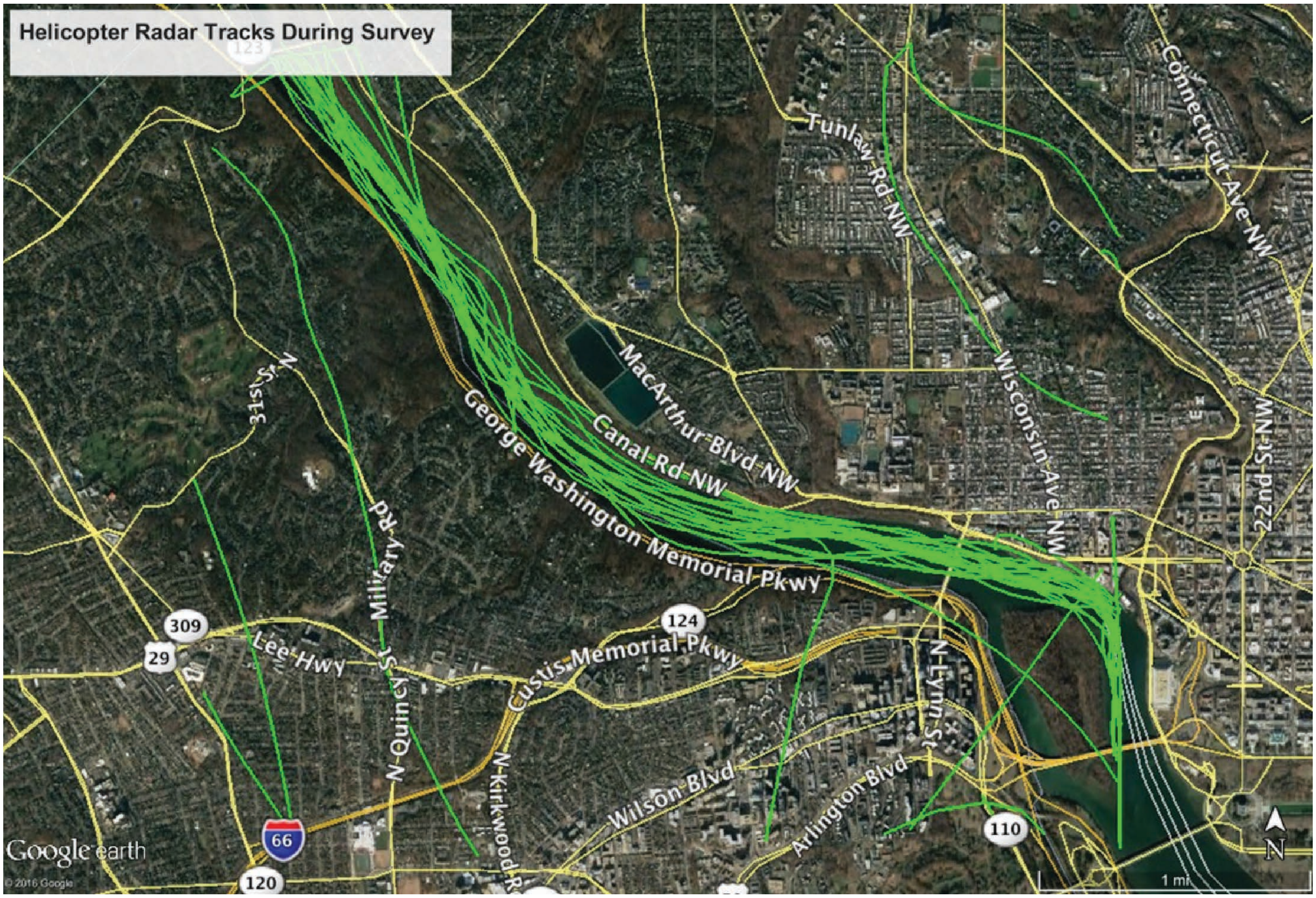


Figure 4-6. Helicopter radar tracks during DCA survey.

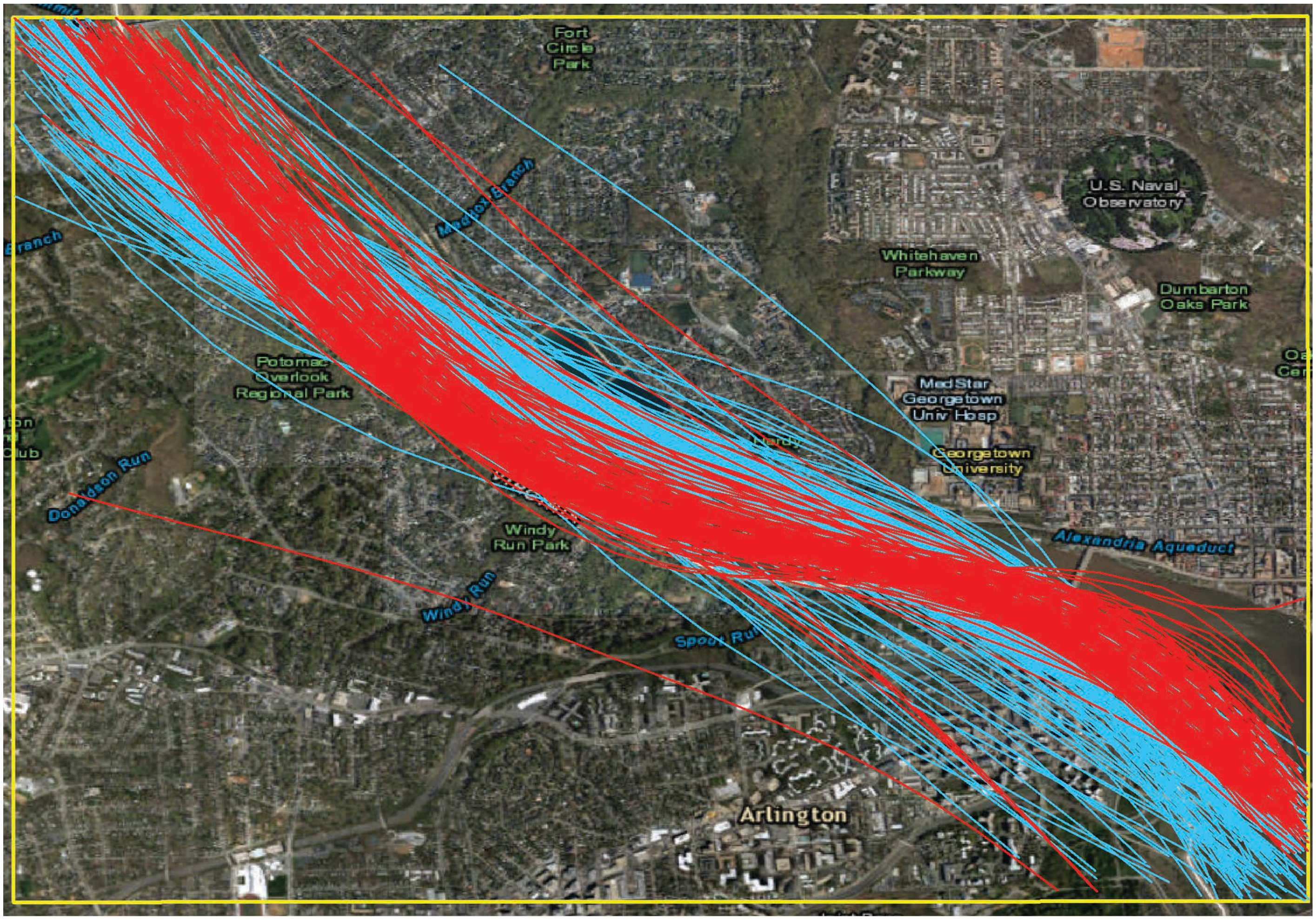


Figure 4-7. Radar tracks for fixed-wing aircraft, typical day during DCA survey (arrivals in red).

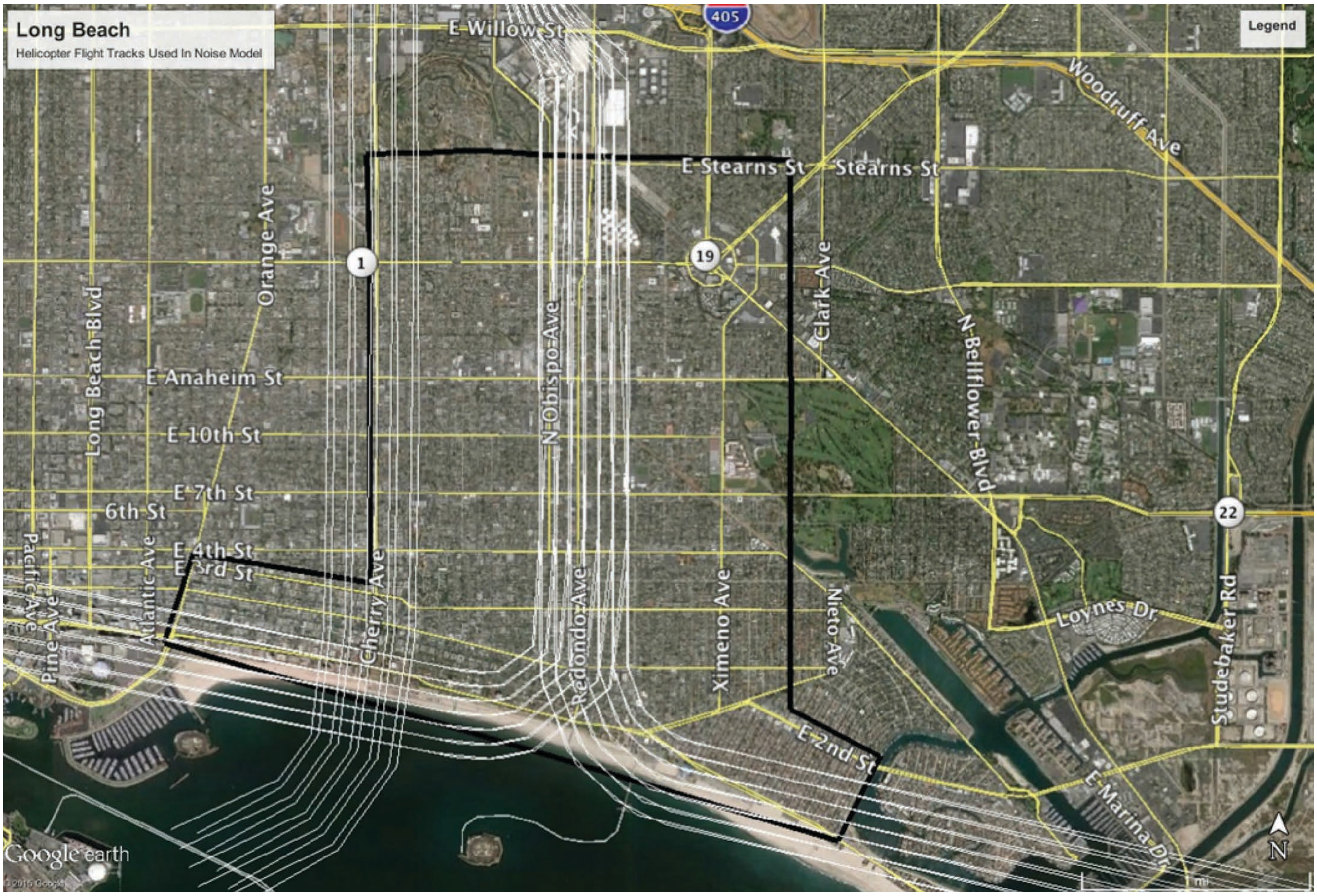


Figure 4-8. Noise model flight tracks for 1 week prior to and during Long Beach survey.

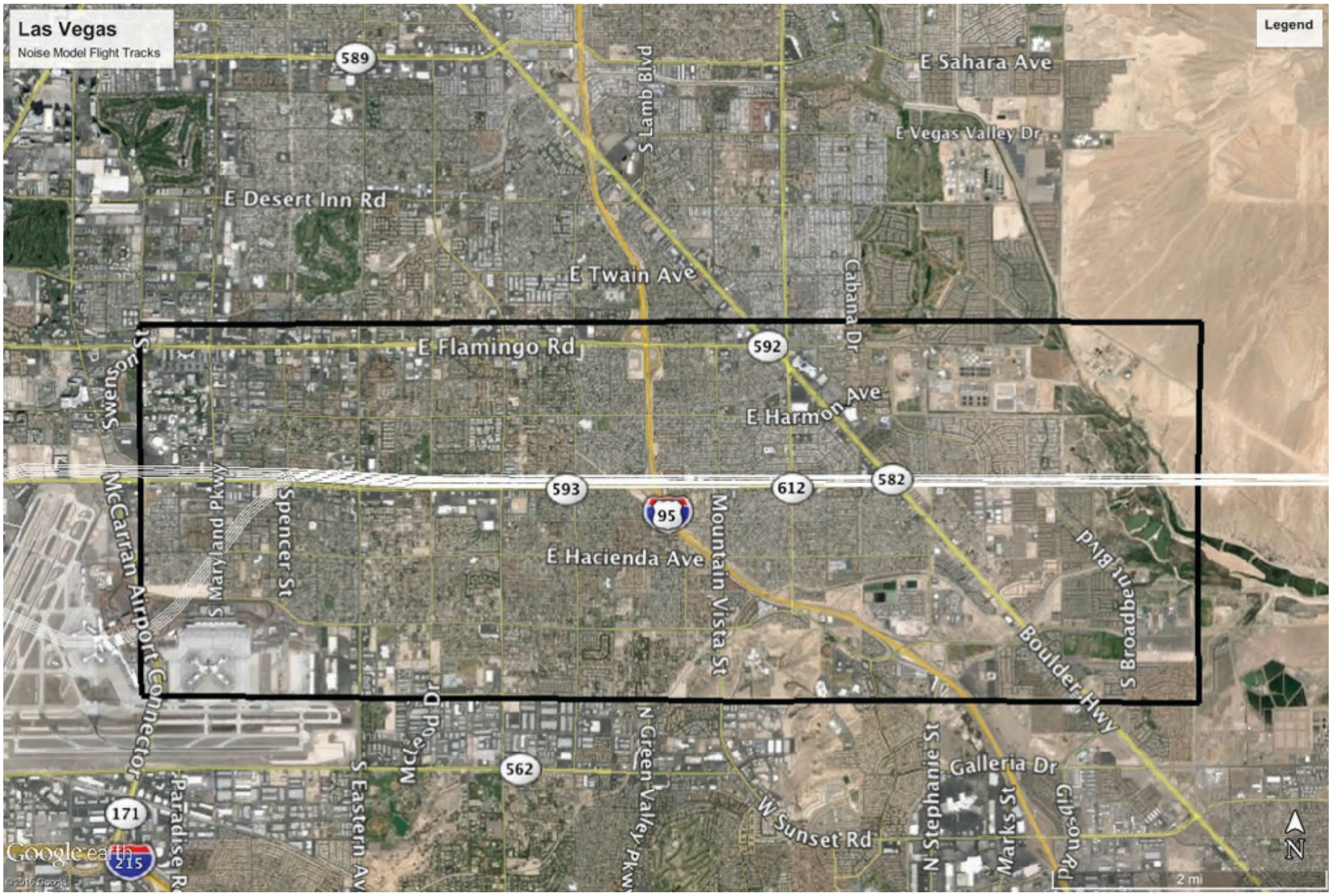


Figure 4-9. Noise model flight tracks for 1 week prior to and during Las Vegas survey.

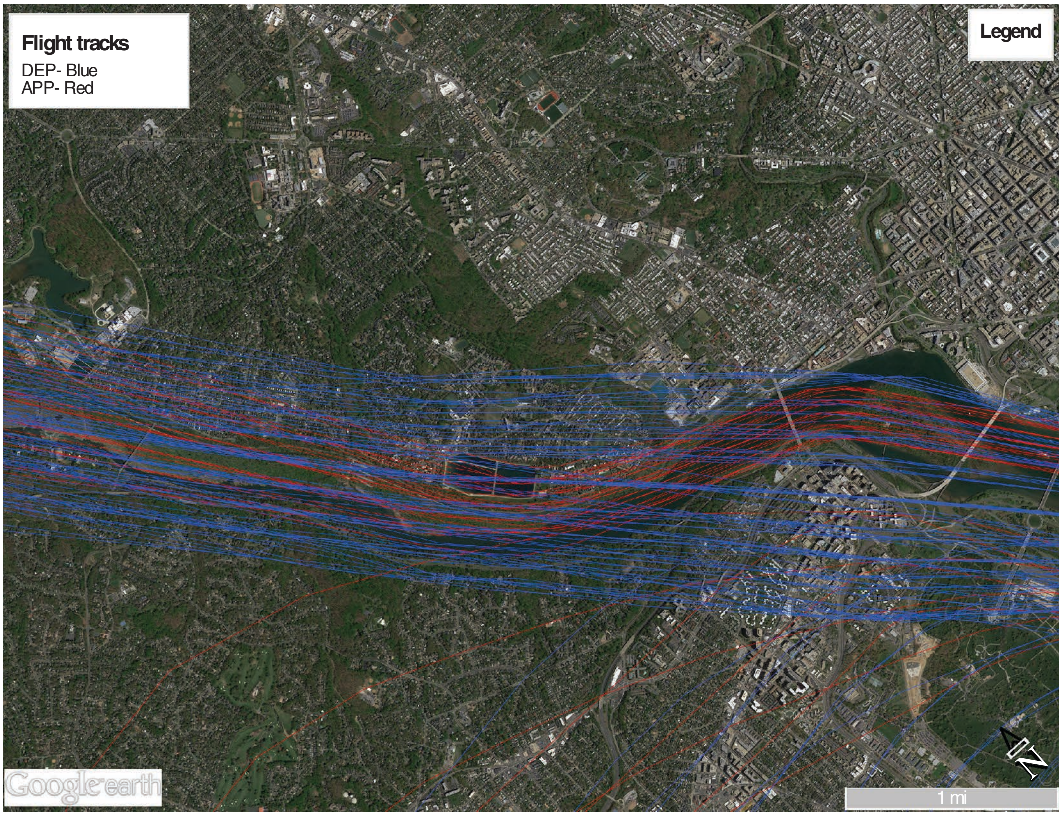


Figure 4-10. Helicopter noise model tracks for DCA survey modeling.

4.4 Estimation of Noise Exposure Values to Survey Respondents' Homes

Sampling frames prepared for each study area contained names and addresses for each household in the study area. This personally identifiable information was replaced by case numbers to comply with confidentiality requirements of the Institutional Review Board. Latitude and longitude coordinates then were coded into the noise model by case numbers. Point locations for respondents' residential addresses sufficed for purposes of calculating helicopter DNL values by case numbers and associated noise measurement locations.

4.5 Sampling Strategy

Several steps were required to prepare sampling frames for each study area. The first step was to develop preliminary definitions of helicopter-only noise contour bands adjacent to helicopter flight tracks at each airport. INM noise modeling was used to define these noise contour bands. Eight such preliminary helicopter noise exposure bands, shown in Figure 4-11, were identified at LGB. Seven such preliminary exposure bands were identified at LAS, as shown in Figure 4-12. The sampling bands in Washington D.C. are shown in Figure 4-13.

In each study area, households within the preliminary noise exposure bands were then identified from information contained in the two telephone databases (landline and cell phone) by latitude/longitude coordinates for the street addresses. This measure permitted a count of the number of interview-eligible sites within each noise contour band. The same latitude/longitude

Figure 4-11. Preliminary helicopter-only noise exposure bands in vicinity of helicopter flight tracks at LGB.

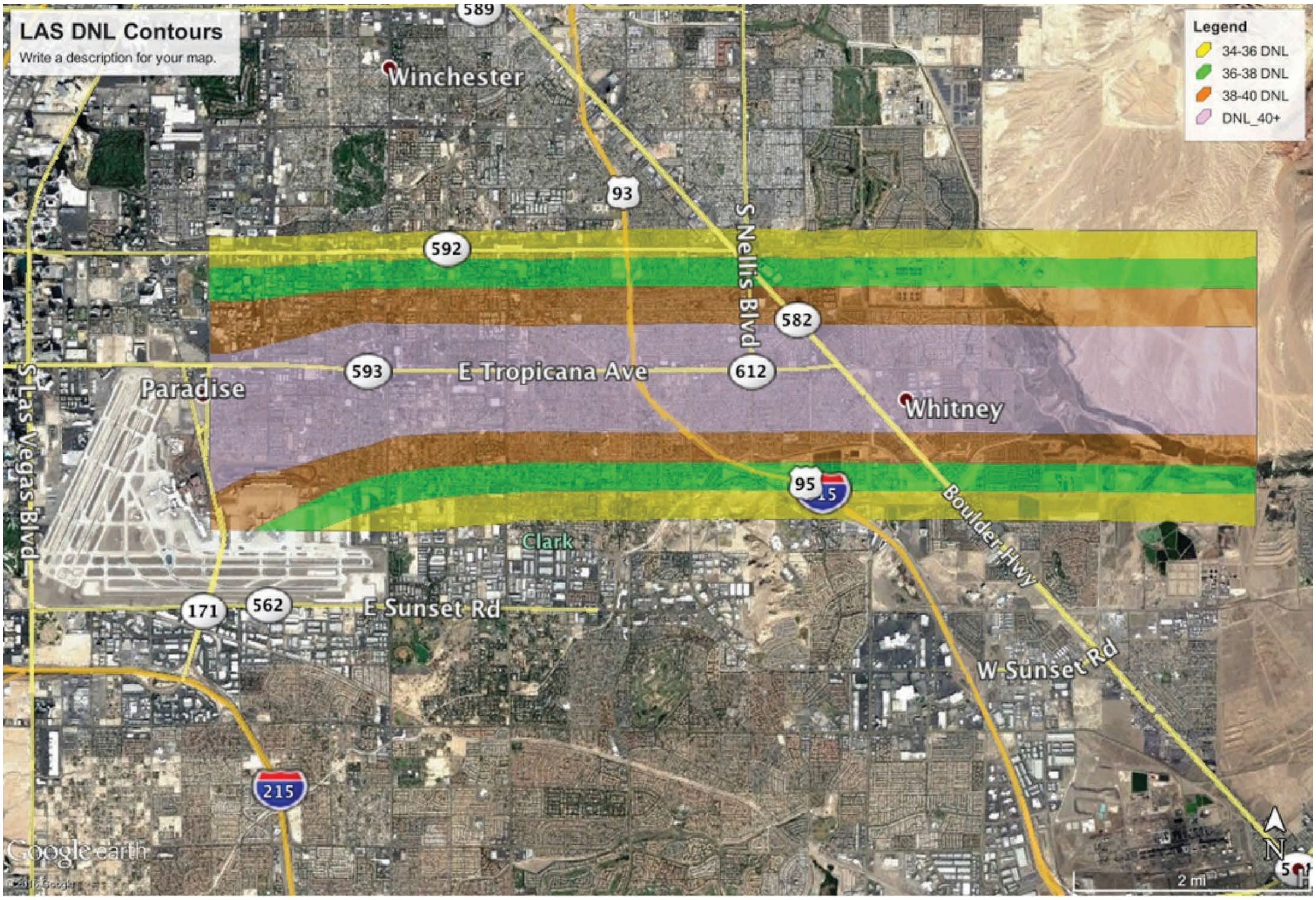


Figure 4-12. Preliminary helicopter-only noise exposure bands in vicinity of helicopter flight tracks at LAS.

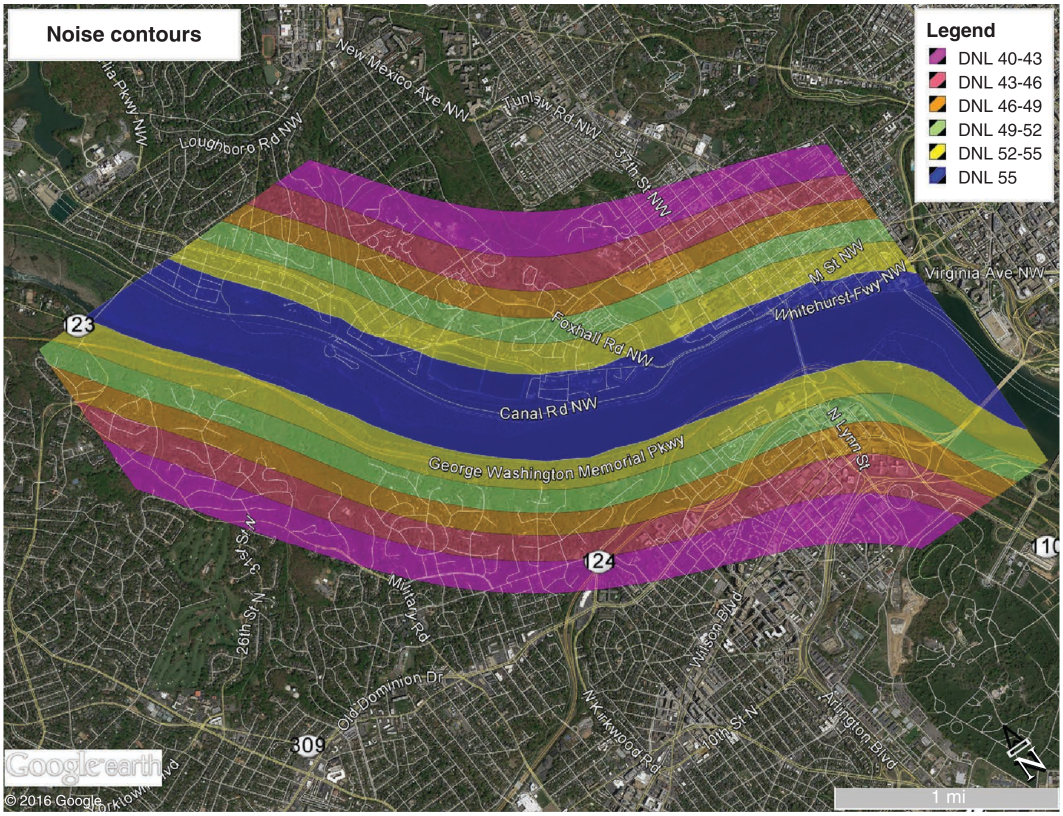


Figure 4-13. Noise exposure bands for DCA helicopter noise survey.

coordinates were later used by noise modeling software to refine the preliminary estimates of helicopter noise exposure for each respondent.

The landline and cell phone databases were compiled from public records and proprietary databases.[16]

The first of the two databases contained telephone-subscribing households in a nationwide, U.S. landline database (generally known as "Listed Landline" database). This database contains records of all known U.S. households subscribing to landline telephone service. A second database, containing records of wireless telephone subscribers, were drawn from a proprietary database of wireless phones containing more than 125 million wireless phones nationally. (The wireless phone database is one developed from data provided by cell phone users and collected by commercial users.)

A joint sampling frame was constructed from the telephone-subscribing households within areas eligible for interview in the two databases, from which a stratified (by expected helicopter noise exposure) random sample was then drawn. The LGB sample released for dialing contained 7,684 listed landline-subscribing households and 2,878 wireless-subscribing households. The LAS sample contained 4,688 listed landline-subscribing households and 3,135 wireless-subscribing households. The DCA sample contained 2,873 listed landline-subscribing households and 1,351 wireless-subscribing households. These were divided into replicates of 1,000 (listed landline) and 500 (wireless subscribing) telephone numbers for efficiency of use in computer-assisted telephone interviewing (CATI). In this context, replicate refers to a sub-sample of the entire database. The database was divided in these replicates for efficiency in achieving the minimum number of callbacks to each number where a respondent did not agree to an interview and to ensure no more calls were initiated than needed to achieve the sample goals.

4.6 Interviewing Procedures

A single structured telephone interview was sought from an adult member of each household within sample replicates released for interview contact attempts. The structured interview, introduced as a study of neighborhood living conditions, was based on a questionnaire containing fifteen items. The questionnaire is reproduced in Chapter 3, Table 3-5. Questions posed to respondents are shown in black; closed response categories and codings for them are shown in blue; and instructions to interviewers are shown in red.

CATI methods were used by a total of 152 trained and centrally supervised interviewers to make 18,385 interview contact attempts. As many as 15 contact attempts (an initial attempt followed by up to 14 callbacks at different times of day over a weeklong interviewing period) were made to households identified in the sampling frame. Interviewers sought to conduct an interview with any adult, verified household member. Fields (1993) has shown that demographic variables such as age, sex, social status, income, education, home ownership, dwelling type, and length of residence have no systematic effect on reports of noise-induced annoyance.

CHAPTER 5

Analyses of Noise Exposure Measurements and Interview Findings

For reasons previously described, helicopter noise exposure levels were estimated by both measurement and modeling at the Long Beach and Las Vegas sites, and by noise modeling alone in Washington, D.C.

5.1 Comparison of Measurement and Modeling Estimates of Exposure Levels at Long Beach and Las Vegas Survey Sites

The Long Beach and Las Vegas survey areas were fully developed residential areas, with substantial background noise. DNLs associated with helicopter operations were therefore estimated for measurement sites within each of these two survey areas by cumulating measured sound exposure level (SEL) values for each helicopter flyover during the week prior to interviewing. An analysis was then conducted on a flyover-by-flyover basis to determine whether noise levels recorded during flyovers represented helicopter-produced noise exposure or noise exposure produced by other noise sources.

5.1.1 Measured DNLs

The times of the closest point of approach (CPA) of helicopter flights to each monitoring site were entered into a database. The database also included all 1 second L_{eq} data (A-weighted, C-weighted, and ⅓ octave band) for a period of 1 minute prior to and 1 minute after the CPA time. Signal-to-noise ratios of flyovers were adequate to distinguish helicopter noise emissions from ambient noise near CPA times, but were difficult to unambiguously distinguish from background noise at greater distances and times before and after CPA.

SEL values as a function of distance for both A- and C-weighted SEL values were accordingly examined more closely. The examination showed that any noise event associated with a helicopter flight track that passed within a 3,000-foot radius of a monitoring point had a maximum A-weighted noise level (L_{max}) ≥ 55 dB, lasted at least 3 seconds, and could be attributed to a helicopter overflight. Measured noise levels that met these criteria were accumulated to compute daily, helicopter-only DNL values for each site. (C-weighted L_{max} values were not used for this purpose, because the background noise included substantial C-weighted noise.)

5.1.2 Modeled DNLs

Operational information and radar data recorded during the survey were then used to model DNL at each measurement site. This was used to compare modeled to measured DNL values. Several iterations of the model were completed so that at each site the modeled noise matched the

Table 5-1. Helicopter operations data.

Type of Helicopter	Average Daily Overflights		
	Day	Night	Total
Long Beach			
B206L	0.4	0.1	
R22	1.8	0.4	
R44	2.4	0.5	
S76	1.7	0.3	
SA350D	9.2	1.8	
	15.5	3.1	18.6
Las Vegas			
EC130	103.4	11.4	
SA350D	31.6	3.4	
	135.0	14.8	149.8
Washington, D.C.			
A109	3.4	0.0	
B212	5.0	0.0	
S61	1.6	0.0	
S70	3.6	0.0	
SA365N	4.6	0.0	
	18.2	0.0	18.2

measured DNL values. Locations of dispersed flight tracks and numbers of operations assigned to dispersed tracks in the modeling software were modeled to measured estimates of DNL values. Table 5-1 shows the numbers of helicopter operations by aircraft type and time of day.

Table 5-2 compares measured with modeled noise levels at the Long Beach and Las Vegas survey sites. Differences between measured and modeled DNL values were less than 2 dB, except at Site 4 in Long Beach.[17] Differences of this magnitude are well within (1) the overlapping uncertainty of measurement, (2) uncertainty in noise modeling, (3) the uncertainty inherent in the measurement system for SEL (approximately + 0.8 dB, per ISO 20906, Annex B), and (4) the sampling uncertainty for a short-term measurement period.

5.1.3 Relation of A-Weighted to C-Weighted SELs

A- and C-weighted SEL differences were computed for each flight in each study area using measurement data. Figures 5-1 and 5-2 plot A- and C-weighted SELs against each other at the two study sites. The two noise metrics are highly correlated at each site, despite the scatter about the regression line of about ±5 dB. The difference between A- and C-weighted SEL is greater at Las Vegas (approximately 10 dB difference) than at Long Beach (approximately 5 dB difference). This is almost certainly due to the absence of smaller Robinson rotorcraft from the Las Vegas fleet. The 1 second L_{eq} thresholds at LGB and LAS were 55 and 50 dB, respectively. The difference in threshold was due to ambient noise levels. The result was that most events correlated had

Table 5-2. Comparison of measured with modeled DNL values.

	DNL			
Study/Estimation Method	Site 1	Site 2	Site 3	Site 4
LGB Measured	47.1	48.8	47.9	44.7
LGB Modeled	46.0	47.5	49.7	49.3
Difference*	-1.1	-1.3	1.8	4.6
LAS Measured	52.0	50.6	48.7	52.9
LAS Modeled	53.0	49.1	46.8	52.9
Difference*	1.0	-1.5	-1.9	0.0

*Positive numbers indicate that the modeled DNL was greater than the measured DNL.

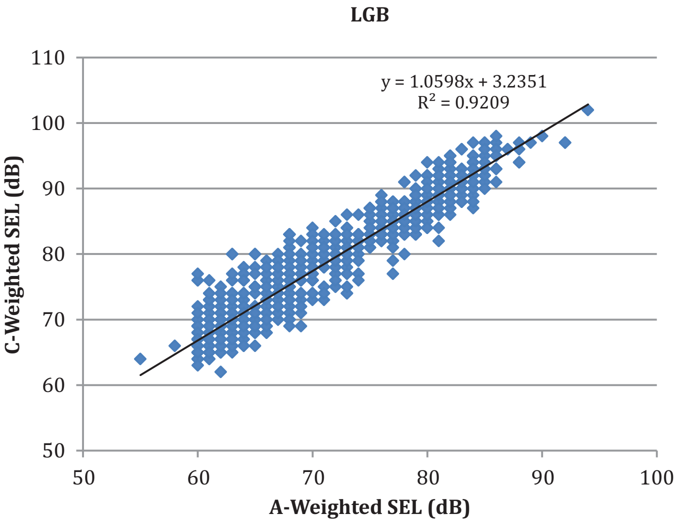


Figure 5-1. ***Comparison of measured A-weighted and C-weighted SELs of helicopter overflights in Long Beach interviewing area.***

SELs above 60 and 55 dB, respectively. The handful of events with SELs below these levels were events that exceeded the threshold, but had very short durations.

Section 5.6 analyzes C-weighted and low-frequency exposure estimates in greater detail at the three survey sites.

5.2 Disposition of Contact Attempts

A total of 10,562 contact attempts (7,684 to land line telephones and 2,878 to wireless telephones) were made in Long Beach, and 7,803 contact attempts (4,668 to land line telephones and 3,135 to wireless telephones) in Las Vegas. For Washington D.C. 4,224 (2,873 landline and 1,351 wireless) contact attempts were made. Table 5-3 summarizes the outcomes of these

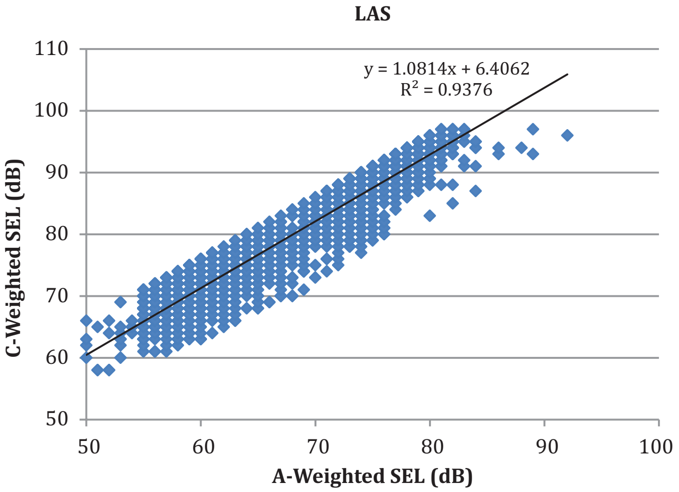


Figure 5-2. ***Comparison of measured A-weighted and C-weighted SELs of helicopter overflights in Las Vegas interviewing area.***

Table 5-3. Interview completion and refusal rates by site and type (landline/wireless) of telephone service.

Sample Disposition	Long Beach		Las Vegas		Washington, D.C.	
	Landline	Wireless	Landline	Wireless	Landline	Wireless
Total Sample Released for Dialing	7,684	2,878	4,688	3,135	2,873	1,351
Non-Sample	3,511	419	2,713	1,028	1,137	553
Noncontact	1,913	1,022	0	0	1,244	390
Non-Sample + Noncontact	5,424	1,441	2,713	1,028	2,381	943
Contacted Sample	2,260	1,437	1,975	2,107	492	408
Refused Interviews	1,466	432	1,348	1,973	152	306
Completed Interviews	794	295	607	134	340	102
Interview Completion Rate	35.1%	20.5%	30.7%	6.4%	69.1%	20.7%
Interview Refusal Rate	64.9%	30.1%	68.2%	93.8%	30.9%	75.0%

interview contact attempts. The "non-sample" category includes disconnects, businesses and other non-residential telephone numbers, fax machines, modem lines, wrong addresses, changed numbers, and non-English speaking households. "Noncontacts" includes busy signals, no answer, call blocked, and answering machines after fifteen attempts to contact. The completion rates are calculated as {completed interviews/[total – (non-sample + noncontact)]}, while the refusal rates are calculated as {refused interviews/[total – (non-sample + noncontact)]}.

5.3 Locations of Respondents' Residences

The locations of households that completed interviews are shown in Figures 5-3, 5-4, 5-5, and 5-6 as green dots, enlarged sufficiently to preserve confidentiality of individual respondents. These figures also show the approximate locations of households in which respondents were highly annoyed by helicopter noise (and in the case of Washington, D.C., interviews, by fixed-wing aircraft noise.)

Households completing interviews were generally well dispersed geographically throughout the study areas, as were highly annoyed respondents. In Long Beach, some clustering of highly annoyed respondents was observed along the Redondo corridor, and along the northern section of the coastal route. Much less clustering was observed in Las Vegas along Tropicana Avenue, and in the Washington, D.C., area.

5.4 Analysis of Interview Responses

5.4.1 Tabulation of Responses

Table 5-4 displays responses to individual questionnaire items for the three interviewing sites, both separately and combined. (Percentage values may sum to less than 100 because invalid responses were omitted.) The reported results do not differentiate between respondents contacted by home landline and wireless telephones.

Table 5-5 shows similar information for mean estimated helicopter noise exposure levels and distances from flight corridors.

5.4.1.1 Narrative Account of Responses to Questionnaire Items

This sub-section summarizes responses to individual questionnaire items across sites in general terms. More detailed accounts of the findings are presented in the following subsections.

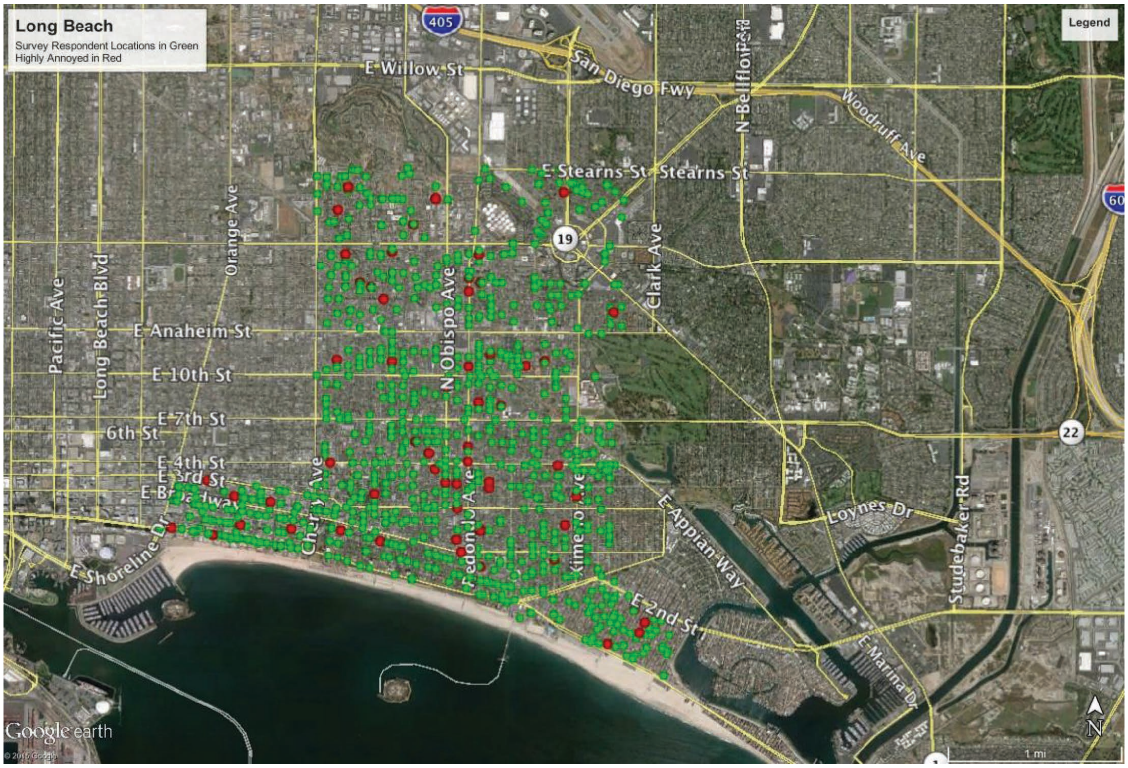


Figure 5-3. Approximate locations of Long Beach respondents (in green), and those highly annoyed by helicopter noise (in red).

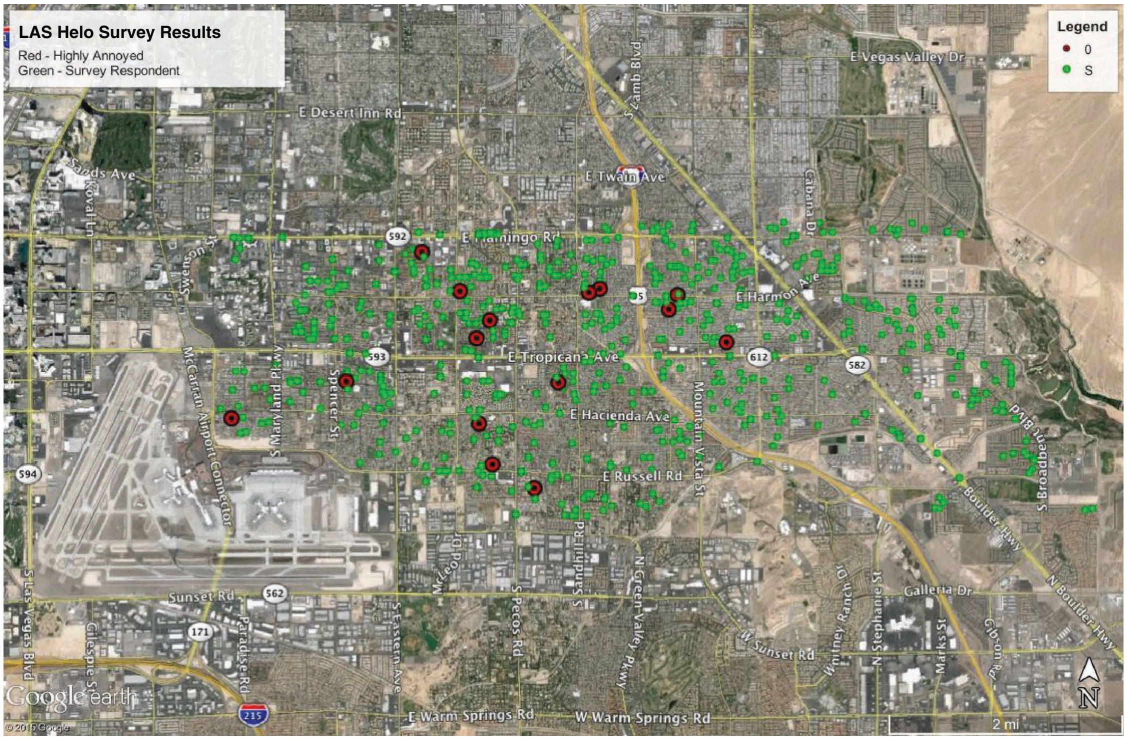


Figure 5-4. Approximate locations of Las Vegas respondents (in green), and those highly annoyed by helicopter noise (in red).

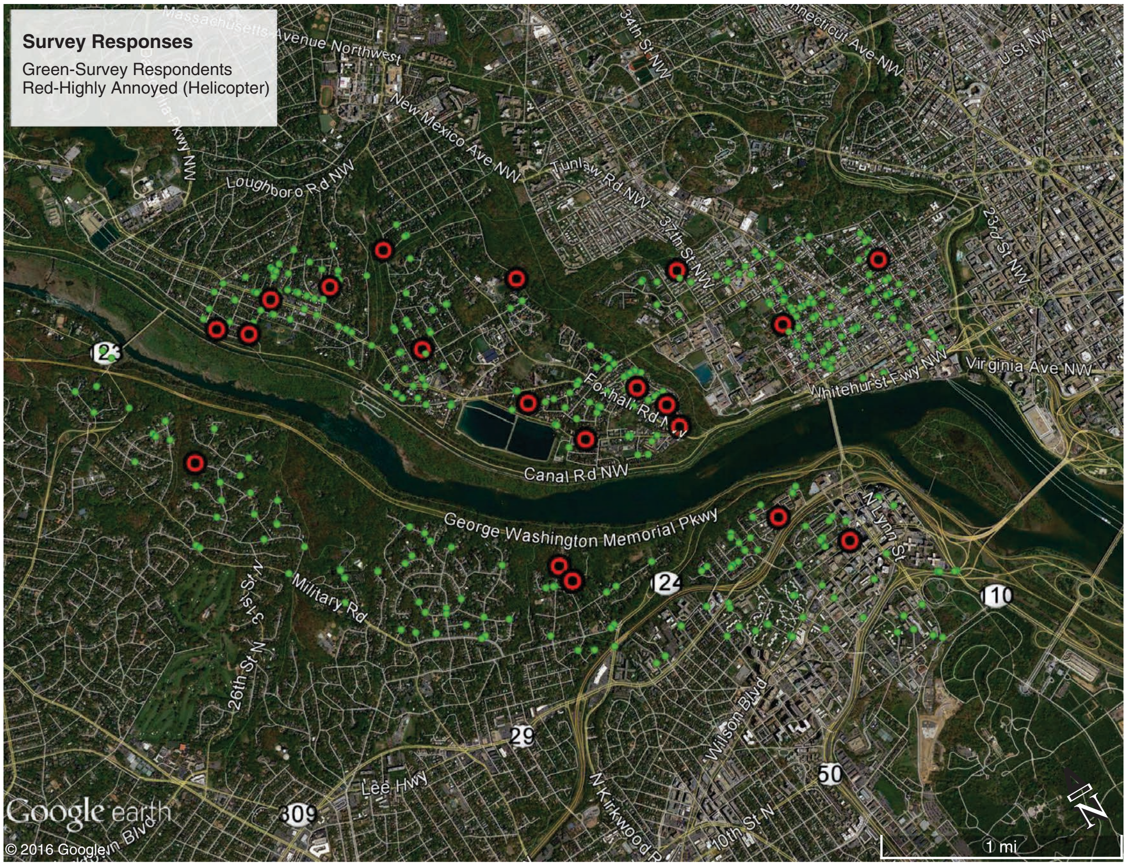


Figure 5-5. Approximate locations of Washington respondents (in green), and those highly annoyed by helicopters (in red).

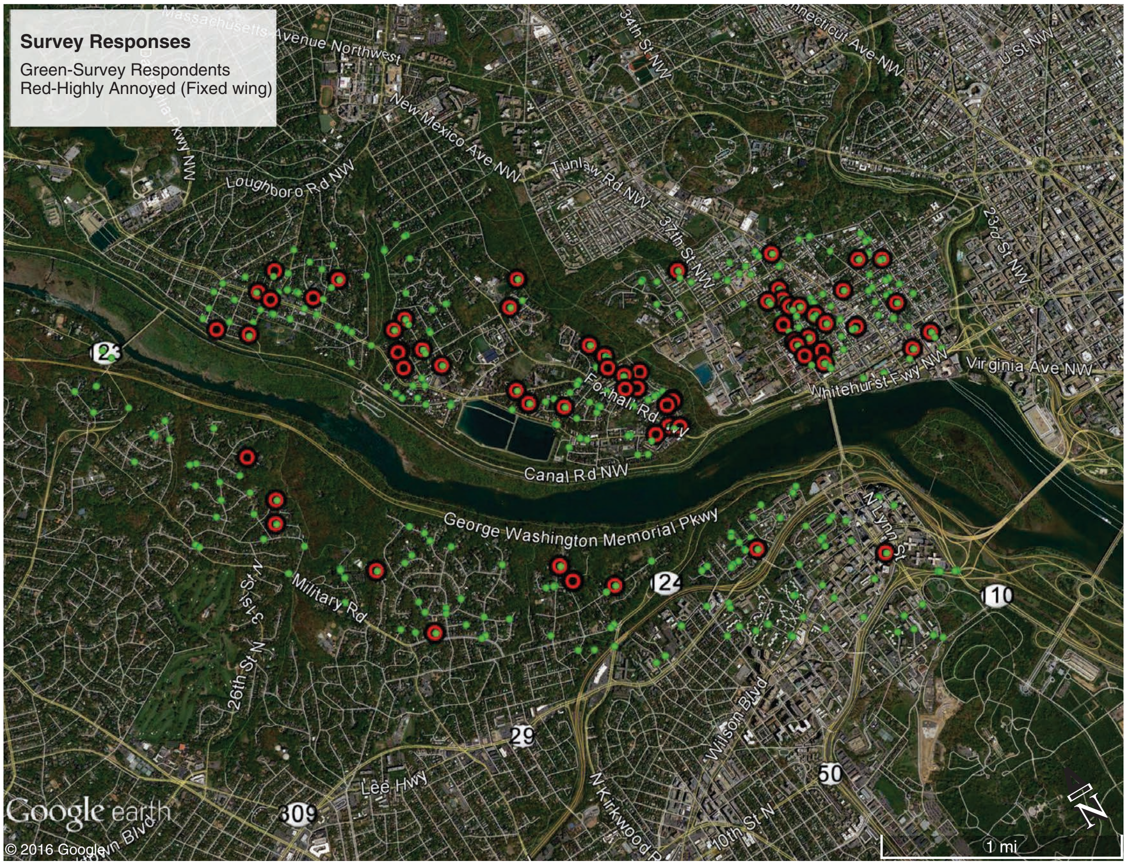


Figure 5-6. Approximate locations of Washington respondents (in green), and those highly annoyed by fixed-wing aircraft noise (in red).

Table 5-4. Questionnaire response percentages and frequencies.

QUESTIONNAIRE ITEM	CODING	LONG BEACH % (count) *N* = 1,089	LAS VEGAS % (count) *N* = 741	WASHINGTON % (count) *N* = 442	COMBINED SITES % (count) *N* = 2,272
1 Duration of residence	less than one year	2.6% (28)	2.7% (20)	2.7% (12)	2.6% (1,573)
	at least 1 year but less than 2 years	5.8% (63)	3.2% (24)	2.0% (9)	4.2% (98)
	2 to 5 years	23.0% (250)	19.8% (147)	18.6% (82)	21.2% (475)
	5 to 10 years	52.5% (572)	59.2% (439)	67.9% (300)	57.7% (1,311)
	more than 10 years	16.2% (176)	15.0% (111)	8.8% (39)	14.3% (326)
4 Characterization of neighborhood as quiet or noisy	Quiet	68.1% (742)	84.1% (623)	47.1% (208)	69.2% (1,573)
	quiet except for aircraft	4.2% (32)	6.1% (45)	31.9% (141)	10.2% (232)
	Noisy	24.4% (266)	8.6% (63)	3.4% (15)	17.9% (407)
4A Judged noisiness of neighborhood	quiet (from Item 4)	68.1% (742)	84.1% (623)	47.1% (208)	69.2% (1,573)
	Slightly noisy	2.8% (31)	1.8% (13)	1.1% (5)	2.2% (49)
	Moderately noisy	13.5% (147)	3.9% (29)	5.6% (38)	9.4% (214)
	Very noisy	4.2% (46)	1.6% (12)	5.0% (22)	3.5% (80)
	Extremely noisy	3.5% (38)	1.2% (9)	2.7% (12)	2.6% (59)
5A Annoyance of street traffic noise	not at all (from Item 5)	71.7% (781)	85.7% (635)	83.0% (367)	78.5% (1,783)
	Slightly	8.3% (90)	5.8% (43)	4.8% (21)	6.8% (154)
	Moderately	10.9% (119)	4.3% (32)	7.5% (33)	8.1% (184)
	Very	3.9% (43)	1.8% (13)	0.9% (4)	2.6% (60)
	Extremely	4.1% (45)	1.2% (9)	2.7% (12)	2.9% (66)
6A Frequency of notice of helicopter noise	not noticed (from Item 6) or less than once a day	36.9% (402)	51.4% (381)	47.5% (210)	43.7% (993)
	about once a day	17.0% (294)	19.3% (143)	18.6% (82)	22.8% (519)
	a few times a day	19.1% (208)	16.5% (122)	16.5% (73)	17.7% (403)
	several times or more per hour	4.5 (49)	6.3% (46)	5.0% (22)	5.1% (117)
7A Judged annoyance of helicopter noise	not at all (from items 6 and 7)	67.6% (736)	85.4% (633)	71.8% (317)	74.2% (1,686)
	Slightly	6.2% (67)	2.3% (17)	4.5% (20)	4.6% (104)
	Moderately	7.5% (82)	3.5% (26)	7.7% (34)	6.3% (142)
	Very	3.9 (42)	1.5% (11)	2.5% (11)	2.8% (64)
	Extremely	5.2 (57)	1.9% (14)	4.5% (20)	4.0% (91)
8A Frequency of notice of other aircraft noise	not noticed (from Item 8) or less than once a day	69.3% (755)	66.5% (493)	24.0% (106)	59.6% (1,354)
	once a day	14.2% (154)	12.8% (95)	12.2% (54)	13.3% (303)
	a few times a day	6.3% (69)	9.0% (67)	23.3% (103)	10.5% (239)
	several times or more per hour	1.4% (15)	6.1% (45)	31.4% (139)	8.8% (199)
9A Annoyed by aircraft other than helicopters	not at all (from Item 9)	86.5% (942)	90.6% (671)	50.5% (223)	80.8% (1,836)
	Slightly	2.2% (24)	2.3% (17)	5.2% (23)	2.8% (64)
	Moderately	2.8% (31)	1.6% (12)	14.7% (65)	4.8% (108)
	Very	1.1% (12)	0.8% (6)	7.9% (35)	2.3% (53)
	Extremely	1.8% (20)	1.2% (9)	15.2% (67)	4.2% (96)
10A Degree of annoyance with helicopter thumping or slapping sounds	not at all (from Item 10)	79.5% (866)	87.2% (646)	75.8% (335)	81.3% (1,847)
	Slightly	5.5% (60)	4.2% (31)	4.5% (20)	4.9% (111)
	Moderately	3.6% (39)	3.7% (20)	4.8% (21)	3.5% (80)
	Very	2.0% (22)	0.9% (7)	3.2% (14)	1.9% (43)
	Extremely	2.0% (22)	1.3% (10)	3.2% (14)	2.0% (46)
11A Annoyed by helicopter buzzing	not at all (from Item 11)	77.6% (845)	87.0% (645)	79.6% (352)	76.9% (1,747)
	Slightly	6.2% (67)	23.2% (24)	2.5% (11)	4.2% (95)
	Moderately	4.8% (52)	3.0% (22)	4.1% (18)	4.5% (102)
	Very	1.5% (16)	0.7% (5)	1.8% (8)	4.0% (92)
	Extremely	2.1% (23)	1.3% (10)	2.5% (11)	1.9% (44)
12A Annoyed by helicopter whining or tonal	not at all (from Item 12)	83.6% (910)	90.7% (672)	80.1% (354)	85.2% (1,936)
	Slightly	2.8% (31)	1.6% (12)	3.2% (14)	2.5% (57)
	Moderately	2.0% (22)	1.8% (13)	2.9% (13)	2.1% (48)
	Very	1.7% (19)	0.7% (5)	1.6% (7)	1.4% (31)
	Extremely	1.7% (18)	0.9% (7)	2.0% (9)	1.5% (34)
13A Annoyed by helicopter vibrations or rattling	not at all (from Item 13)	76.4% (832)	87.4% (648)	74.9% (331)	79.9%(1,811)
	Slightly	5.5% (60)	4.0% (30)	6.1% (27)	5.1% (117)
	Moderately	4.6% (50)	1.6% (12)	4.3% (19)	3.6% (81)
	Very	2.9% (32)	0.9% (7)	2.7% (12)	2.2% (51)
	Extremely	3.4% (37)	1.6% (12)	3.4% (15)	2.8% (64)
14 Frequency of notice of vibration or rattling noises	once a week or less	60.7% (661)	48.6% (360)	55.2% (244)	55.7% (1,265)
	once a day	7.8% (85)	4.7% (35)	5.9% (26)	6.4% (146)
	several times a day	5.6% (61)	4.0% (30)	6.3% (28)	5.2% (119)
15A Frequency of complaint	never (from Item 15)	96.2% (1,048)	98.1% (727)	92.5% (409)	96.1% (2,184)
	Once	0.5% (5)	0.1% (1)	1.1% (5)	0.5% (11)
	a few times	0.7% (8)	.05% (4)	1.6% (7)	0.8% (19)
	many times	0.4% (4)	0.8% (6)	1.1% (5)	0.7% (15)

Table 5-5. Means and standard deviations of respondents' helicopter noise exposure levels and distances from flight corridors.

MEASURE	Long Beach Mean (SD) *N*=1,089	Las Vegas Mean (SD) *N*=741	Washington Mean (SD) *N*=442	Combined Sites Mean (SD) *N*=2,272
Mean DNL Due to Helicopters (standard deviation of DNL)	40.3 (6.4)	43.8 (5.5)	43.3 (4.8)	42.0 (6.1)
Mean Distance from Flight Corridor, in Decimal Nautical Miles (standard deviation of distance from center of corridor)	0.42 (0.3)	0.49 (0.3)	0.42 (0.2)	0.44 (0.3)

SD = standard deviation.

Duration of Residence (Item 1). All of the neighborhoods in which interviewing was conducted were characterized by stable residential populations. Fewer than 3% of the respondents at any of the interviewing sites had lived at their current addresses for less than 6 months prior to the conduct of the present study, while half or more of the respondents had lived at their current addresses for 5 to 10 years. The populations of the interviewing sites were thus thoroughly familiar with helicopter noise exposure.

Characterization of Neighborhood as Quiet or Noisy (Item 4). Large majorities of respondents in Long Beach and Las Vegas described their neighborhoods as quiet. Nearly half of the respondents in Washington did as well. Nonetheless, nearly a quarter of the respondents in Long Beach described their neighborhood as noisy, and nearly a third of the respondents in Washington described their neighborhood as "quiet, except for aircraft noise."

Only small percentages of respondents at all sites described their neighborhoods as "highly" ("very" or "extremely") noisy: 7.7% in Long Beach and Washington, and 2.8% in Las Vegas. These figures closely resembled the percentages of respondents highly annoyed by traffic noise in Long Beach and Las Vegas (8.0% in Long Beach and 3% in Las Vegas), but were only about half (3.6%) of the percentage describing their neighborhoods as very or extremely ("highly") noisy in Washington.

Frequency of Notice of Helicopters (Item 6). Figure 5-7 shows how often respondents reported noticing helicopters in Long Beach, Las Vegas, and Washington, respectively. Only small minorities reported noticing helicopters more than a few times a day, and responses in the three survey areas were quite similar. This finding was unexpected because respondents at LAS were exposed to ten times as many helicopter operations as LGB.

Association between Helicopter Noise Annoyance and Interviewing Method. A 2 × 2 Chi-square analysis revealed no significant difference in reports of high annoyance by helicopter noise and the respondent's form of telephone subscription (wireless or landline) in the combined data from the three interviewing sites, $p = .561$. Likewise, no statistically significant differences in the prevalence of high annoyance were observed at any of the three data collection sites individually, $p > .17$.

Annoyance with Specific Characteristics of Helicopter Noise (Items 10–12). *Blade Slap* Roughly 80% of all respondents indicated in questionnaire Item 10 that they were not annoyed in any degree by main rotor impulsive noise ("thumping or slapping"). Only about 4% of respondents across sites described themselves as highly annoyed by such sounds.

Tail Rotor/Sideline Noise A similar percentage of respondents indicated in questionnaire Item 9 that they were not at all annoyed by "buzzing" noises (of the sort often created by tail

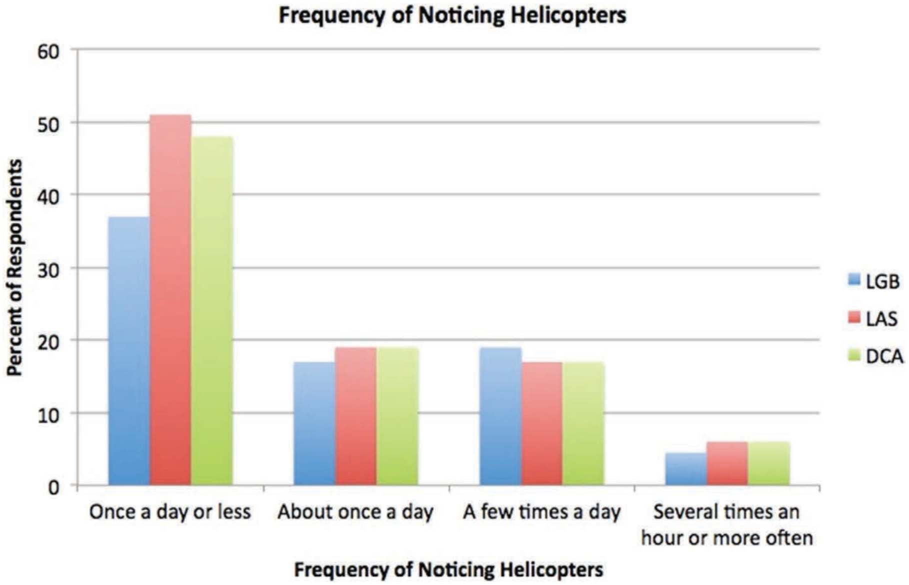


Figure 5-7. Frequency of notice of helicopters at interviewing sites.

rotors or interactions of the tail rotor with the main rotor wake). Only about 6% of respondents across sites described themselves as highly annoyed by such sounds.

Whining or Tonal Noise Slightly higher percentages of respondents (85%) at all sites indicated that they were not at all annoyed by whining or tonal noise (presumably jet engine inlet noise). Only about 3% of respondents across sites described themselves as highly annoyed by whining or tonal sounds.

Annoyance Due to Helicopter-Induced Vibration and Rattling (Items 13–14). About 80% of all respondents were not annoyed in any degree by helicopter-induced vibration and rattling sounds in their homes. Five percent of all respondents described themselves as highly annoyed by vibration or rattling.

A one-way analysis of variance conducted on responses made by Long Beach and Las Vegas respondents revealed a statistically significant difference in distance to flight track between respondents who were and were not annoyed to any degree by in-home vibration and rattling, $F(1, 1718) = 6.17$, $p = .013$. The absolute difference was quite small, however, $\eta^2 = .004$, with a 95% confidence interval (CI) extending from <.001 to .011. Those who reported no annoyance lived farther from the flight track ($M = 0.45$ nm, $SD = 0.27$) than those who lived closer to the flight track ($M = 0.41$ nm, $SD = 0.27$).

Frequency of Complaint (Item 15). Only about 4% of all respondents overall reported that they had complained about helicopter noise. Only in Washington did more than 1% of respondents report having complained more than once.

5.4.1.2 Evidence Relevant to Hypotheses Identified During Planning for the Current Study

Seven hypotheses were identified in Chapter 2 of this report. Evidence concerning these hypotheses is discussed below.

Hypothesis 1. Decibel for decibel, rotary-wing aircraft is more annoying than fixed-wing aircraft. Washington was the only interviewing site at which respondents were exposed to appreciable amounts of cumulative noise due to both helicopter and fixed-wing overflights. Figure 5-8 plots (a) percentages of respondents highly annoyed by helicopter and fixed-wing aircraft noise, and (b) percentages of respondents annoyed to any degree in Washington.

Note that cumulative exposure to aircraft noise was greater for fixed-wing aircraft than helicopters in Washington, D.C., and that the expected relationship between noise and annoyance is more evident for fixed-wing aircraft. Note also that only 4 of the 442 respondents reporting high annoyance were exposed to fixed-wing aircraft noise levels in the 45–50 dB range, calling into question the reliability of the 0% high annoyance data point.

In only one range of cumulative noise levels (~50–55 dB) did substantial numbers of respondents report high annoyance to both fixed-wing aircraft and helicopters. The rates of 21% high annoyance for fixed-wing aircraft and 7% for helicopters were substantially different. The rates for annoyance to any degree appear to be quite similar for helicopters and fixed-wing aircraft in the 45–50 dB range, but higher for fixed-wing aircraft other than helicopters in the 50–55 dB range at 43% and 18%, respectively.

The question of whether fixed-wing or helicopter noise was the more annoying at the Washington, D.C., interviewing site was addressed by comparing aircraft noise source responses to helicopter responses (note the higher noise level of fixed-wing aircraft noise in Figure 5-8). Of the 398 cases available for analysis, 44 cases had missing values on one or both of the annoyance measures. The two measures of annoyance were logarithmically transformed prior to inferential analysis due to strong positive skewness. The fixed-wing aircraft generated greater annoyance, as described in detail in the next paragraph.

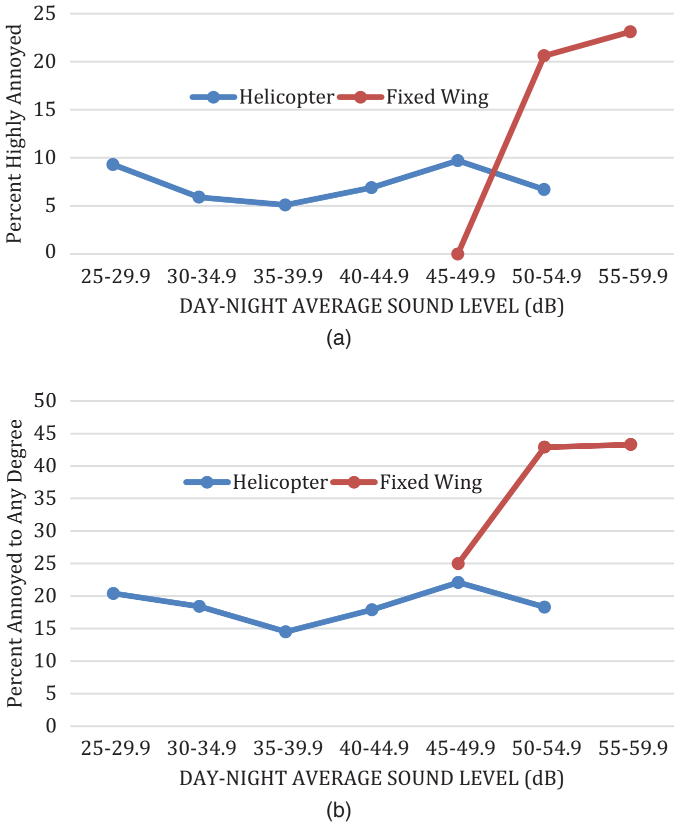


Figure 5-8. Proportion of respondents (a) highly annoyed and (b) annoyed to any degree by helicopter and fixed-wing aircraft noise at Washington study site.

Repeated-measures analysis of variance with varying covariates revealed significantly greater annoyance due to fixed-wing aircraft noise (after adjusting for fixed-wing DNL) than helicopter noise (after adjusting for helicopter DNL), $F(1, 396) = 23.70$, $p < .001$, partial $\eta^2 = .06$ with 95% confidence limits from .02 to .11. On an original scale in which 0 = not at all annoying or not noticing noise source to 4 = extremely annoying, mean annoyance for helicopter noise (log) was 0.108 ($SD = 0.217$) and the mean annoyance for fixed-wing aircraft noise (log) was 0.255 ($SD = 0.292$). The greater annoyance reported for exposure to fixed-wing aircraft, although statistically significant, was small, at less than one standard deviation difference in annoyance between the two noise sources. This evidence is both meager and inconclusive. It could well be more the product of recent changes in the fixed-wing flight patterns than differences in perceived annoyance relative to helicopter noise. (Changes in noise exposure associated with the changes in flight tracks were fully accounted for in the noise modeling done for this analysis.)

5.4.1.3 Annoyance by Helicopter Versus Fixed-Wing Aircraft Noise at Long Beach and Las Vegas

A similar analysis was conducted at the Long Beach and Las Vegas interviewing sites by once again adjusting for the frequency of noticing helicopter noise and fixed-wing aircraft noise as covariates to determine which aircraft type was more annoying. Of the 1,507 cases available for analysis, 323 cases were missing values on one or more of the four measures. Repeated-measures analysis of variance with varying covariates revealed significantly greater annoyance due to helicopter noise (after adjusting for frequency of noting helicopter noise) than fixed-wing aircraft noise (after adjusting for frequency of noticing fixed-wing or helicopter noise), $F(1, 1505) = 31.04$, $p < .001$, partial $\eta^2 = .04$ with 95% confidence limits from .02 to .06. On an original scale in which 0 = not at all annoying or not noticing noise source to 4 = extremely annoying, the mean annoyance for helicopter noise (log) was 0.087 ($SD = 0.20$) and mean annoyance for fixed-wing aircraft noise (log) was 0.021 ($SD = 0.11$). These findings assume no difference in actual loudness of the two types of aircraft noise in the two locations beyond differences in frequency of noticing them.

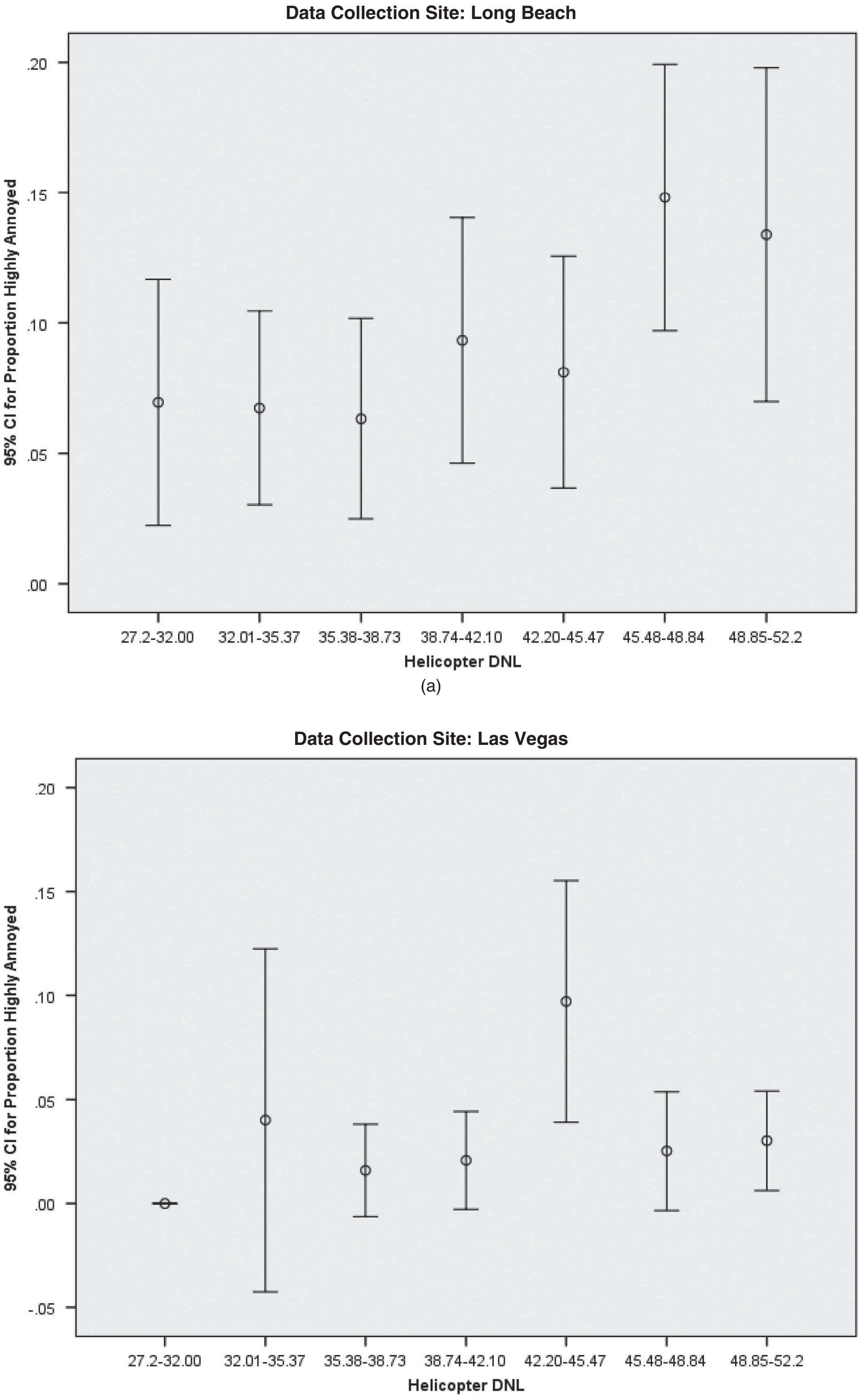
5.4.1.4 Dosage-Response for High Annoyance

The three panels of Figure 5-9 show proportions of respondents highly annoyed by helicopter noise within seven categories of DNL at all three interviewing sites.

Binary logistic regression analysis showed a statistically significant relationship between high annoyance (very or extremely annoyed by helicopter noise) and the sound level to which respondents were exposed in Long Beach, but not in the Las Vegas or Washington, D.C., data collection sites. Among the 1,089 Long Beach respondents, 1,050 were at home during the week before data collection and 99 of them were highly annoyed by helicopter noise (Table 5-4 and Table 5-6). A small (Nagelkerke $R^2 = .019$) but significant dosage-response relationship was observed, $\chi^2(1, N = 1{,}050) = 9.28$, $p = .002$. The odds ratio (B_e) was 1.107, with 95% confidence limits from 1.061 to 1.327. The dosage-response relationship was not statistically significant at Long Beach, $p = .538$ or in Washington, $p = .143$.

5.4.1.5 Annoyance to any Degree due to Helicopter Noise

A 2 × 3 (annoyance to any degree by data collection site) analysis of variance predicting helicopter DNL revealed statistically significant main effects of annoyance and site, but not their interaction (Figure 5-10). Helicopter noise exposure was greater for those reporting being at least slightly annoyed ($M = 43.47$, $\mathrm{SE} = 0.339$) than those who were at home but reported no annoyance ($M = 42.26$, $SE = 42.26$), $F(1, 2191) = 10.83$, $p = .001$. However, the relationship accounted for little variance in noise exposure, partial $\eta^2 = .005$ with 95% confidence limits from .001 to .012. Data collection site also predicted differences in noise exposure, $F(2, 2191) = 50.97$, $p < .001$, partial $\eta^2 = .044$ with 95% confidence limits from .012 to .063. Noise exposure differences are presented in Table 5-5.

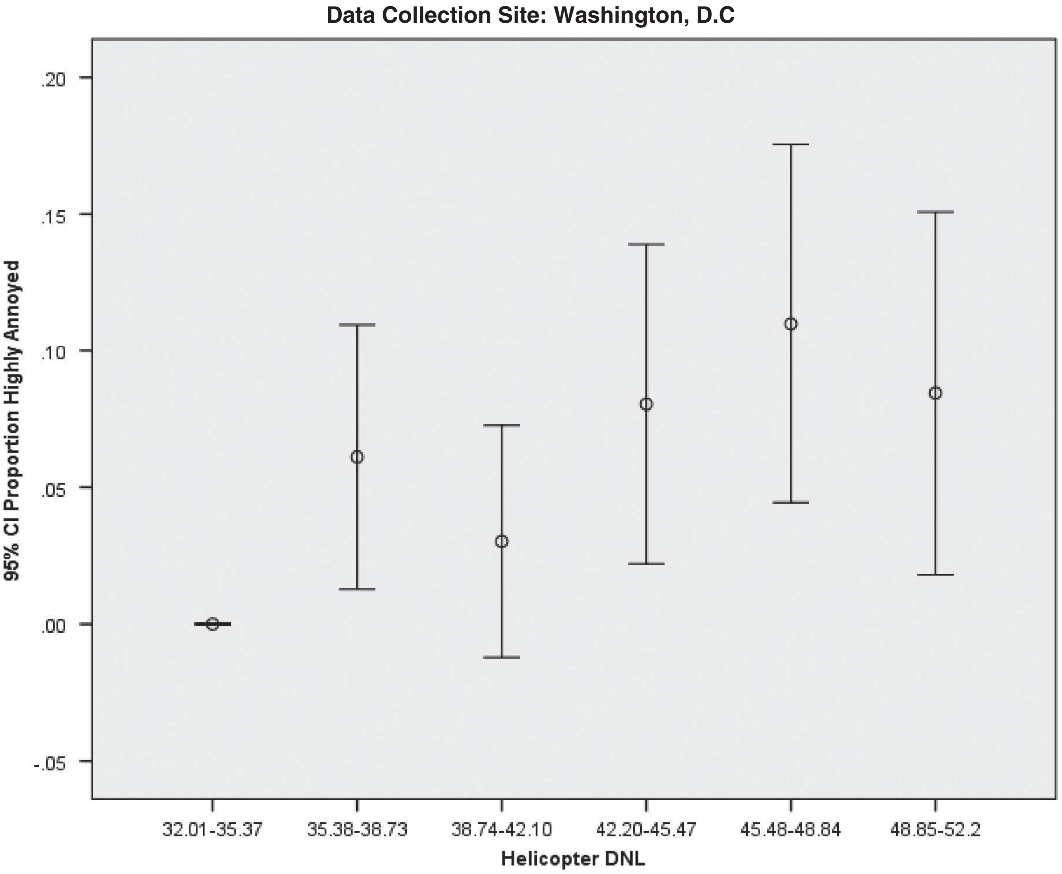


(a)

(b)

Figure 5-9. Proportions (with 95% CIs) of respondents highly annoyed by helicopter noise within (a) Long Beach and (b) Las Vegas.

(continued on next page)



Data Collection Site: Washington, D.C

(c)

Figure 5-9. (Continued) Proportions (with 95% CIs) of respondents highly annoyed by helicopter noise within (c) D.C. data collection sites.

Table 5-6. Summary of logistic regression analyses of proportion highly annoyed by various helicopter noises for three data collection sites.

Noise Type	Site	HA/N^a	B	Standard Error	Wald	df	p	Nagelkerke R^2	Odds Ratio (B_e)	95% CI for Odds Ratio	
										Lower	Upper
In-home vibration/ rattling	LGB	69/1050	0.059	0.066	0.811	1	.368	.002	1.061	0.933	1.206
	LAS	19/728	0.081	0.145	0.315	1	.575	.002	1.085	0.817	1.440
	DCA	27/419	0.194	0.132	2.148	1	.143	.013	1.214	0.937	1.573
Thumping and Slapping	LGB	44/1050	0.145	0.083	3.08	1	.079	.010	1.156	0.983	1.359
	LAS	17/728	0.138	0.356	0.79	1	.374	.006	1.148	0.846	1.558
	DCA	28/419	0.188	0.138	1.84	1	.174	.012	1.207	0.920	1.583
Buzzing	LGB	39/1050	0.360	0.092	8.03	1	.005	.030	1.297	1.084	1.553
	LAS	18/728	-0.051	0.157	0.10	1	.748	.001	0.951	0.698	1.295
	DCA	19/419	0.219	0.168	1.69	1	.192	.014	1.244	0.896	1.728
Whining	LGB	37/1050	0.069	0.088	0.61	1	.436	.002	1.071	0.901	1.274
	LAS	12/728	0.199	0.190	1.10	1	.294	.010	1.221	0.841	1.771
	DCA	16/419	-0.037	0.176	0.045	1	.832	<.001	0.963	0.683	1.360

[a] HA = Number of respondents highly annoyed; N = Number of valid responses; B = the customary symbol for slope; "Wald" = the value of a Wald test for the significance of the slope; "df" = the usual abbreviation for degrees of freedom; p = the customary symbol for significance; "Nagelkerke R^2" is an adjusted coefficient of determination; the odds ratio is a measure of an association of exposure and an outcome; CI = confidence interval.

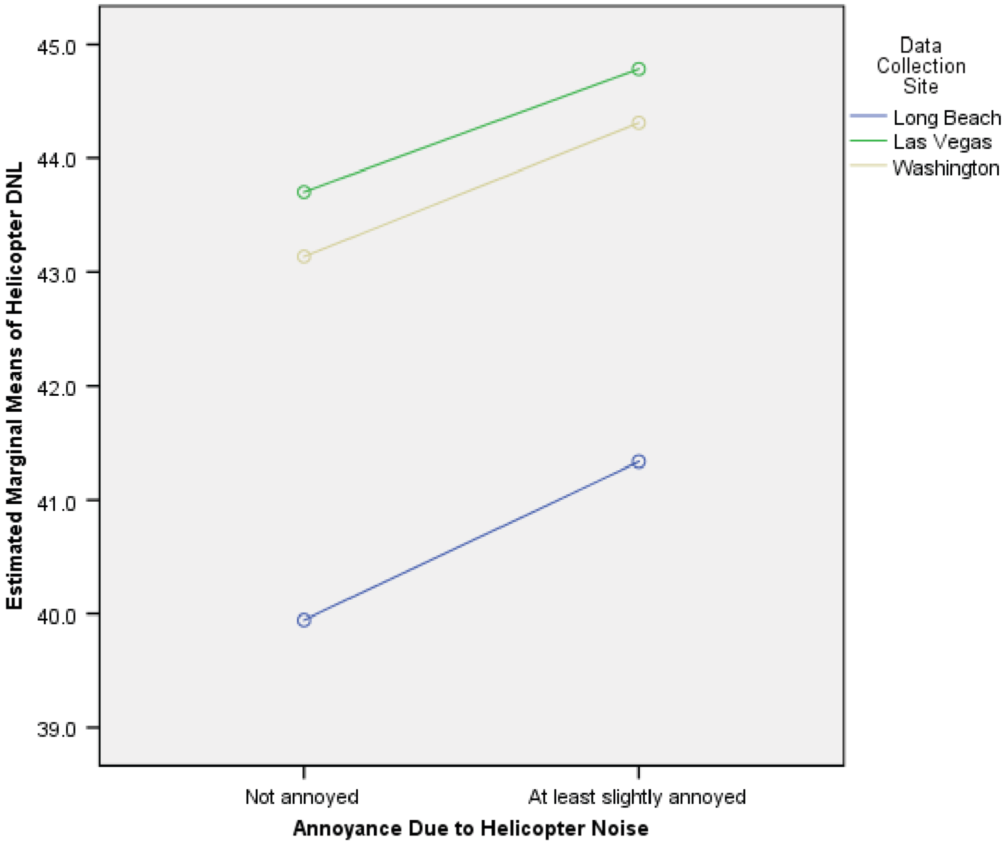


Figure 5-10. Prediction of helicopter DNL by reported annoyance due to helicopter noise and data collection site.

Hypothesis 2. The prevalence of annoyance due to rotary-wing noise is most appropriately predicted in units of A-weighted cumulative exposure. At only one of the three interviewing sites was there a good correlation between annoyance and the A-weighted decibel. Neither the C-weighted nor the helicopter-adjusted LFSL exhibited any greater correlation with annoyance. At the Las Vegas and Washington, D.C., interviewing sites, annoyance was unrelated to dose, as measured by the A-weighted, C-weighted, or the helicopter-adjusted LFSL.

At the Washington, D.C., interviewing site, a controversy over relocated fixed-wing tracks may have obscured any dependence of annoyance on dose.[18] The low doses of helicopter noise for the three studies cannot be ignored, however. It would have been advantageous to have surveyed a community with higher helicopter noise dose (greater than 60 DNL). To do that, a survey would have had to occur around a military facility. The research panel restricted the surveys to civil helicopter routes thus limiting the noise dose to DNL below 60 dB. See Section 5.6 for details on the low-frequency analysis.

Hypothesis 3. Main rotor impulsive noise controls the annoyance of helicopter noise (and hence requires an impulsive noise "correction" to A-weighted measurements). Noise measurements included A- and C-weighted impulsive noise levels. The difference between these and non-impulsive A- and C-weighted levels differed only by constants. However, the civil helicopters measured in this study do not produce the main rotor impulsive noise levels that military helicopters can produce in certain flight regimes. That is not to say there were none, but that the levels were not as pronounced as with heavier helicopters. This hypothesis would be better tested where there were heavy military helicopter operations so that the impulsive noises were more pronounced. Therefore, no clear conclusion could be drawn from these surveys.

Hypothesis 4. The prevalence of annoyance due to helicopter noise is heavily influenced by indoor secondary emissions (rattle and vibration) due to its low-frequency content. Binary logistic regression analyses were conducted for high annoyance due to in-home vibration/rattling as well as other helicopter sounds: BVI (thumping or slapping), buzzing, and whining. Table 5-6 summarizes these analyses.

No statistically significant relationship was observed between annoyance due to in-home vibration and rattling and annoyance due to noise level alone. The dosage-response relationship between helicopter noise exposure and annoyance due to "buzzing" noises differed significantly from chance in Long Beach, but not in Las Vegas or Washington, D.C. Figures 5-11 through 5-14 show proportions of reports of high annoyance for each of the specific noise types.

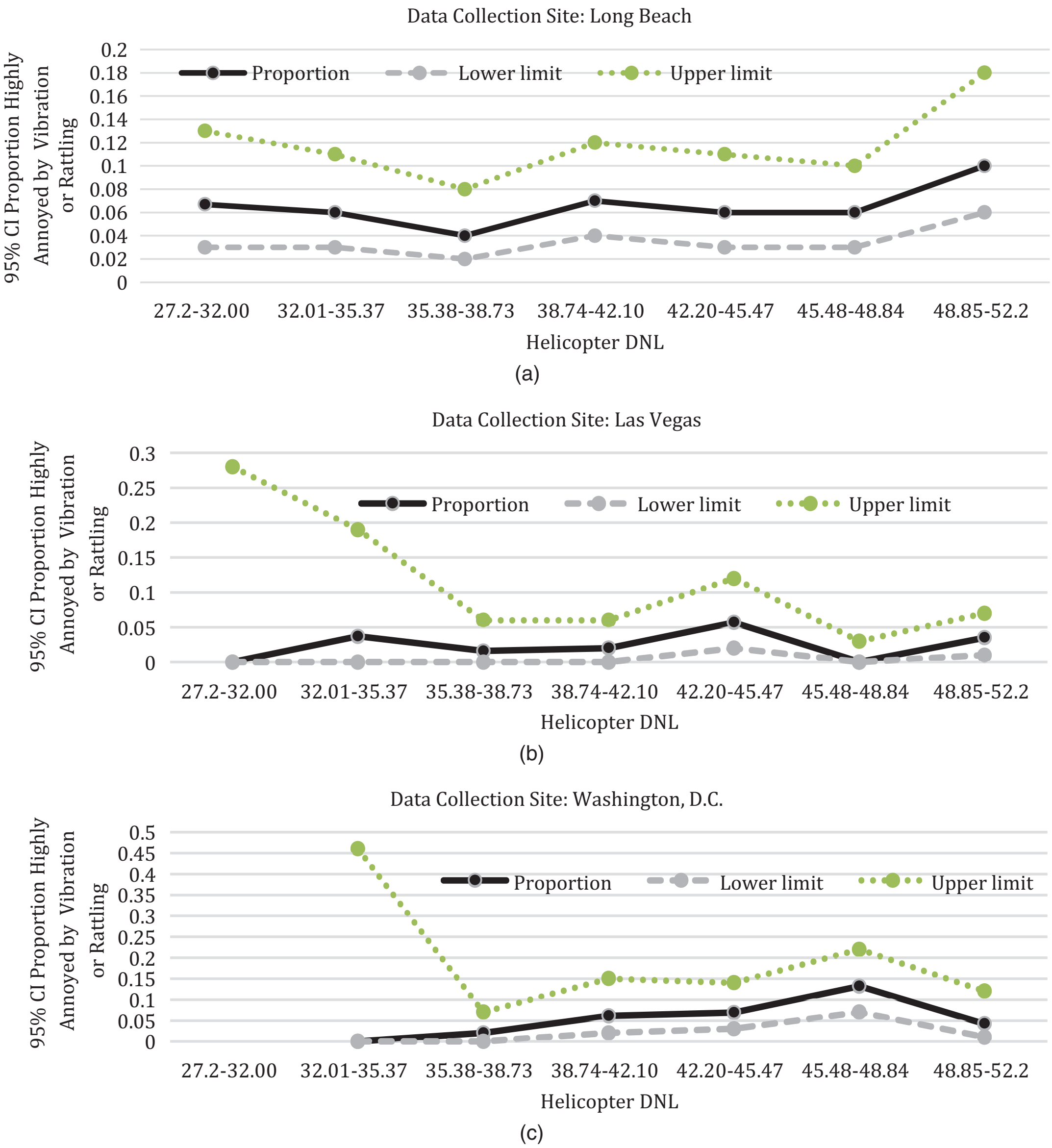
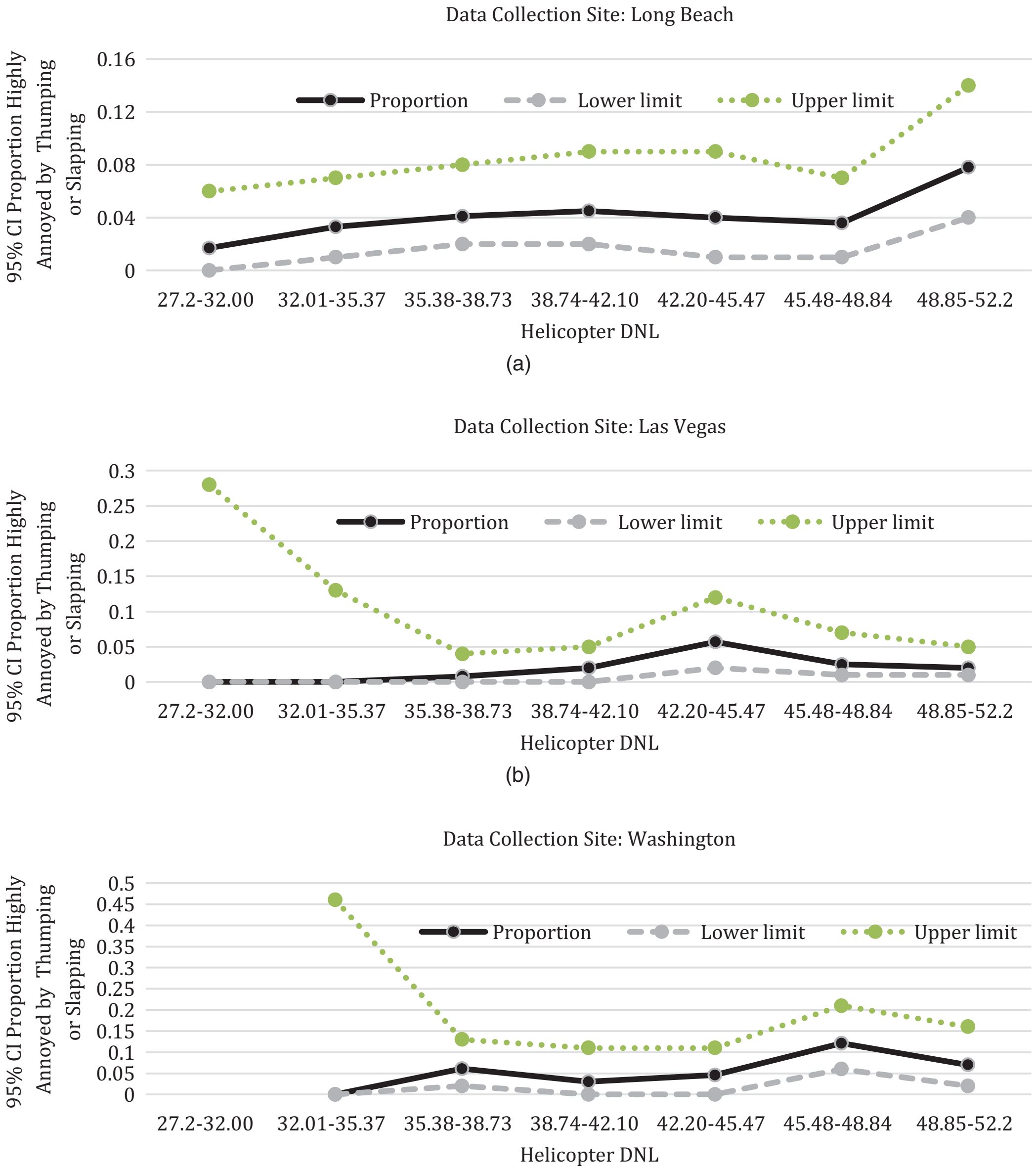


Figure 5-11. Proportion (with 95% CIs) of respondents highly annoyed by helicopter in-home vibration or rattling within (a) Long Beach, (b) Las Vegas, and (c) D.C. interviewing sites. Asymmetric CIs were calculated using the Clopper-Pearson method.



(a)

(b)

(c)

Figure 5-12. Proportion (with 95% CIs) of respondents highly annoyed by helicopter thumping and slapping (BVI) noise at (a) Long Beach, (b) Las Vegas, and (c) D.C. interviewing sites. Asymmetric CIs were calculated using the Clopper-Pearson method.

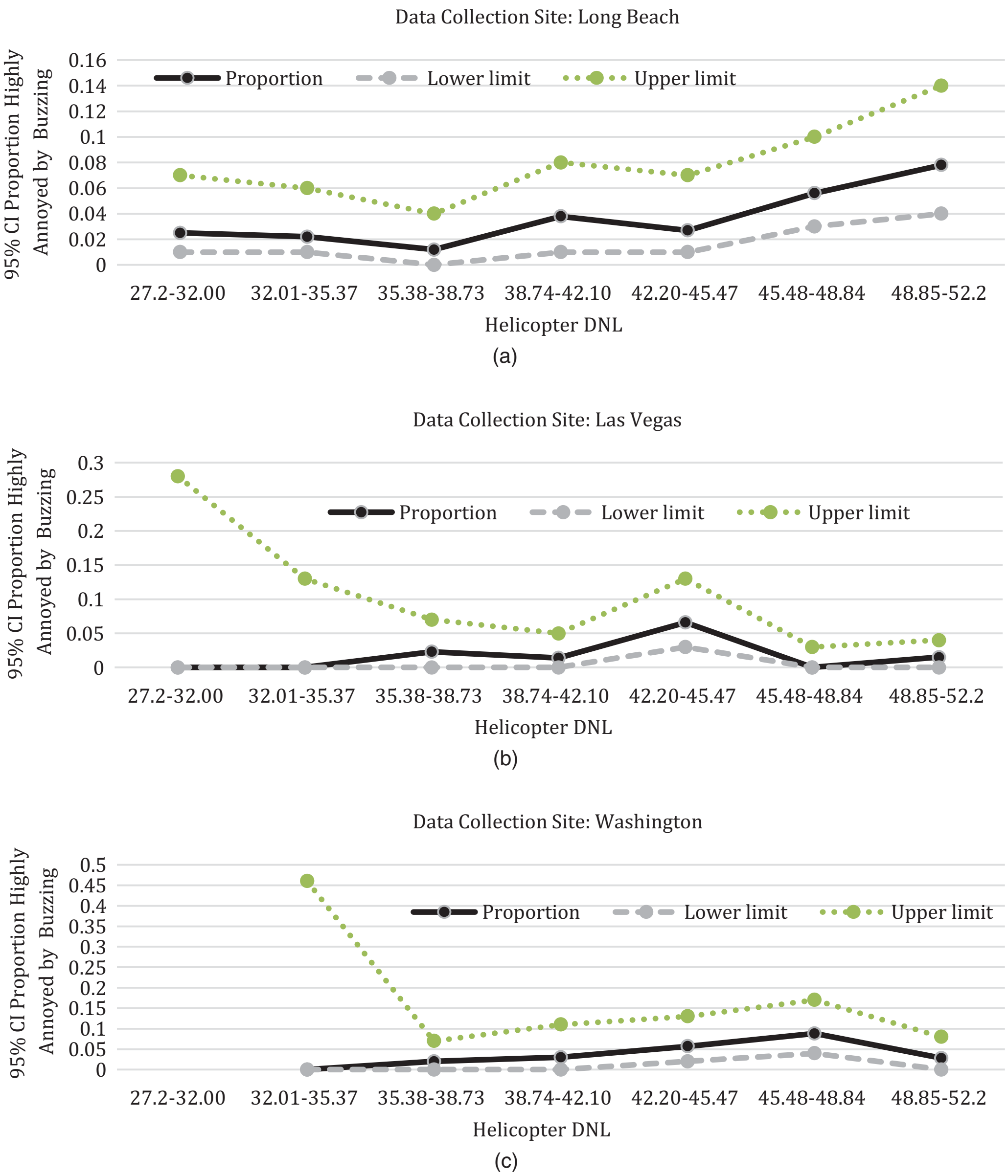
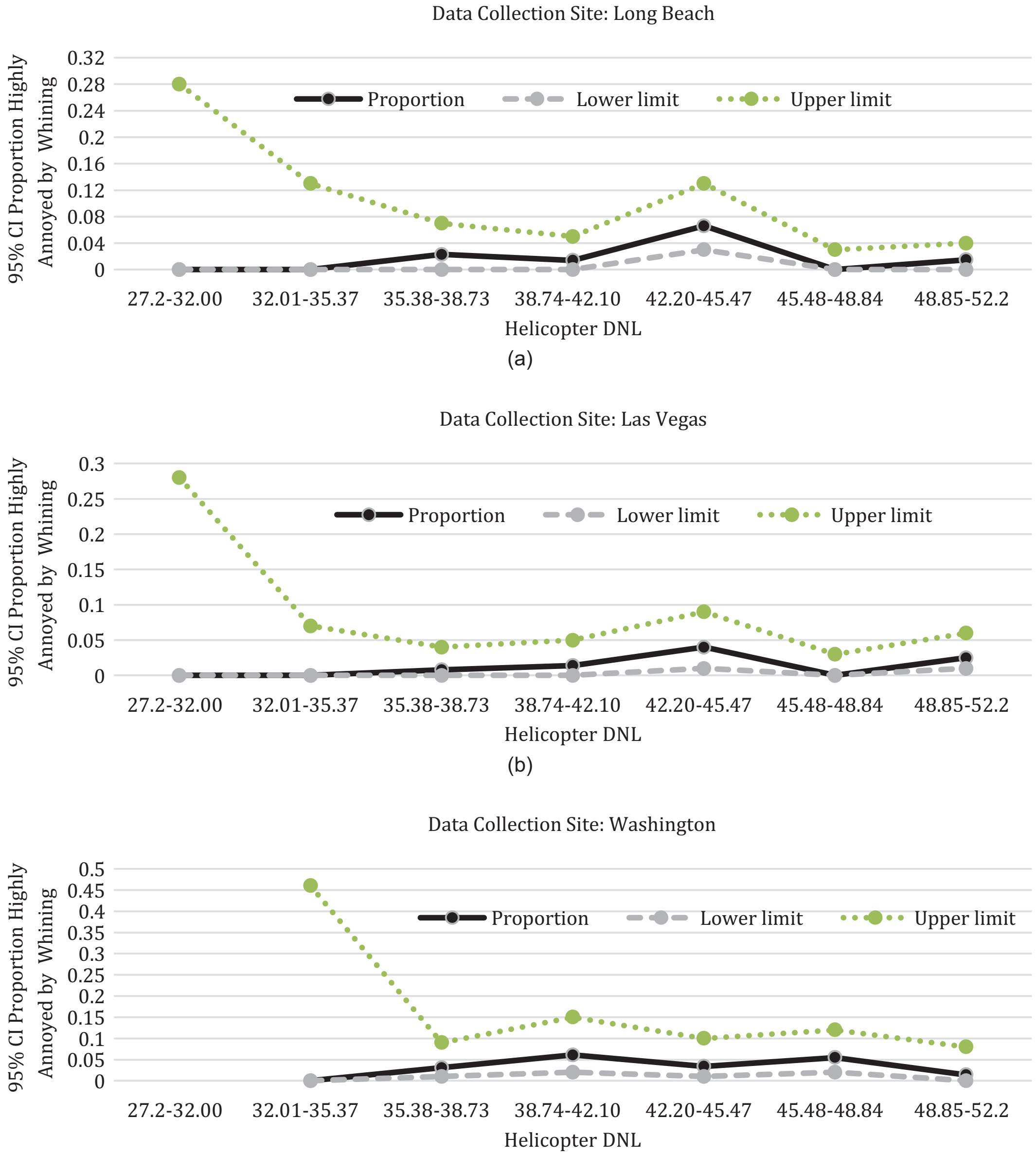


Figure 5-13. Proportion (with 95% CIs) of respondents highly annoyed by helicopter buzzing noise within (a) Long Beach, (b) Las Vegas, and (c) D.C. interviewing sites. Asymmetric CIs were calculated using the Clopper-Pearson method.



(a)

(b)

(c)

Figure 5-14. Proportion (with 95% CIs) of respondents highly annoyed by helicopter whining noise within (a) Long Beach, (b) Las Vegas, and (c) D.C. data collection sites. Asymmetric CIs were calculated using Clopper-Pearson method.

The logistic regression of buzzing noises on helicopter noise exposure was the only one that was unlikely to have arisen by chance alone, but even it accounted for very little variance in the relationship between annoyance and exposure. In the apparent absence of any strong association between helicopter noise exposure and annoyance at the low exposure levels that were available for study, it is likely that nonacoustic factors may have controlled community response to helicopter noise at the study sites.

Hypothesis 5. The prevalence of annoyance due to helicopter noise is heavily influenced by nonacoustic factors. It is clear from the differences in response in the Long Beach and Las Vegas communities that nonacoustic factors strongly influence community response in these communities. Las Vegas had approximately ten times the number of flights, albeit at a higher altitude, and yet a substantially reduced fraction of the population were highly annoyed. The higher altitude effect on DNL (in the range of a 3 to 4 dB reduction) was nowhere near the effect of the higher number of operations on DNL (plus 10 dB). Aircraft fleet mix cannot account for the difference either. In Washington, D.C., the public concern over moved fixed-wing flight tracks negated the dosage-response effect for both fixed-wing and helicopter noise. No acoustic factors can account for these differences. Note that the literature (Fidell et al. 2011) discusses a myriad of nonacoustic factors that can contribute to people's attitude to noise. The primary nonacoustic factors are fear and distrust. Certainly, the low altitudes of helicopters could be contributing to fear. Other factors that may be playing a role are expectations, invasion of privacy, the apparent need for the helicopter operations, or a perception that not enough is being done to control helicopter noise.

Predicting Helicopter Noise Annoyance from Annoyance Due to Other Noise Sources. As an indication of possible individual differences and/or response bias, a binary multiple logistic regression examined whether high annoyance by fixed-wing aircraft and high annoyance by traffic noise (very or extremely annoyed) predicted whether an individual was highly annoyed by helicopter noise. Site was included as a predictor, along with interactions between site and the other two sources of noise annoyance to account for differences among sites. Data for this analysis were provided by 2,197 of the 2,272 respondents (others reported not being at home during the period in question). The eight-predictor model showed prediction of high annoyance that was significantly better than would be expected by chance, χ^2 (8, $N = 2{,}197$) = 178.59, $p < .001$. The fit of the model to the data was very good, Hosmer-Lemeshow χ^2 (2, $N = 2{,}197$) = 0.531, $p = .767$ (where $p = 1.0$ indicates perfect fit); the variance in high annoyance due to helicopter noise is accounted for moderately well, Nagelkerke $R^2 = .20$. Table 5-7 shows the results of the logistic regression.

Table 5-7. Logistic regression analysis of high annoyance due to helicopter noise as a function of high annoyance due to other noise sources, data collection site, and interactions.

Variable	*B*	Standard Error	Wald	df	*p*	Odds ratio (B_e)	95% CI for OR	
							Lower	Upper
LGB vs. DCA	1.406	0.429	10.74	1	**.001**	4.078	1.760	9.452
LAS vs. DCA	0.143	0.487	0.09	1	.789	1.153	0.444	2.996
Fixed-wing aircraft	2.685	0.465	33.36	1	**<.001**	14.658	5.894	36.457
Traffic	2.159	0.701	9.49	1	**.002**	8.667	2.193	34.243
LGB vs. DCA by fixed-wing aircraft	-0.354	0.506	0.34	1	.560	0.702	0.214	2.303
LAS vs. DCA by fixed-wing aircraft	0.023	0.816	<0.01	1	.978	1.023	0.207	5.064
LGB vs. DCA by traffic	-0.825	0.758	1.19	1	.276	0.438	0.099	1.936
LGB vs. DCA by traffic	0.643	0.897	0.51	1	.474	1.902	0.328	11.036
Constant	-4.000	0.410						

B = the customary symbol for slope; "Wald" = the value of a Wald test for the significance of the slope; "df" = the usual abbreviation for degrees of freedom; *p* = the customary symbol for significance; the odds ratio is a measure of an association of exposure and an outcome; CI = the confidence interval; OR = odds ratio.

Reporting high annoyance with helicopter noise is predicted by reports of high annoyance by traffic and fixed-wing noise sources, and by whether respondents lived in Long Beach versus Washington, D.C. Respondents who were highly annoyed by fixed-wing aircraft noise were almost fifteen times more likely to be highly annoyed by helicopter noise than those who were not highly annoyed by fixed-wing aircraft noise. Respondents who were highly annoyed by traffic noise were more than 8.5 times as likely to be annoyed by helicopter noise. Residents of Long Beach were about four times more likely to be highly annoyed by helicopter noise than were residents of D.C. (An earlier analysis, not shown, indicated that residents of Long Beach were about three times as likely to be highly annoyed by helicopter as those living in Las Vegas, $p < .001$.) None of the interactions between site and noise type differed significantly from chance, $p > .05$. Thus, the analysis suggests fairly strong individual differences in reporting high annoyance due to different noise sources.

In other words, a respondent who reported high annoyance to any other noise source was much more likely to be annoyed by helicopters. This adds to the common belief in varying levels of noise sensitivity, but it does not rule out that this may be associated with nonacoustic variables such as expectations.

Hypothesis 6. The prevalence of annoyance due to helicopter noise is heavily influenced by proximity to helicopter flight paths. Binary logistic regression analysis was used to determine whether proximity to the flight track influences a high degree of annoyance due to helicopter flight paths. At Long Beach, the dosage-response relationship was small (Nagelkerke $R^2 = .018$) but statistically significant, $\chi^2(1, N = 1{,}050) = 8.70, p = .003$. Odds ratio ($B_e$) was 0.279 (indicating a negative relationship between distance and annoyance) with 95% confidence limits from 0.117 to 0.662. The dosage-response relationship failed to approach statistical significance at Long Beach, $p = .664$. Thus, proximity to flight path is as good a predictor of high annoyance as noise level. The relationship of annoyance to distance is discussed further in Section 5.5.2.

Hypothesis 7. Complaints lodged about helicopter noise are more reliable predictors of the prevalence of annoyance than measures of exposure to helicopter noise or proximity to helicopter flight paths. ***Complaints by Annoyance.*** Only a very few respondents (2.6%) indicated that they had ever registered complaints (Item 15). However, a Chi-square analysis of whether respondents complained by whether they were at least slightly annoyed by helicopter noise revealed a statistically significant relationship, $\chi^2(1, N = 2{,}167) = 73.70, p < .001$, Cramer's $V = .19$. Among the 1,937 respondents who reported no annoyance by helicopter noise, 1.3% complained; of the 330 respondents who reported at least slight annoyance by helicopter, 9.4% registered complaints. Thus, a reasonably clear relationship was found between the prevalence of annoyance (in any degree) and complaint behavior.

Complaints by Noise Exposure. A 2 × 2 analysis of variance examined whether complaining (yes or no) was related to noise exposure or site or their interaction. There was no statistically significant difference in noise exposure for those who did and did not complain, $p = .722$, nor was there a significant interaction with the site $p = .649$. The difference between sites was statistically significant, $F(2, 2155) = 5.36, p = .005$ but small, $\eta^2 = .005$.

Note that this correlation analysis refers to noise complaints as those provided in the survey response, i.e., did the responder file a noise complaint. This analysis is not referring to the noise complaints filed with the airports. Unfortunately, the noise complaints collected by the airports either did not segregate helicopter complaints from fixed-wing, were not geocoded and available for GIS analysis, or both.

5.4.1.6 Additional Relationships with Helicopter Noise Exposure

Were Helicopters Noticed? A between-subjects two-way (site by notice of helicopters) analysis was conducted of noise exposure. Statistically significant main effects for both site and frequency category were observed, but no interactions were noted, as seen in Figure 5-15.

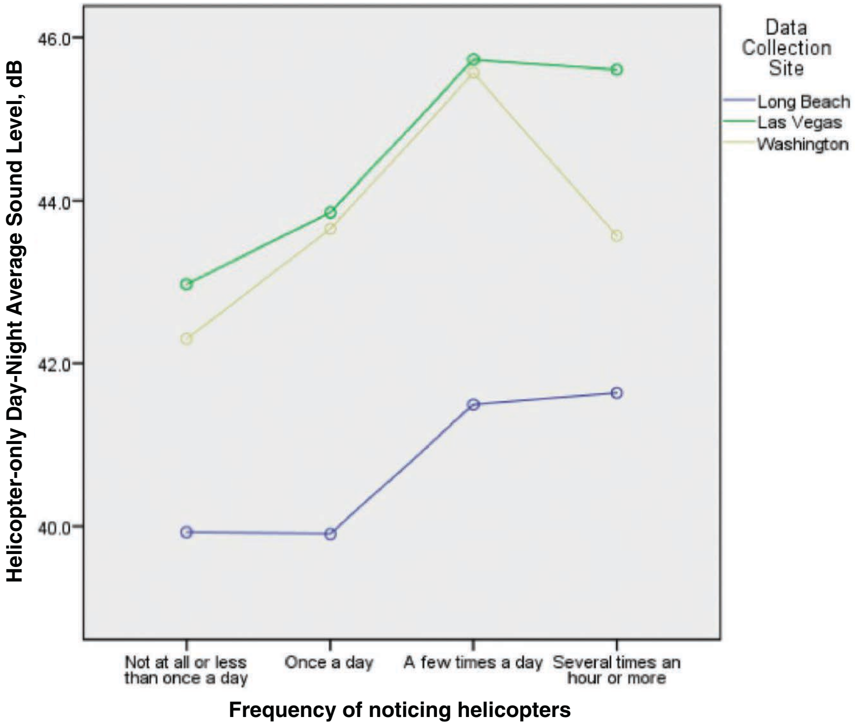


Figure 5-15. Plot of noticing helicopters as a function of DNL.

Helicopter noise exposure was greater for those who noticed helicopters ($M = 43.27$, $SE = 0.192$) than for those who did not notice helicopters ($M = 41.73$, $SE = 0.191$), $F(1, 2107) = 32.17$, $p < .001$, but the relationship was weak, partial $\eta^2 = .02$, with 95% confidence limits from .01 to .03. Figure 5-9a, b, and c show that the ranges of helicopter noise exposure levels, from the low 30 dB to low 50 dB range, was similar at all three sites.

Frequency of Notice of Helicopters. Categories of frequency of noticing helicopters are in Table 5-3. A between-subjects two-way (site by frequency category) analysis was conducted of noise exposure, with planned trend analysis. Statistically significant main effects were observed for both site and frequency category, but no interactions were noted.

The relationship between noise exposure and categories of frequency of noticing helicopters was statistically significant, $F(3, 2020) = 17.34$, $p < .001$, but moderate, partial $\eta^2 = .025$, with 95% confidence limits from .01 to .04. Linear and cubic trends were statistically significant, with $p < .001$ and .013, respectively. As seen in Figure 5-16, the trend is at least speculatively consistent with a sigmoidal dosage-response function. In any event, over a small dynamic range noticeability increased with increasing DNL.

5.5 Relationships Among DNL, Distance, and Percent Highly Annoyed

This section examines two relationships observed in the data. The first shows the relationship between the modeled DNL during the week prior to interview and the distance from the flight corridor centerline. The second shows the relationship between annoyance and DNL during the week prior to interview. DNL and distance from a noise source are obviously highly correlated, but annoyance could conceivably be more closely related to proximity to direct overflights.

5.5.1 DNL Versus Distance Relationships

Figures 5-16 through 5-18 show DNL versus distance relationships for Long Beach, Las Vegas, and Washington D.C., respectively. They show orderly reductions in SELs with distance. The Long Beach data has the greater variance likely due to a much greater dispersion of flight tracks within a corridor and the existence of two corridors affecting the survey area, the Cherry Avenue corridor, and the split in the Redondo corridor into a westbound and eastbound leg at the coastline. For those respondents living directly under the corridor (i.e., within 0.1 nm of the centerline) the sound exposure does not change appreciably with distance. At 1 nm from centerline, DNL dropped by 19 and 17 dB, respectively, for Long Beach and Las Vegas.

5.5.2 Dosage-response Relationships

The following paragraphs describe dosage-response relationships between SELs and the prevalence of annoyance.

5.5.2.1 Washington, D.C.

Figures 5-19 through 5-22 show relationships between (A-weighted) DNL and the prevalence of high annoyance observed among respondents at the Washington, D.C., interview site. Separate relationships are shown for fixed- and rotary-wing aircraft. The first relationship, for fixed-wing aircraft, shows the percent highly annoyed in Figure 5-19 and the number of respondents in Figure 5-20. Figure 5-21 (for helicopters) shows the percent highly annoyed. Figure 5-22 shows the number of respondents for helicopters.

Figure 5-23 shows the annoyance of exposure to helicopter noise as a function of reciprocal distance [20 Log (1/distance), where distance is in nautical miles]. Thus, 0 dB on the logarithmic scale indicates 1 nautical mile. The multiplier of 20 was chosen because at distances greater that

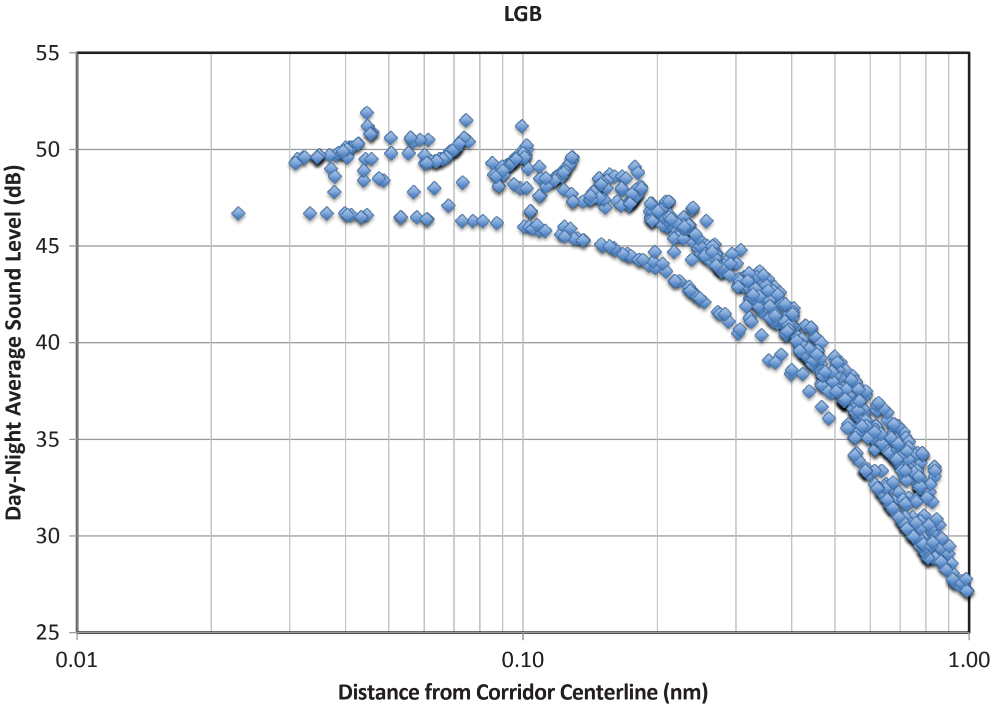


Figure 5-16. INM-generated DNLs for each respondent at LGB as a function of respondent distance from two flight corridor centerlines.

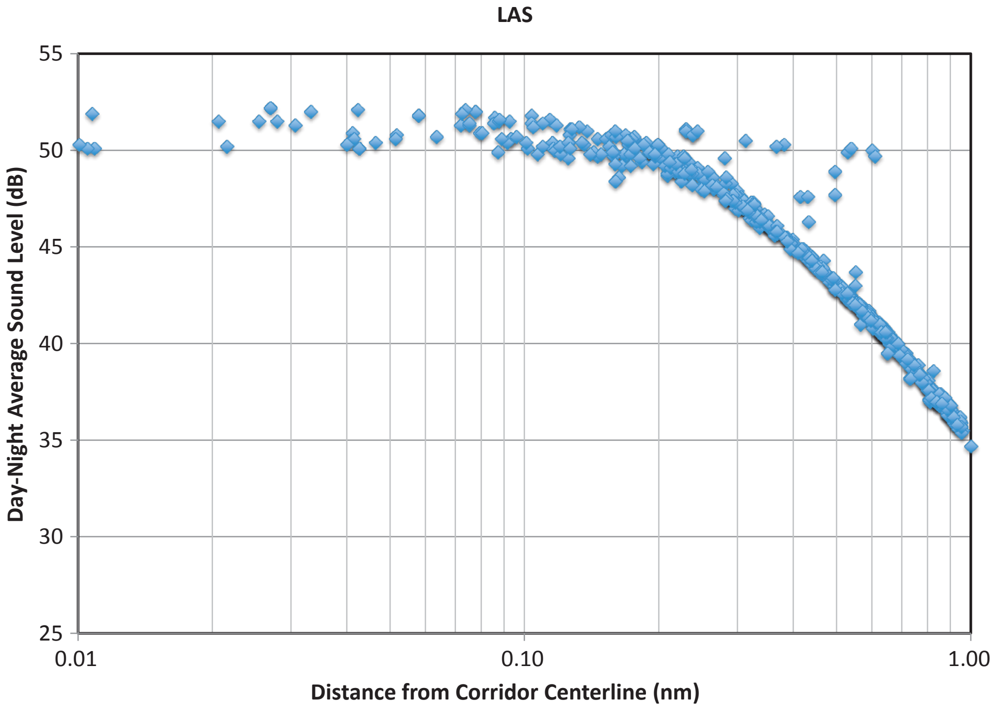


Figure 5-17. INM-generated DNLs for each respondent at LAS as a function of respondent distance from flight corridor centerlines.

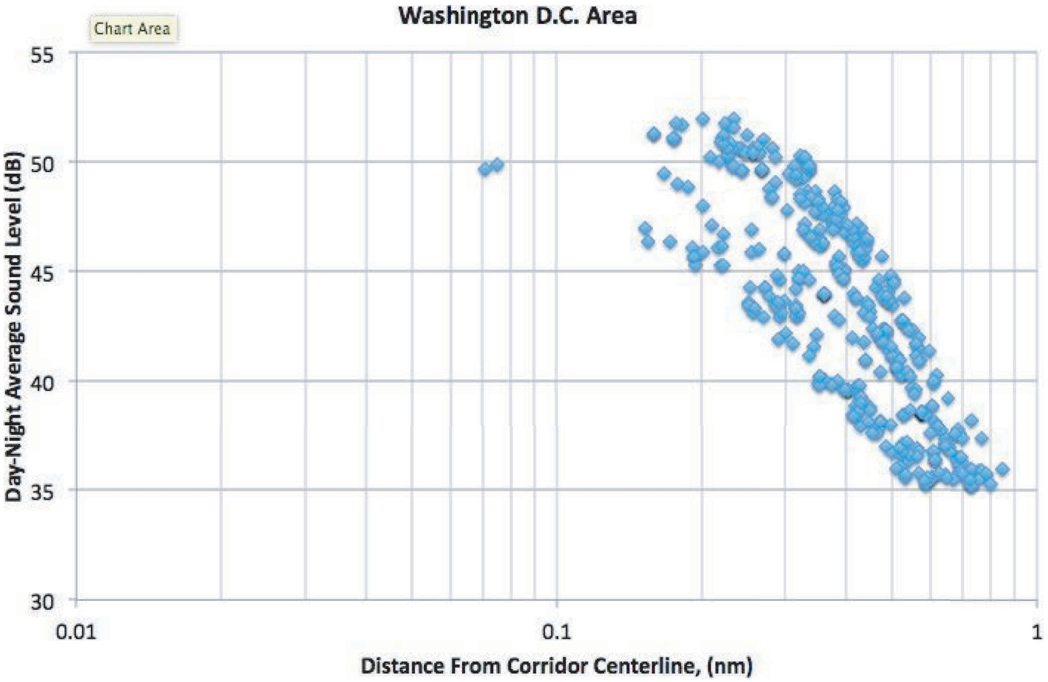


Figure 5-18. INM-generated DNLs for each respondent at DCA as a function of respondent distance from flight corridor centerline.

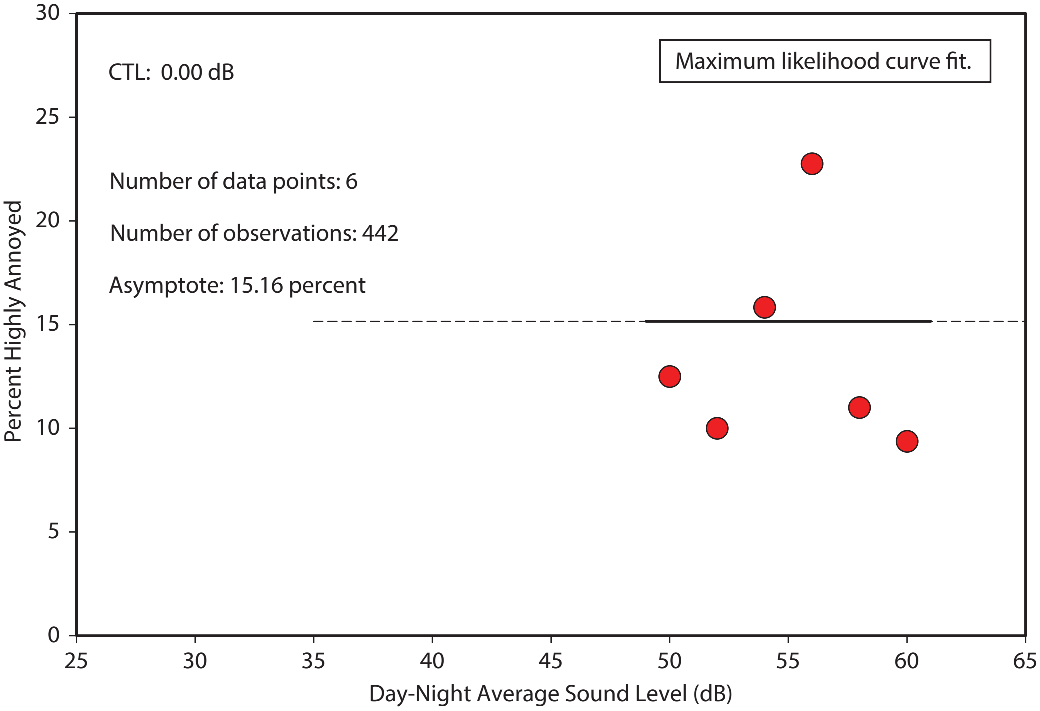


Figure 5-19. ***Percent of respondents highly annoyed at the Washington, D.C., interview site as a function of A-weighted DNL for fixed-wing aircraft.***

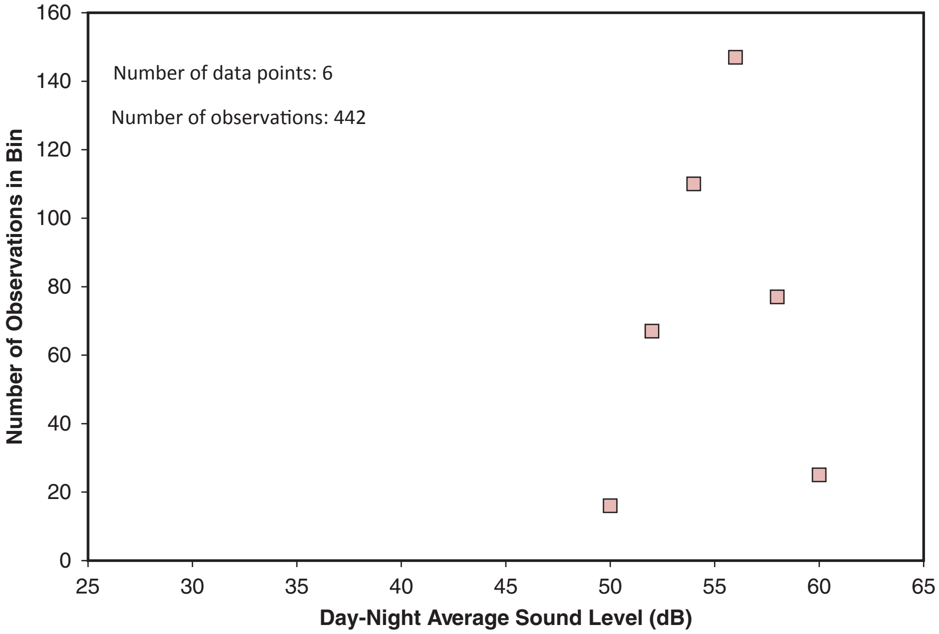


Figure 5-20. ***Number of respondents in each fixed-wing noise exposure category at the Washington, D.C., interview site (Bin = histogram bin).***

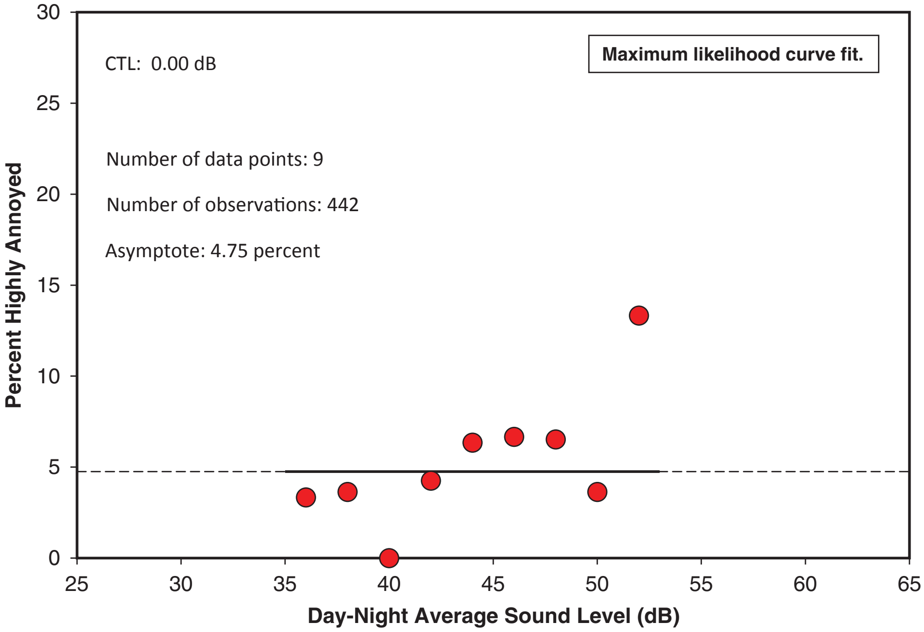


Figure 5-21. **Percent of respondents highly annoyed at the Washington, D.C., interview site as a function of A-weighted DNL for helicopters.**

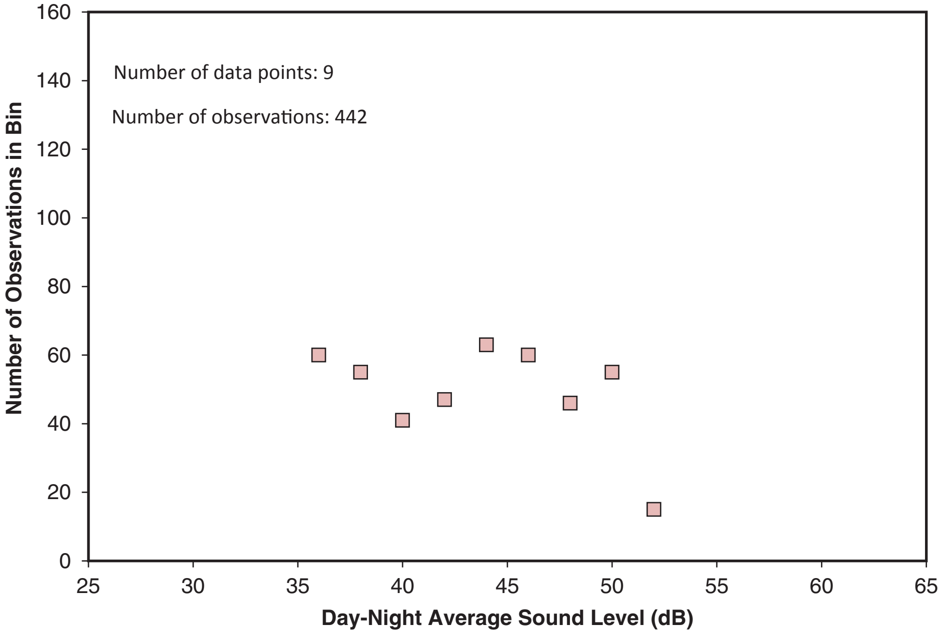


Figure 5-22. **Number of respondents in each helicopter noise exposure category at the Washington, D.C., interview site.**

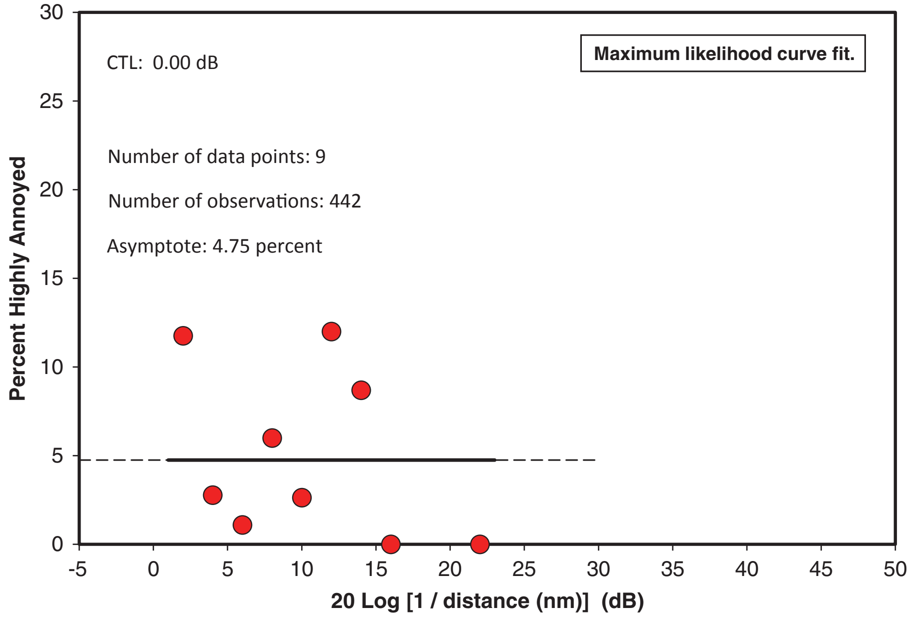


Figure 5-23. Percent of respondents highly annoyed at the Washington, D.C., interview site as a function of distance from helicopter corridor.

a few hundred feet, most INM noise-power-distance (NPD) curves drop off at that rate when SEL is plotted as a function of log [distance]. Figure 5-24 shows the number of interviews at each distance.

5.5.2.2 Las Vegas

Both A- and C-weighted measurements of DNL were available for analysis at the Las Vegas interviewing site. Wind-related, low-frequency noise measurement artifacts were less severe at LAS

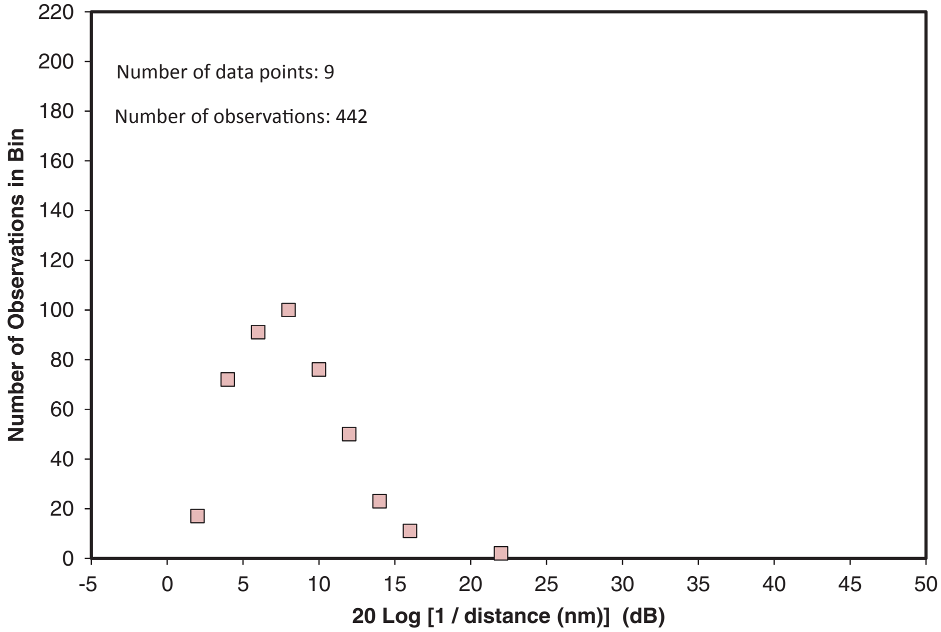


Figure 5-24. Number of respondents in each helicopter noise exposure category at the Washington, D.C., interview site.

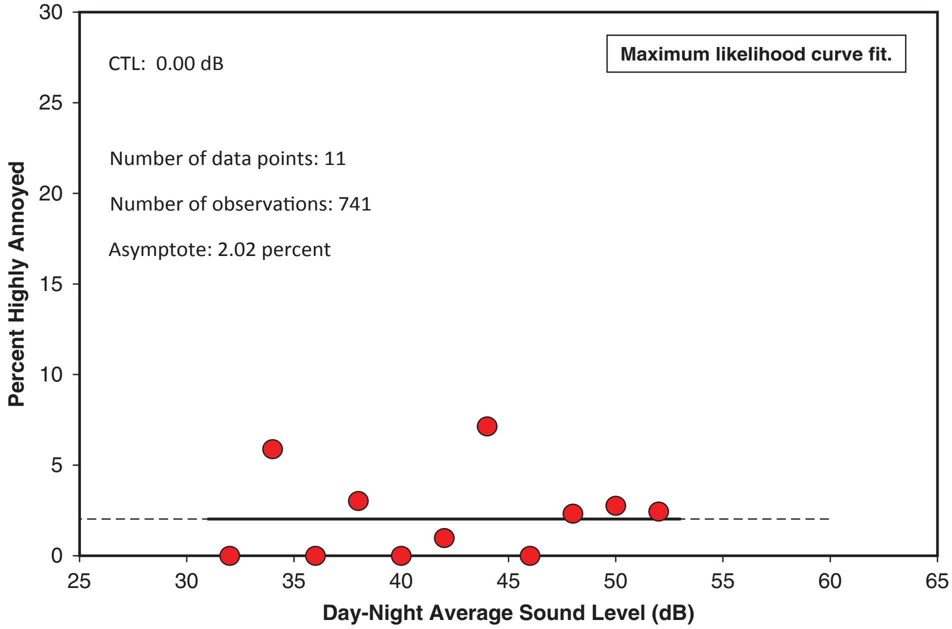


Figure 5-25. LAS, percent highly annoyed as a function of A-weighted DNL for helicopters.

than at LGB. Figure 5-25 plots the prevalence of percent highly annoyed against (A-weighted) DNL. Figure 5-26 shows the number of survey respondents in each exposure bin. No obvious trend of increasing annoyance with increasing noise level was observed: annoyance is nearly constant at all noise exposure levels. If there is a sigmoid function to the data for Las Vegas, the increase in annoyance with dose must occur at much higher noise levels than were encountered in LAS. The result is that all of the data are on the asymptote. This asymptote is at about 2 percent highly annoyed independent of noise exposure. Significantly, the asymptote does not go to zero at low noise exposure levels.

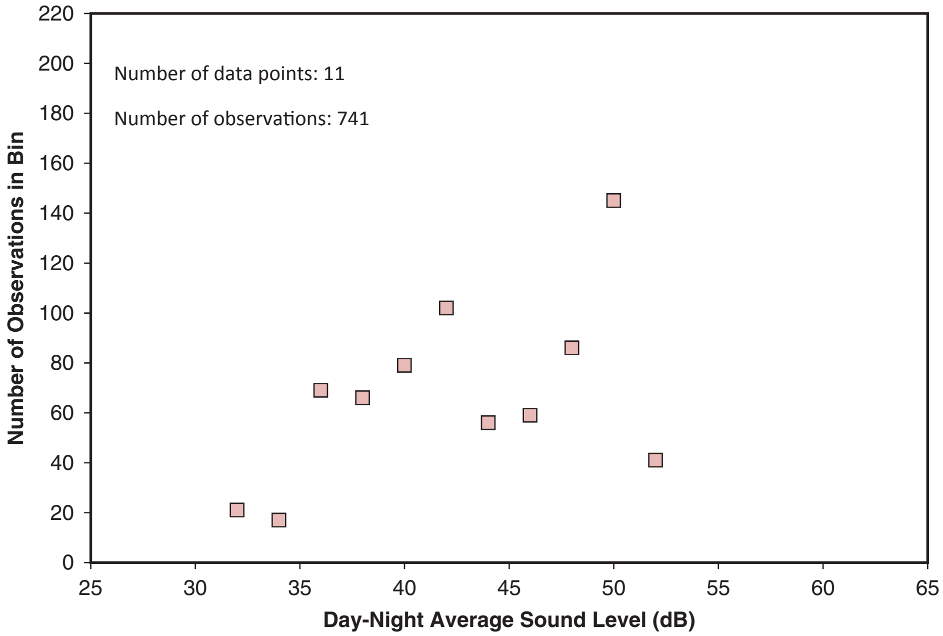


Figure 5-26. LAS, number of respondents for each helicopter survey point.

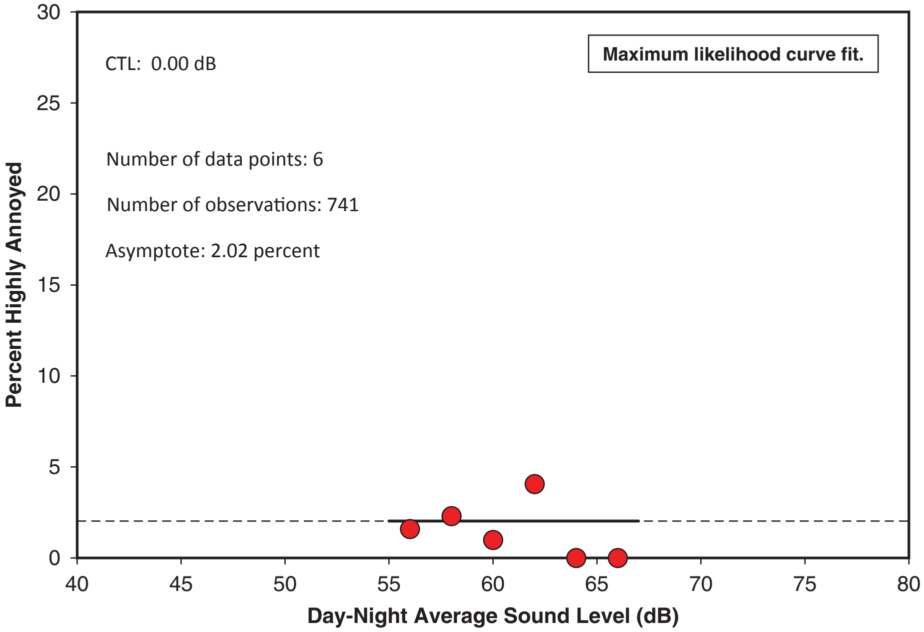


Figure 5-27. LAS, percent highly annoyed as a function of C-weighted DNL for helicopters.

Figure 5-27 shows the percent highly annoyed as a function of the C-weighted DNL. The C-weighting includes low-frequency noise far more effectively than does the A-weighting. Figure 5-28 shows the number of survey respondents for each survey bin. The C-weighted DNL response curve is similar to the A-weighted DNL, or in other words, flat. The asymptote shows a flat 2% highly annoyed independent of noise exposure, even accounting for the low-frequency noise.

In the hypothesis that annoyance response is a function of acoustic and nonacoustic parameters, nonacoustic parameters must be the dominating response.

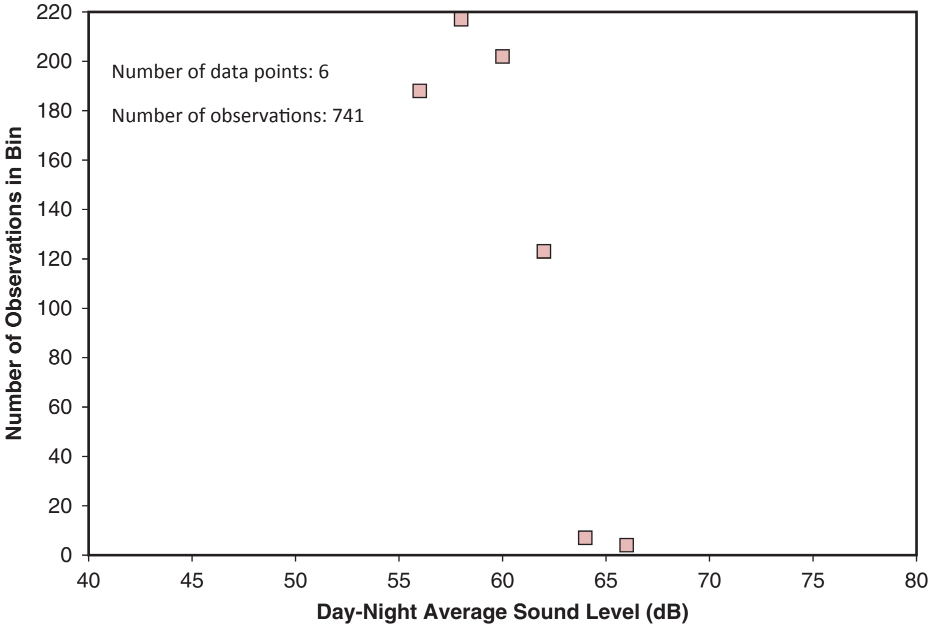


Figure 5-28. LAS, number of respondents for each helicopter C-weighted survey point.

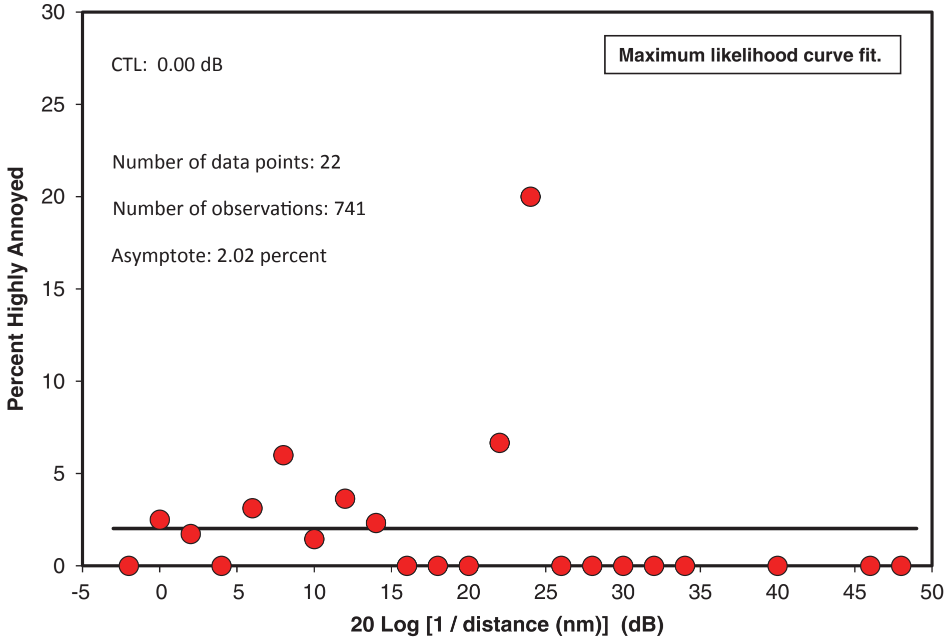


Figure 5-29. LAS, percent highly annoyed as a function of distance from helicopter corridor.

Figure 5-29 shows response as a function of reciprocal distance in the same manner as for Washington, D.C. Other than a singular point, there is no clear trend of increasing annoyance with decreasing distance to the helicopter corridor. Figure 5-30 shows the number of survey respondents for each survey bin.

5.5.2.3 Long Beach

Dosage-response graphs for Long Beach are shown in Figures 5-31 and 5-33 for the A-weighted DNL and reciprocal distance, respectively. Figures 5-32 and 5-34 show the number of respondents for each survey point.

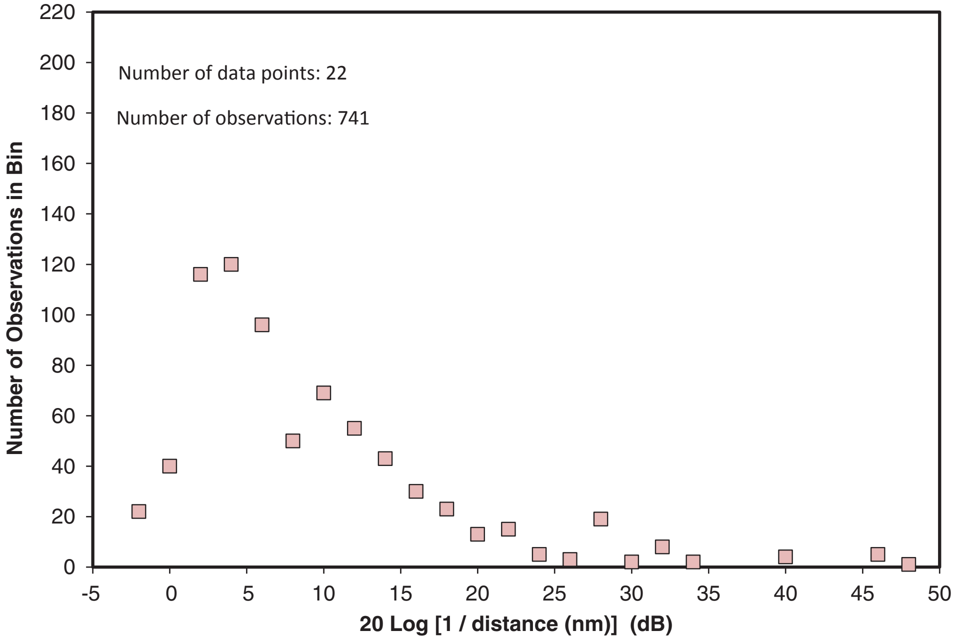


Figure 5-30. LAS, number of respondents for each helicopter distance.

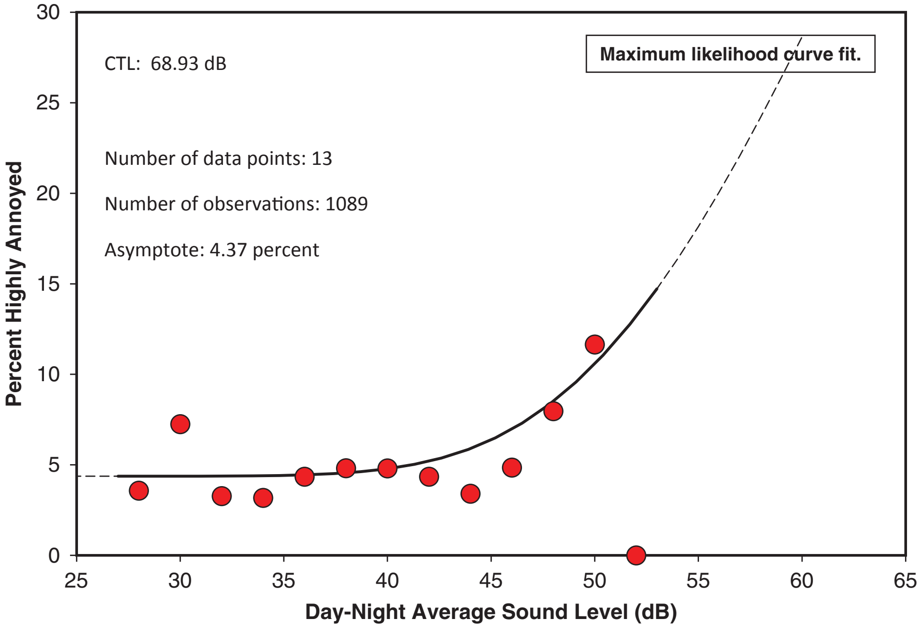


Figure 5-31. LGB, percent highly annoyed as a function of A-weighted DNL for helicopters.

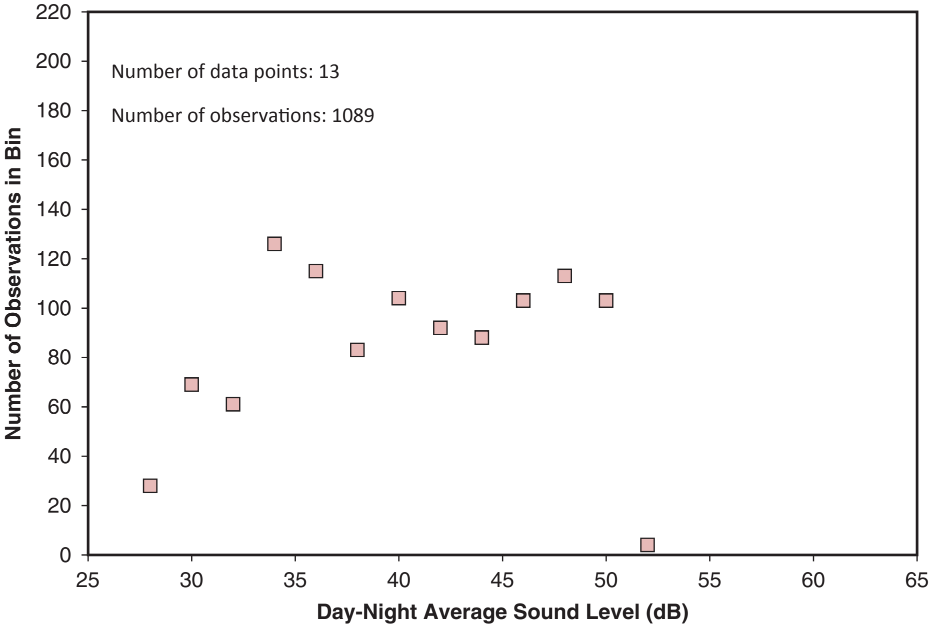


Figure 5-32. LGB, number of respondents for each helicopter survey point.

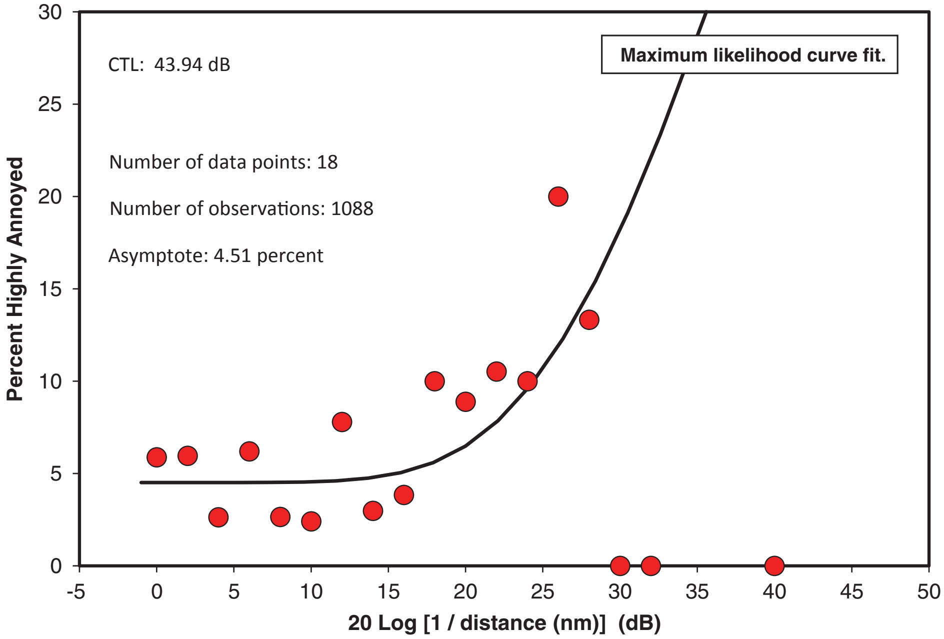


Figure 5-33. LGB, percent highly annoyed as a function of distance from helicopter corridor.

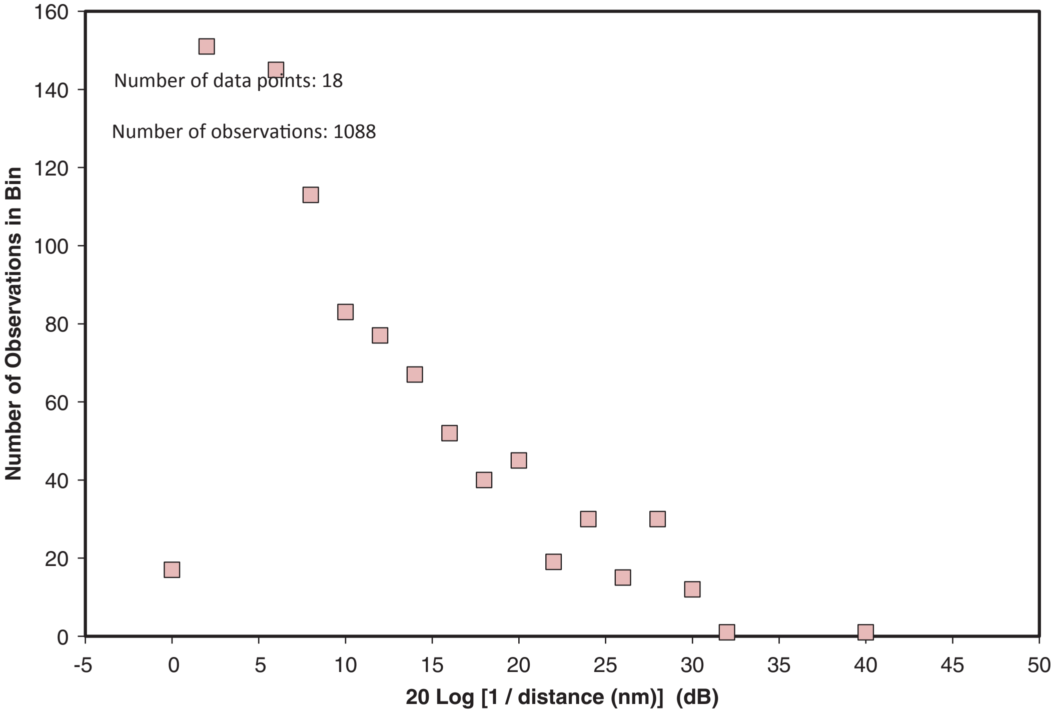


Figure 5-34. LGB, number of respondents for each helicopter distance.

The Long Beach dosage-response curve shows an increasing level of annoyance with increasing A-weighted DNL. This was the only survey site of the three sites where this clear trend is shown. Of note is the fact that the percent highly annoyed does not go to zero at lower noise exposures, but, in fact, the asymptote flattens out at about 4 percent highly annoyed no matter how low the DNL. Again, the hypothesis that annoyance response is composed of acoustic and nonacoustic response suggests that there are nonacoustic reasons that 4 percent of the population is highly annoyed with helicopters independent of noise dose.

Figure 5-33, the relation of percent highly annoyed to the reciprocal of distance, also shows a trend of higher annoyance with closer distance, but with much higher unexplained scatter in the data at higher DNL.

5.5.3 Dosage-response Relationship for Combined Sites

Figure 5-35 shows the dosage-response results for all three sites on the same plot. The solid lines represent the actual range of survey data and the dashed lines represent the curve developed from data extrapolated further out. Clearly each site is unique, indicating that each community has a unique response. The presence of residual annoyance as shown by the asymptote is a significant finding. It may indicate that the reason for apparent elevated helicopter complaints over those of fixed-wing has little to do with people's differing sensitivity to noise levels from the two sources.

However, whatever is underlying the observed residuals results in people being annoyed where similar levels from fixed-wing aircraft would likely result in zero high annoyance (meaning the helicopter annoyance is spread over a much larger geographic area than would otherwise have been predicted). Even a few percent highly annoyed over a vastly larger land area could add up to a "critical mass" of annoyed citizens. This is an unexpected but very real phenomenon.

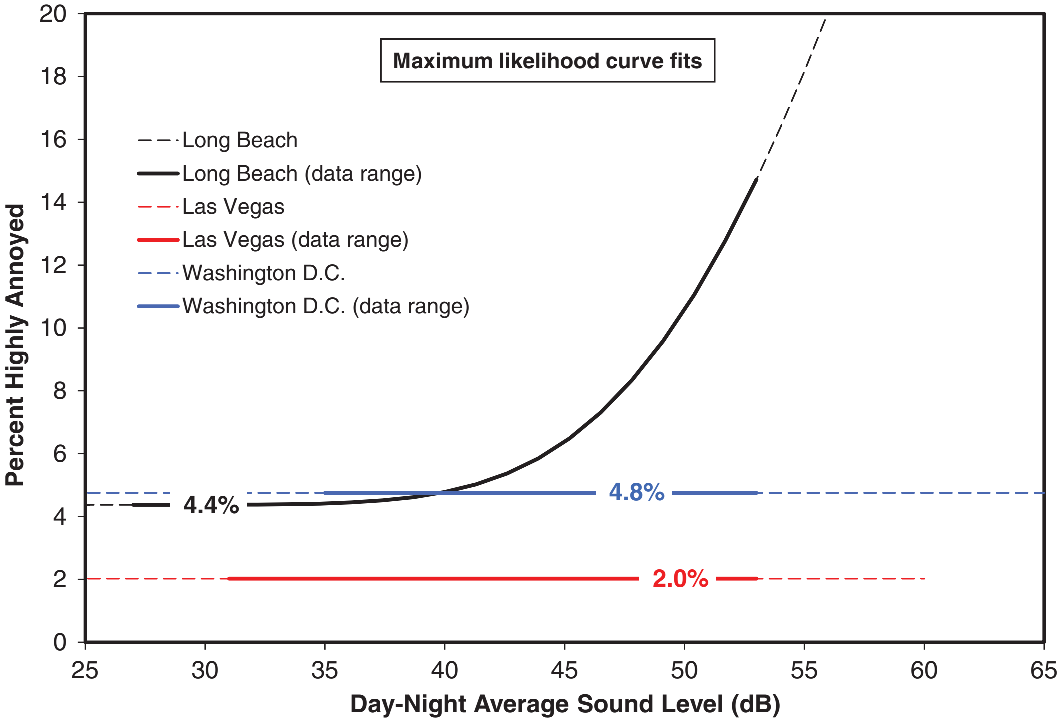


Figure 5-35. Composite results for all three sites.

5.6 Results of Low-Frequency Noise Analysis

Low-frequency noise emissions of helicopters are of particular concern as identified in Chapter 1 of this report. Fixed-wing jet aircraft noise consists of broadband noise spread over the audio spectrum, but helicopter noise is characterized by distinct frequency characteristics. Most helicopter noise is concentrated at lower frequencies. The following sections describe the results of the low-frequency noise analysis.

5.6.1 Measuring Low-Frequency Helicopter Noise

Most sound level meters include the ability to measure A- and C-weighted decibels, and using C-weighted decibels will capture the low-frequency components of helicopter noise. The downside to using the C-weighted decibel is that it does not identify if the noise is down in the range where rattle and vibration are induced which, as identified by the Low-Frequency Noise Expert Panel, is at frequencies below 80 Hz inclusive.

A more advanced method of identifying LFSLs is by measuring noise in ⅓ octave bands. This produces not one measure of a sound level, but 36 individual measures of a sound level, one for each ⅓ octave band from 6 Hz to 20,000 Hz. An even more advanced method using narrow band analysis divides the spectrum into 400 narrow bands for even higher resolution.

Another consideration in the measurement of helicopter noise is the time weighting. This is a complex topic that is difficult to simplify. Basically, the human response to a changing sound level is not instantaneous. In the days of sound level meters with a moving needle, the time averaging was done using a "slow" or a "fast" response that controlled how fast the needle moved. Slow response was generally used and was designed to approximate the human ear response to changing sound. Another weighting was developed for very short duration noise, such as a gunshot. This time weighting is called impulse weighting. With the advent of digital sound measurement devices, the slow and fast weightings are obsolete and instead a 1-second equivalent sound level is measured. This represents all of the acoustic energy contained within 1 second of time no matter how sudden the sound is. But short duration sounds such as gunshots or the impulsive noise of a helicopter noise is averaged into that 1 second. During LAS and LGB measurement programs the A- and C-weighted impulsive noise was also measured along with the 1 second equivalent sound level data.

5.6.2 Modeling the Low-Frequency Noise Level of Helicopters

The INM and now AEDT include the capability to calculate both A-weighted and C-weighted noise levels as well as noise levels based on EPNL, a ⅓ octave band based metric that was developed to reflect human perception of noisiness, not loudness, that includes penalties for pure tones. However, the database of aircraft noise levels built into INM and AEDT do not have data for frequencies below 50 Hz. One goal of this analysis is to determine if this deficiency precludes meaningful use of INM and AEDT for low-frequency studies of helicopter noise (note that there is no issue with the database as it is for A-weighted metrics).

5.6.2.1 Noise Measurement Data Collected for this Study

Noise measurements were made during the LAS and LGB studies. The measurement systems, described earlier, included the measurement of the A- and C-weighted decibel and the ⅓ octave band data from 6 Hz to 20,000 Hz. The impulse A- and C-weighted sound pressure level was also recorded. A special discussion of measuring low-frequency noise is warranted here. Sound measurement systems consist of a microphone and windscreen combination connected by cable to the recording sound level meter. The windscreen is designed to remove the sounds of the wind passing over the microphone grid. In general, and what was used for this study, a 4-inch windscreen made of open cell foam is used. As wind speed increases, the noise of the wind over the windscreen increases, especially at low frequencies. During the measurements at Las Vegas, wind was consistently very low and made a better dataset to test response to low-frequency noise. The Long Beach data, while having periods of calm was more generally windy, consistent with the coastal location: two weather fronts moved in through the study area during the survey. For this reason, the low-frequency response data were analyzed using the Las Vegas data.

5.6.2.2 Processing the LFSL Data

The measurement system collected data for each 1 second of every day that include the aforementioned A-weighted, C-weighted, and ⅓ octave band data. These data were used to build a large database that included all the data for all four sites for the 7 days of measurement. The following method was used to analyze the data:

1. Aircraft radar data was obtained from the airport. Helicopter noise events were identified by matching the noise event time to the time of helicopter point of closest approach to the noise monitoring site.
2. A database was generated that included only helicopter noise events at each site. Each event consisted of the helicopter type and one record of data for each second of the noise event. The events were defined by the time at which the A-weighted level exceeded 55 dB and the time at which the event noise dropped below 55 dBA. This threshold allowed for isolating the helicopter noise from ambient noise as well as possible. Since all four measurement sites were in quiet residential areas, ambient noise levels were low with only passing cars as a significant intrusion. The database consisted of 110,821 1-second records in the helicopter event database.
3. For each 1-second record, the C-weighted sound pressure level was calculated using all of the available ⅓ octave bands and once again not using any ⅓ octave data below 50 Hz (to simulate the C-weighted data as would be computed by INM or AEDT).
4. For each 1-second record the LFSL was computed for that 1 second using the original definition of LFSL and expanding the definition of LFSL to include lower ⅓ octave bands. LFSL was recalculated with lower frequency bands down to and including 16 Hz, 10 Hz, and 6 Hz.
5. For each helicopter noise event at each site the SEL was computed using the A, C, and LFSL scale and using the A-weighted and C-weighted impulse scales.

5.6.3 Results of Low-Frequency Data Analysis

An example of the sound spectrum in terms of ⅓ octave band sound pressure level is shown in Figure 5-36. The spectrum shown is for 1-second records with the highest LFSL, most strongly influenced by the high levels in the 20 and 25 Hz ⅓ octave bands.

5.6.3.1 Frequencies Used for LFSL Calculations

The LFSL calculation was run using the original definition of 25 to 80 Hz as well as using lower frequency bands of 16 Hz, 10 Hz, and 6 Hz. There was significant difference between LFSL calculations based on 25 and 16 Hz lower bands, typically in the range of 5 dB. The difference between LFSL based on 16, 10, or 6 Hz was about 0.1 dB. Therefore, for the purposes of this study, LFSL was redefined as the arithmetic average of the ⅓ octave band sound pressure levels from 16 to 80 Hz and is labeled $LFSL_{16}$.

5.6.4 Comparison of Low-Frequency Metrics to A-Weighted Metric

Table 5-8 lists the various noise exposure metrics for the four measurement sites in Las Vegas. Included are the energy average SEL for all helicopter events in terms of the A, C, impulse A, and

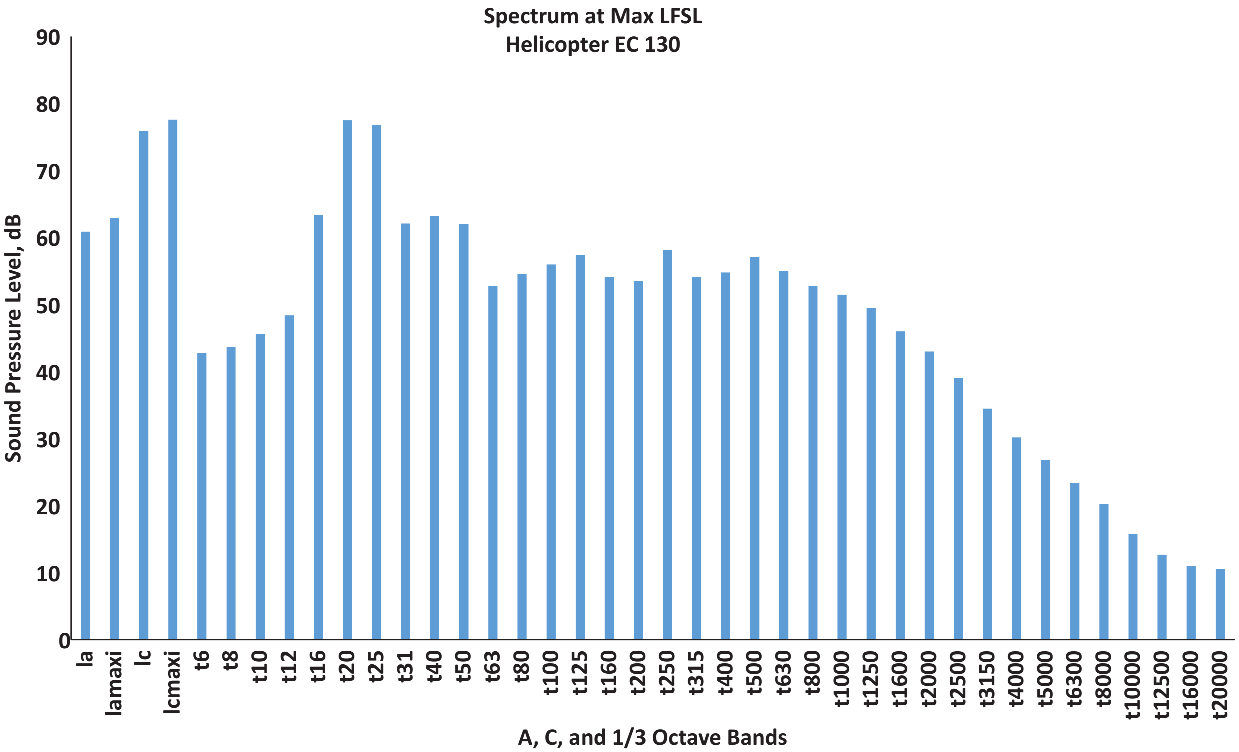


Figure 5-36. Sample spectrum for typical helicopter at the LAS interviewing site.

impulse C scales. Also calculated and shown is the SEL for C-weighting using only the frequency data available in INM and AEDT, i.e., frequencies above 50 Hz inclusive.

Note that the distance from the measurement site to the centerline of the helicopter corridor is also provided. The sites are not numbered in order of distance.

The first observation is that the SEL computed using only the INM/AEDT frequencies differs substantially from the true C-weighted SEL. This is important because it means that INM or AEDT can not be used for analyzing low-frequency noise in the study. INM nor AEDT can be used to compute C-weighted DNL for the social survey data. However, the measurement data can be used to convert the A-weighted DNL data computed by the noise model into C-weighted DNL. Figure 5-37 shows the relation of A-weighted SEL to C-weighted SEL as a function of distance to the helicopter tracks. The attenuation of sound with distance is highly dependent on the sound frequencies. For example, if the air temperature is 15 degrees, the sound frequency is

Table 5-8. A-weighted and low-frequency metrics at four measurement sites in LAS.

		Energy Average					Maximum of All Events		Arithmetic Average of Max LFSL	
Site	Close Appr. ft	A-weighted SEL	C-weighted SEL	SELcinm	A-weighted impulse SEL	C-weighted impulse SEL	LFSL	$LFSL_{16}$	LFSL	$LFSL_{16}$
1	394	77.3	87.4	83.1	85.4	90.9	85.0	87.6	74.0	78.6
2	1,864	74.7	89.0	82.7	78.6	91.6	84.7	87.1	74.3	79.1
3	2,419	73.3	86.3	80.3	77.2	88.9	81.7	84.3	72.1	76.8
4	762	77.3	87.7	82.8	86.6	91.6	85.5	89.9	73.4	78.8

Note: SELcinm is a C-weighted SEL, as calculated by FAA's INM (now AEDT) software. INM has no information about the acoustic energy of aircraft noise in frequency regions lower than the 50 Hz ⅓ octave band.

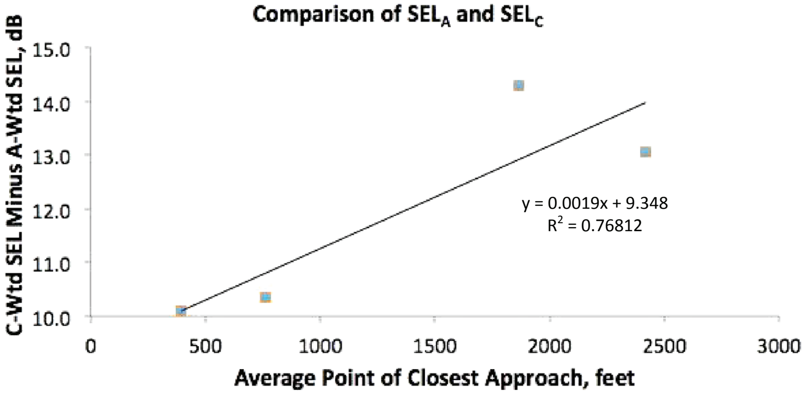


Figure 5-37. The relation of A- and C-weighted SEL for the LAS measurement data. (Wtd = weighted.)

50 Hertz, and if the atmosphere relative humidity is 40% then the attenuation due to this atmosphere is 0.111 dB per km. For the same conditions but for 500 Hertz, the attenuation is 2.18 dB per km, and at 5,000 Hertz, the attenuation is 69.7 dB per km. So, in this example, the attenuation over any reasonable distance from a helicopter (e.g., 500 or 1,000 meters) at the lowest frequencies is essentially 0; at middle frequencies, it is a few dB; and at high frequencies, nearly all of the sound is eliminated.

The A-weighted and C-weighted metric differs with distance because the atmosphere absorbs high-frequency sounds very efficiently and is very poor at absorbing low-frequency sounds. At larger distances, the low-frequency component of helicopter noise is heard more than the higher frequencies, which affect the A-weighted metric more, because the atmosphere has absorbed the high-frequency sounds.

The difference between A-weighted and C-weighted SEL as a function of distance can be used to convert the social survey receptor A-weighted DNL to an estimate of C-weighted DNL. This was calculated, and then used to create a C-weighted dosage-response curve, shown in Figure 5-28.

As evidenced from Table 5-8 and Figure 5-37, the C-weighted metric has a higher value than the A-weighted metric due to the concentration of low-frequency noise in the range of 16 to 80 Hz.

Table 5-9 also shows the energy average SEL in terms of the A-weighted impulse scale and C-weighted impulse scale. Again, these values are also significantly higher than the normal A-weighted SEL. Figure 5-38 plots the A-weighted impulse SEL against the normal A-weighted SEL. Impulse weighting, even with the heavy discounting of low-frequency noise by the A scale, shows a significant increase in level.

Lastly, the LFSL_{16} can be compared to the energy average A-weighted SEL. This is a bit of mixed comparison and is done with some caution. SEL is a measure of exposure, i.e., the acoustic energy

Table 5-9. Differences in A-weighted and low-frequency metrics, LAS.

		Differences Relative to A-Weighted SEL			
Site	**Close Appr. ft**	**C-weighted SEL - A-weighted SEL**	**Average max LFSL16 - A-weighted SEL**	**A-weighted impulse SEL - A-weighted SEL**	**C -weighted impulse SEL - A-weighted SEL**
1	394	10.1	1.3	8.1	13.6
2	1,864	14.3	4.4	3.8	16.9
3	2,419	13.1	3.5	3.9	15.7
4	762	10.4	1.4	9.3	14.2

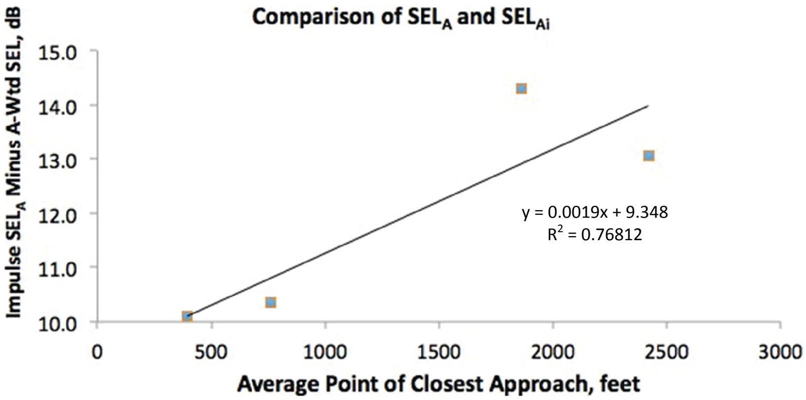


Figure 5-38. Relation of A- and A-weighted impulse SEL (SEL$_{Ai}$) for LAS measurement data.

during an entire event. LFSL is defined as a value at the time of a maximum. LFSL was defined this way because rattle either occurs or does not occur and any attempt to average LFSL, energy or arithmetic, will blur the ability to predict rattle. Figure 5-39 compares A-weighted SEL with LFSL$_{16}$. This comparison shows that the low-frequency components of helicopter noise have a significant potential to cause rattle that cannot be predicted from A-weighted SEL.

5.6.4.1 Summary of Low-Frequency Noise Analysis

Figures 5-37 through 5-39 all have nearly identical slopes. That means that C-weighted, A-weighted impulse, and LFSL$_{16}$ have nearly identical relationships to the A-weighted decibel. This means that understanding response to civil helicopter noise will not be enhanced by using special low-frequency or impulse metrics.

Table 5-8 summarizes the differences between the various metrics.

5.7 Noise Complaint Data

5.7.1 Long Beach Helicopter Noise Complaints

Table 5-10 shows the year 2015 helicopter noise complaints as recorded by the city of Long Beach. Of these 878 complaints, 89 occurred during the month of July (during which the survey was done). There is also another helicopter noise complaint database being built by the FAA as part of the LA Helicopter Initiative for all of the LA area. The City of Long Beach provides its

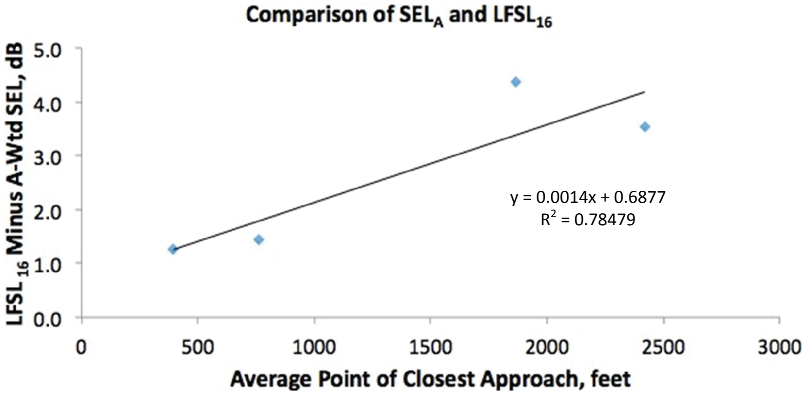


Figure 5-39. Relationship of A-weighted SEL to LFSL$_{16}$.

Table 5-10. Long Beach helicopter complaints during the year 2015.

Month	Helicopter Complaints
January	38
February	23
March	29
April	32
May	28
June	79
July	89
August	131
September	59
October	174
November	136
December	60

Source: LGB Airport Noise Office.

complaint data to the FAA, so the Long Beach data is a subset of the FAA database. The FAA database included 110 Long Beach complaints during the survey period. The Long Beach and the FAA databases include a field for address but it is often populated with a telephone number and not an address. For those 110 complaints in Long Beach during the social survey that did include at least a street name, the majority are in the study area.

5.7.2 Las Vegas Helicopter Noise Complaints

Clark County Division of Aviation recorded 3,963 noise complaints during the year 2015, of which 59 were helicopter noise complaints. None of the noise complaints were in the survey area, although two were just outside the study area (Source: Memorandum, Department of Aviation, “October, November, December and Annual 2015 Noise Complaint Reports,” Clark County Division of Aviation, January 28, 2016).

5.7.3 Washington, D.C., Area Helicopter Noise Complaints

The MWAA reported a total of 8,670 noise complaints for all aircraft in the year 2015. Of these, 343 were from Arlington and 7,930 were from NW Washington (Source: “2015 Annual Aircraft Noise Report,” MWAA, undated). The MWAA does not segregate noise complaints by fixed-wing or helicopter and there is not a way to recover which complaints were helicopter based.

CHAPTER 6

Conclusions and Discussion

This chapter discusses conclusions that may be drawn about the major hypotheses investigated in the current study.

Hypothesis 1: Decibel for decibel, rotary-wing aircraft noise is more annoying than fixed-wing aircraft noise.

No compelling evidence was found for the "excess" annoyance of civil helicopter noise with respect to that of fixed-wing aircraft noise. A likely reason for the absence of such evidence is that the study was conducted at interviewing sites with relatively low levels of helicopter noise exposure. If the study had been conducted in communities overflown by noisier military helicopters, the conclusion might have differed. Interviewing sites with relatively low levels of cumulative exposure to helicopter noise were not selected for study by preference, but rather because sites with greater levels of civil helicopter noise exposure could not be located, or were unsuitable for interviewing for lack of residential exposure.

The majority of the urban residential population overflown by scheduled civil helicopter operations is exposed to helicopter noise during cruise conditions, during straight and level flight at altitude. Even though maneuvering helicopters can be more complex and variable noise sources than fixed-wing aircraft in the vicinity of landing pads, the character of their noise emissions in the cruise regime may not differ as greatly in character from that of fixed-wing aircraft.

In the Washington, D.C., interviewing area, a notably greater rate of annoyance was observed for fixed-wing aircraft than for helicopters. Because noise exposure due to fixed-wing aircraft was considerably greater than that for helicopters in Washington, D.C., it was not possible to draw inferences about the relative annoyance of the two noise sources on a decibel-for-decibel basis.

A greater annoyance prevalence rate for helicopters than for fixed-wing aircraft was observed only in the Long Beach study area, but the respondents in the study area were exposed to very little fixed-wing traffic noise.

For the one site at which a reasonable dosage-response function could be inferred for annoyance due to exposure to helicopter noise, the DNL at which 50% of the population would be highly annoyed by helicopter noise was estimated at 69 dB. That is 4 dB less than the grand average for the 44 fixed-wing aircraft ($L_{dn} = 73.4$ dB, per Fidell et al. 2011). An indirect inference can therefore be drawn that helicopter noise is 4 dB less tolerable (quite likely for nonacoustic reasons) than the noise produced by fixed-wing aircraft.

Hypothesis 2: Main rotor impulsive noise controls the annoyance of helicopter noise (and hence requires an impulsive noise "correction" to A-weighted measurements).

A strong correlation between the prevalence of high annoyance and (A-weighted) DNL values was observed in only one of the three surveys in the interviewing area. Neither C-weighted measurements nor helicopter-adjusted LFSL measurements were any better at predicting annoyance prevalence rates due to dose. In Las Vegas and Washington, D.C., annoyance was not related to dose as measured by the A-weighted, C-weighted, or the helicopter-adjusted LFSL. In Washington, D.C., a public concern over relocated fixed-wing flight tracks might have made it difficult to discern any dosage-response relationship.

It is also likely that the low range of doses of helicopter noise precluded observation of a strong relationship with annoyance. It would have been advantageous to have surveyed a community with a helicopter noise exposure greater than $L_{\mathrm{dn}} = 60$ dB. To do that, a survey would have had to have been conducted around a military facility. The research panel restricted the surveys to civil helicopter routes, thus limiting the noise dose to DNL below 60 dB.

Measurements of A- and C-weighted impulsive noise levels and non-impulsive A- and C-weighted levels differed only by a constant. However, the rotor disks of the civil helicopters that created the noise exposure measured in this study lack the heavy loading, larger diameter, and high tip speeds of military helicopters. The levels of impulsive noise to which respondents were exposed in this study were considerably lower than those produced by maneuvering, heavier helicopters. This hypothesis would be better tested at sites with heavy military helicopter operations so that the impulsive noises were more pronounced. No clear conclusion could be drawn from the present findings about this hypothesis.

Hypothesis 3: Secondary emissions (rattle) induced by helicopter noise strongly influences its annoyance.

The prevalence of high annoyance was regressed on reported in-home vibration/rattling as well as on BVI (thumping or slapping), buzzing, and whining noise. No statistically significant relationship was observed between annoyance due to in-home vibration and rattling and annoyance due to noise level alone.

The dosage-response relationship between helicopter noise exposure and annoyance due to buzzing differed significantly from chance, and was unlikely to have arisen by chance alone in Long Beach, but not in Las Vegas or Washington, D.C. The regression of reported buzzing noises on helicopter noise exposure was the only one that was unlikely to have arisen by chance alone, but it accounted for very little variance in the relationship between annoyance and exposure. In the apparent absence of any strong association between helicopter noise exposure and annoyance at the low exposure levels that were available for this study, it is likely that nonacoustic factors had a greater effect than exposure levels on community response to helicopter noise.

Hypothesis 4: The annoyance of helicopter noise is strongly influenced by nonacoustic factors.

No acoustic factors can account for observed differences in the annoyance of exposure to helicopter noise at the interviewing sites. Given the observed differences in response at the Long Beach and Las Vegas interviewing sites, it is likely that nonacoustic factors were more salient than noise exposure in determining community response. Respondents in Las Vegas were exposed to about 10 times the number of flights (albeit at a greater altitude), but a much smaller percentage of the respondents in Las Vegas than in Long Beach reported high annoyance. The higher altitude effect on DNL (about a 3 to 4 dB reduction) was much smaller than the 10 dB effect of a greater number of operations on DNL.

Aircraft fleet mix cannot account for the difference in annoyance prevalence rates either. In Washington D.C., the concern over the change in fixed-wing flight tracks obscured the dosage-response effect for both fixed-wing and helicopter noise.

Hypothesis 5: Annoyance is better predicted by time-integrated proximity to flight tracks than by acoustic measures.

Regression analyses showed that proximity to the flight path was as good a predictor of self-reported high annoyance with helicopter noise as helicopter noise levels. This is not a surprising finding, since proximity and sound level are highly correlated. It remains unclear, however, whether exposure to the noise of direct overflights was found to be more annoying than exposure to noise of overflights that pass to the sides of residents' homes.

Additional hypotheses examined: Complaints lodged about helicopter noise are more reliable predictors of the prevalence of annoyance than measures of exposure to helicopter noise or proximity to helicopter flight paths.

An analysis of variance revealed no statistically significant difference in noise exposure for respondents who reported complaining than for those who did not. Very few respondents indicated that they had ever registered complaints about helicopter noise, however. Nonetheless, a statistically significant relationship was observed between the likelihood of complaint and reporting some degree of annoyance. Among the respondents who reported no annoyance from helicopter noise, 1.3% complained; of the respondents who reported at least slight annoyance from helicopter noise, 9.4% registered complaints. The likelihood of complaining about helicopter noise is thus at least partially dependent upon some degree of annoyance.

Additional observations: Noise exposure and annoyance, dosage-response relationship

No compelling evidence was found other than at the Long Beach interviewing site of a dosage-related increase in the prevalence of high annoyance. That is, all data points were observed to lie on some non-zero asymptotic value. With the Long Beach data, the rightmost three data points in the dosage-response plot were assumed to be dependent on dose. The remainder were assumed to be independent of dose and lie at some asymptotic value. Similarly, for the distance relationship, the data points at 28 dB and higher were assumed to be dependent on reciprocal distance, and the rest independent.

For Washington, D.C., there is no evidence of annoyance growth with increasing dose or reciprocal distance as shown in Figures 5-19, 5-21, 5-23 and 5-35. For fixed-wing aircraft the asymptotic value of annoyance is about 15%. The range of respondent DNLs is also the same (a 10 dB range from 50–60 dB). However, comparing asymptotic annoyance percentages between fixed- and rotary-wing aircraft, the numbers are 15%, 16%, and 4.75%, respectively—a 10.41 dB difference.

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APPENDIX A

Technical Discussion of Helicopter Noise

This Appendix discusses two distinct matters: the nature of helicopter noise emissions (Section A.1) and the relationship among various measures of helicopter noise levels (Section A.2). The former discussion provides insight into some of the constraints on site selection for subsequent field studies. The latter discussion, which presents the results of an analysis of the relationships among various helicopter noise measurements, can help with the design of field measurements.

A.1 Characteristics of Helicopter Noise in Various Flight Regimes

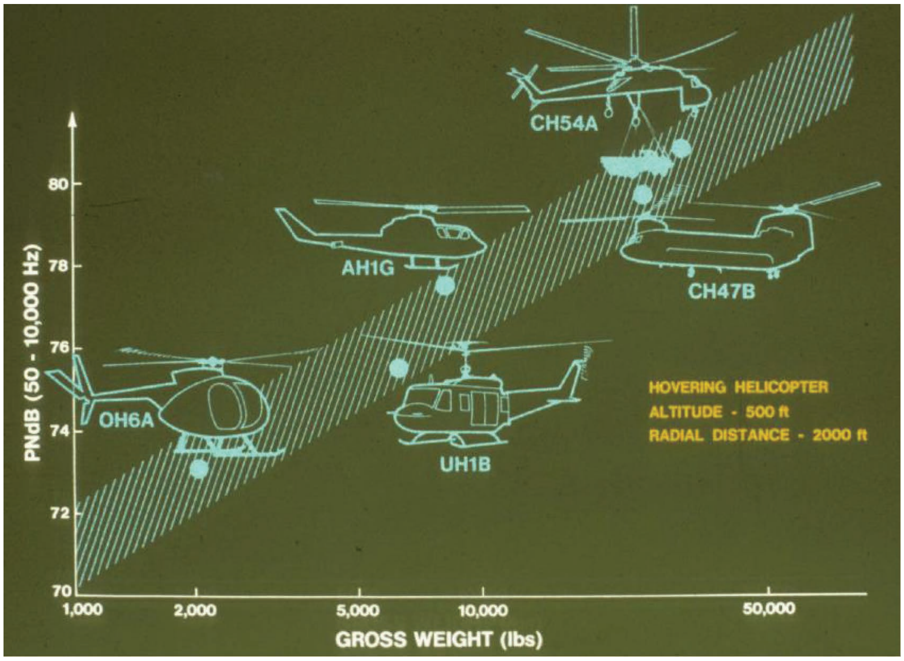
Helicopter noise is an unavoidable by-product of creating the lift necessary to make helicopters and other vertical lift machines fly. When rotating and translating through the air, rotor blades displace the air due to their finite thickness. When these spatial disturbances of the fluid are added at a far-field observer location (keeping track of retarded time), they create harmonic “thickness noise.” The rotating and translating rotor also accelerates air to cause net forces (lift and drag) on the blades. This acceleration of the air, caused by the lift and drag forces, causes small compressible waves that, when added together at the correct retarded time, radiate harmonic noise to an observer far from the noise source. Heavier vehicles produce more noise, as shown in Figure A-1 for a series of older military helicopters. While there is some deviation about the trend line due to design characteristics unique to each model, the trend is readily apparent. Other unsteady aerodynamic sources dependent on design details of particular vehicles can add to the noise. The basic physics of these phenomena has been known for more than six decades—and even longer for propellers.

A.1.1 Major Helicopter Noise Sources

Before addressing the origins and mechanisms of helicopter external noise, it is useful to identify the most noticeable, even if not necessarily the most annoying, sources. The order of importance for producing an acceptably quiet helicopter is shown in Figure A-2 for a generic single rotor helicopter of the light to medium weight class—up to 10,000 lbs.

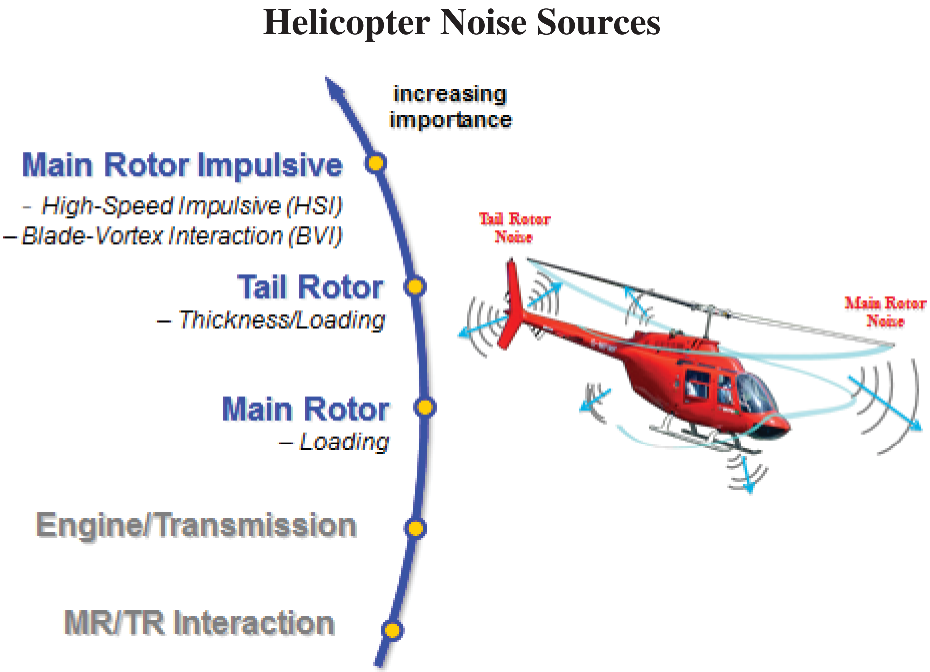
Impulsive harmonic noise sources generally dominate helicopter detectability, and are often thought to be the main source of annoyance, for both the main rotor and tail rotor. The tip region on the advancing side of the rotor near the 90-degree azimuth angle of the rotor disk produces most of the radiated harmonic noise. The thickness and loading noise sources on each blade element are amplified by the high advancing Mach numbers in this region.

At high advancing-tip Mach numbers, thickness noise often becomes more dominant as Mach number increases. At very high advancing-tip Mach numbers, High-Speed Impulsive (HSI) noise



(Source: Old Army Report—Circa 1974)

Figure A-1. Relationship between helicopter weight and perceived noise level.



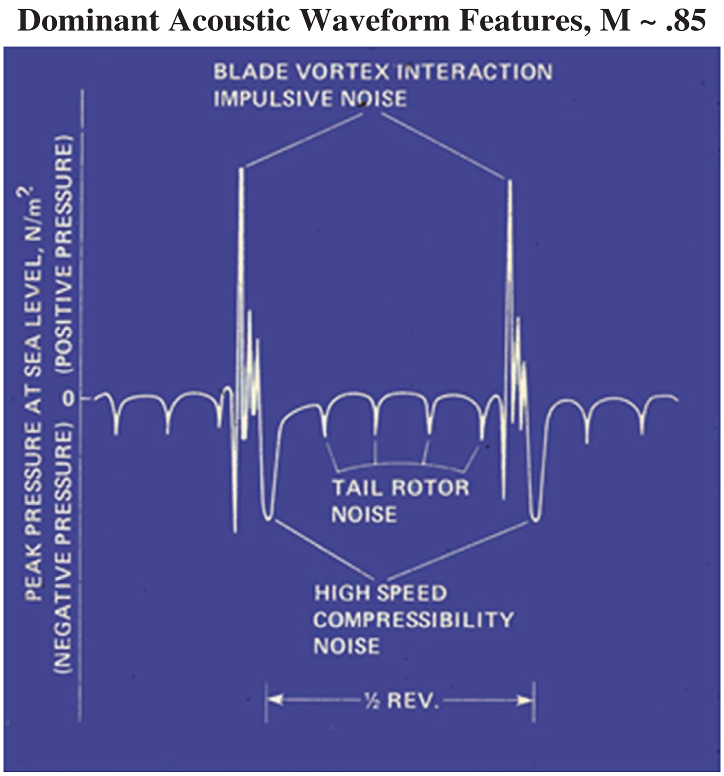
(Source: Schmitz—Sketch from student's University of Maryland PhD thesis.)

Figure A-2. Prioritized contributions of helicopter noise sources to overall emissions.

develops. The local transonic flow around the rotor blade often couples with this radiating acoustic field causing acoustic "delocalization" that radiates local shock waves to an observer in the far-field. When this occurs, the noise produced is nearly always highly annoying, and dominates the acoustic signature of the helicopter. This type of noise tended to dominate the main rotor noise of the "Huey" helicopter of the Vietnam War era. When it occurs, HSI noise clearly dominates the acoustic radiation near the plane of the rotor. Most modern helicopters are designed so that "delocalization" does not occur in normal cruising operations. However, thickness noise remains a main contributor to in-plane noise levels in cruising flight even for modern helicopters. It is also interesting to note that main rotor HSI noise cannot be heard in the helicopter cabin because the radiating waves originate near the tip of the rotor and radiate in the direction of forward flight.

Most helicopters also produce a second impulsive noise caused by sudden, rapid pressure changes occurring on the lifting rotor blades. These pressure changes occur when the rotors pass in close proximity to their previously shed or trailed tip vortices. They normally occur when the helicopter is operating in descending, turning, or decelerating flight, at times when the rotor blades are passing through or near their own wake system. A typical one-revolution period for this type of noise signature radiated from a single main rotor helicopter is shown in Figure A-3. This "wop-wop" sounding impulse stream, called Blade-Vortex-Interaction, BVI, is often the characteristic sound that distinguishes helicopter operational noise from other transportation noise sources in terminal operating areas.

The noise produced by the anti-torque device of a single rotor helicopter can also be a major noise source. When tail rotors are used as the anti-torque device, the dominant sources are


Dominant Acoustic Waveform Features, M ~ .85

(Source: Schmitz, F. H.; Boxwell, D. A.; and Vause,C. R.:High-Speed Helicopter Impulsive Noise. *J. American Helicopter Soc.,* vol. 22, no. 4, Oct. 1977, pp.28-36.)

Figure A-3. A typical one-revolution period for "wop-wop" of noise signature radiated from a single main 2-bladed rotor helicopter.

fundamentally the same as the main rotor. However, the higher operating RPMs of the tail rotor make the lower and mid-frequency tail rotor harmonic noise more noticeable and objectionable to a far-field observer. Because the tail rotor is often unloaded in forward flight, tail rotor thickness noise can often be the first sound heard by a far-field observer.

On some helicopters, the main rotor wake can pass in close proximity to the tail rotor disk in some operating conditions and increase noise emission level. The problem is aggravated by helicopters that operate with "top forward rotating" tail rotors. The problem has been minimized by more careful design and operation.

Aérospatiale introduced a lifting fan for directional control on many of their single rotor helicopters to mitigate tail rotor noise and reduce tail rotor drag in forward flight. The many-bladed fan (the "Fenestron") creates somewhat lower levels of harmonic noise, but at higher frequencies, and can be quite annoying. However, noise at these frequencies is reduced with distance from the source due to atmospheric absorption effects. Fenestron noise therefore contributes little to helicopter noise at long ranges.

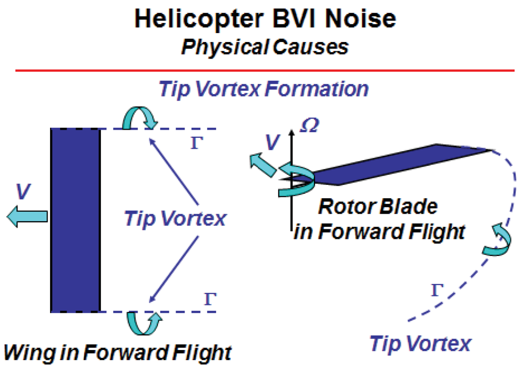
Lower frequency harmonic loading of the helicopter is next in order of acoustic importance. This sound is a direct result of the lift and drag (torque) produced by helicopters. It tends to be most important for civil helicopter operations directly underneath the helicopter. Although it is low frequency in character, it has substantial energy and is partially responsible for the excitation of "rattle" in many instances. For military helicopters, however, the low- to mid-frequency radiated noise near the plane of the rotor is of prime concern, because it often sets the aural and electronically aided detection range of helicopters. This noise is determined by the in-plane drag time history of the rotor and by the thickness of the blades, as noted above.

Engine noise can also be an important noise source. It is controlled by engine choice and on-board installed acoustic treatment. Transmission noise is important in close proximity to the helicopter or internally, but unless excessive, is not usually an external noise problem.

Last on the list of noise sources is "Broadband" noise. It is caused by changes in localized blade pressures caused by aperiodic and/or unsteady disturbances. It is normally of lower level on light- to medium-weight helicopters with normal operational tip speeds, but becomes more important on heavy helicopters as design tip speeds are lowered and the numbers of rotor blades are increased. It is also influenced to a great extent by the local inflow through the rotor system. Higher positive or negative inflow tends to reduce the noise by carrying the disturbed unsteady flow away from the rotor, thus avoiding additional unsteady blade loading and hence additional noise.

Because of their ability to carry large loads and more easily handle the center of gravity issues associated with these large loads, tandem rotor helicopters have also become a workhorse helicopter for the military. The lack of conventional tail rotors on these machines reduces the noise to a degree, but their large overlapped rotor systems often create unsteady inflow to the rotors, making large harmonic noise levels commonplace for such vehicles. Because of their high-tip Mach numbers, tandem rotors also produce large amounts of thickness noise. For a variety of reasons, most tandem rotor helicopters do not operate in commercial airspace in or around noise sensitive areas.

The tiltrotor is another type of dual rotor rotorcraft that was developed by the military. It is being proposed for civilian operations in a scaled down version for executive travel (Agusta 609) to combine a vertical lift capability with conventional turboprop airspeeds. In helicopter mode, the net inflow through the rotor can be controlled, thus controlling BVI noise in the terminal area. Thickness noise at cruise speeds is minimized by converting to aircraft mode at reduced rotor RPM. The reduced RPM in cruise decreases the noise level. Lower frequency noise is still



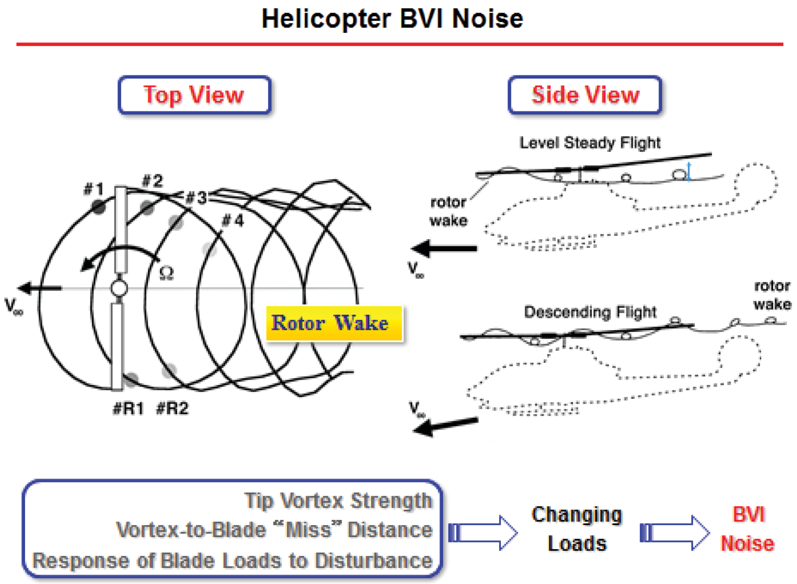
(Source: Boxwell, D. A.; and Schmitz, F. H.: Full-Scale Measurements of Blade-Vortex Interaction Noise. *J. American Helicopter Soc.*, vol. 27, no. 4, Oct. 1982, pp. 11–27.)

Figure A-4. Physical causes of helicopter blade-vortex interaction noise.

present because the disturbance field of the wings induces periodic loading on the blades, creating far-field noise.

A.1.2 Controlling BVI Noise in the Terminal Area

As discussed above, BVI impulsive noise occurs when the rotor operates near its own shed wake. Figure A-4 shows that a vortex is shed from the tip of each rotor blade just as it does for a fixed-wing aircraft. The tip vortex trailed behind each blade interacts with the following blades to create sharp changes in local blade pressure (and thus lift.) The pressure changes push on the fluid and radiate BVI noise. Figure A-5 shows a sketch of the geometry of the BVI interaction process. The top view shows the geometry of the interaction process, while the side view illustrates the closeness of the shed tip vortices to the top tip-path-plane.



(Source: Schmitz, F. H. and Sim. B., Sketch from HAI briefing, Los Angeles, CA 2005.)

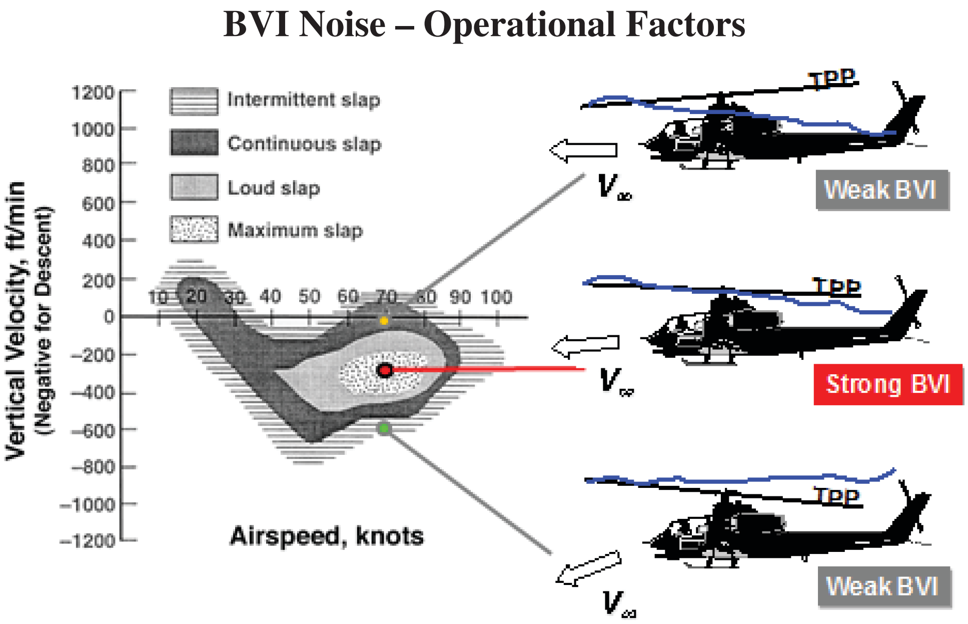
Figure A-5. Geometry of the BVI interaction process.

Figure A-6 shows that this closeness can be controlled to some degree by the choice of the helicopter operating condition. In level flight, the helicopter's shed tip vortices pass under the rotor's tip-path plane and radiate small to moderate amounts of BVI noise. However, as the helicopter descends, the rotor's wake is forced to remain near the rotor's tip-path plane, causing the rotor to closely interact with the shed tip vortices of preceding blades. These strong changes in lift cause large levels of BVI noise radiation. Increasing the descent rates further causes most of the shed tip vortices to pass above the rotor's tip-path plane, which reduces BVI noise levels. Vehicle acceleration/deceleration and turning in flight can also influence the location of the tip vortices with respect to the rotor tip-path plane and hence dramatically change the radiated BVI noise.

Figure A-7 shows in-flight measurements of BVI noise, taken on a microphone about 30 degrees below the plane of the rotor. A rapid series of positive pressure pulses is seen to occur that reach a peak and then decrease with increasing rates of descent at approach airspeeds. Because these pressure pulses are very narrow, they radiate most, but not all, of their energy in the mid- to high-frequency range and can easily annoy and disturb a far-field observer. A narrow band FFT of the pulse time histories illustrates the moderate to high frequency nature of the resulting BVI noise (Figure A-8).

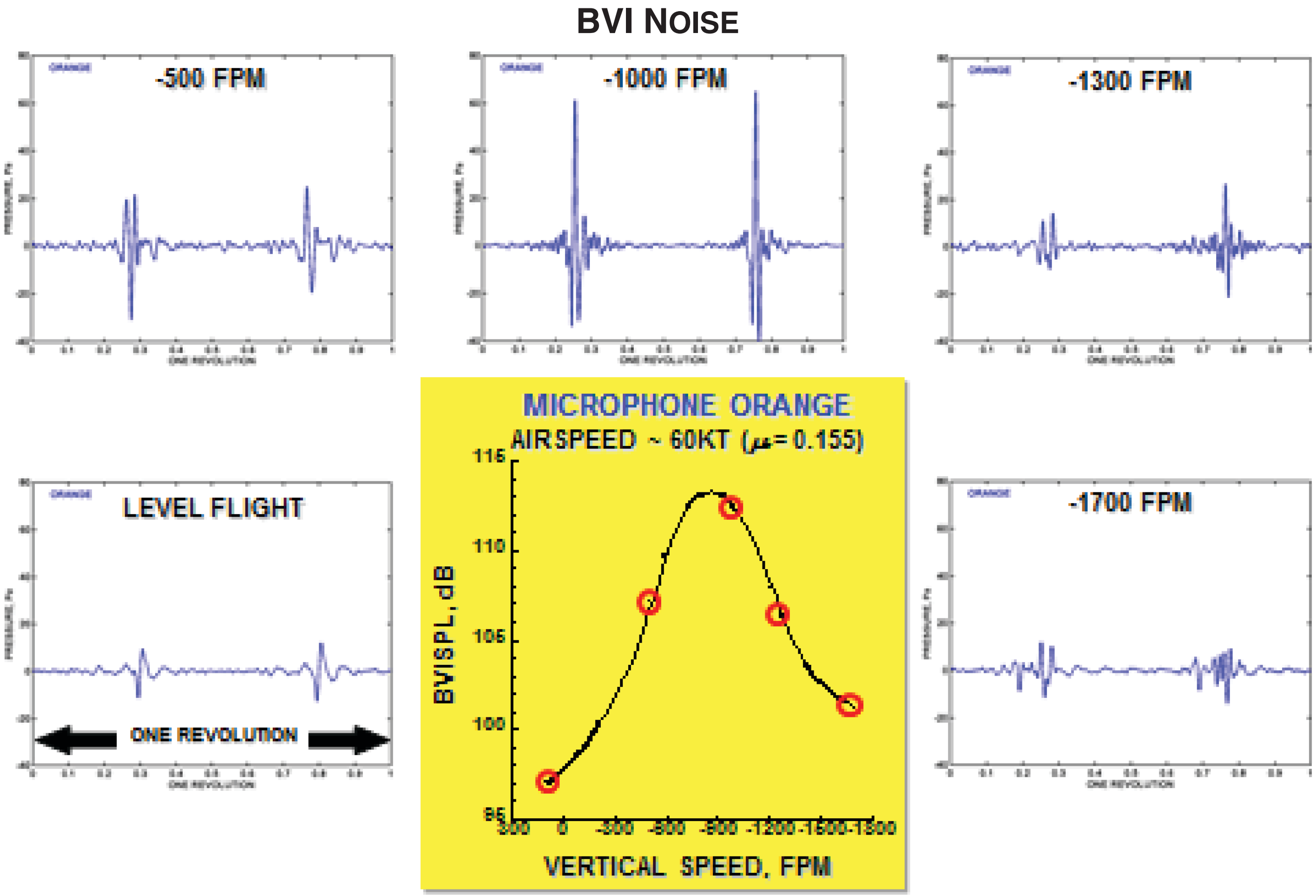
The fact that the radiated BVI noise levels can be controlled by changing the helicopter flight path has not gone unnoticed by the rotorcraft operational community. The Helicopter International Association (HAI) has developed a "Fly Neighborly Program" to make pilots aware that helicopters can be flown quietly near high-density and/or sensitive population zones. Research has also shown that "X-Force" control (acceleration/deceleration and drag/thrust control) can also be effective at minimizing BVI noise. In fact, a 0.1g deceleration is equivalent to a 5.7-degree change in descent angle. A sketch of the use of such techniques is shown in Figure A-9.

Use of operational parameters to minimize noise exposure is well documented. One such example is shown in Figure A-10, in which a Sikorsky S-76 helicopter was flown to minimize ground noise exposure. High rates of descent and deceleration were both used to substantially reduce radiated BVI noise levels.



(Source: Schmitz, F. H. and Sim. B., -Sketch from HAI briefing, Los Angeles, CA 2005.)

Figure A-6. Effect of operating condition on blade slap.



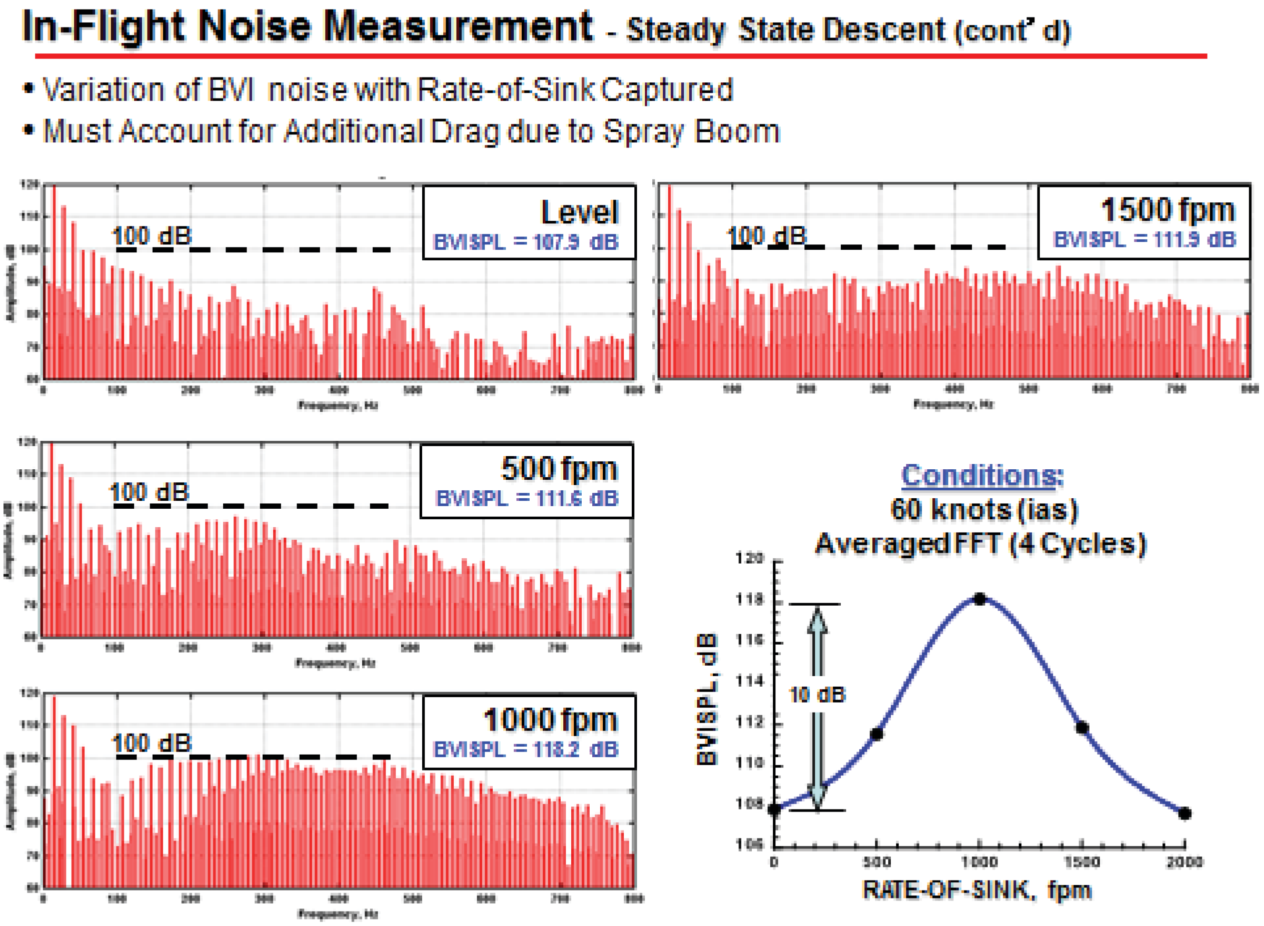
(Source: Schmitz, F. H. and Sim. B., Sketch from HAI briefing, Los Angeles, CA 2005.)

Figure A-7. BVI noise as a function of descent rate and level flight.

Source noise reductions depicted in Figures A-9 and A-10 are not always achievable in normal operations. Weather, winds, other flight traffic, and maneuvering flight can substantially change BVI noise levels. In addition, the BVI noise may become intermittent—occurring for a few seconds (seemingly disappearing) and then reappearing randomly. This often happens in near level flight operations in "bumpy" air—creating intermittent BVI.

A.2 Correlational Analysis of Helicopter Noise Metrics

Version 7.0d[19] of FAA's Integrated Noise Model (INM) permits users to predict helicopter noise exposure in a range of units (noise metrics). INM's databases contain information for a variety of helicopter types that include physical descriptions of aircraft, noise-power-distance (NPD) curves, standard arrival, departure, and level flight profiles, and for some helicopters, hover-in-ground-effect profiles, directivity profiles for each operating mode, and spectral class data for some helicopters. The NPD curves include A-weighted metrics maximum noise level (L_{max} or LA_{max}) and sound exposure level (SEL), and for some aircraft, tone-corrected perceived noise level [PNL(T)] and effective perceived noise level (EPNL). INM uses spectral class data to compute C-weighted metrics: C-weighted maximum noise level (LC_{max}) and C-weighted SEL (CEXP) and time above C-weighted threshold.

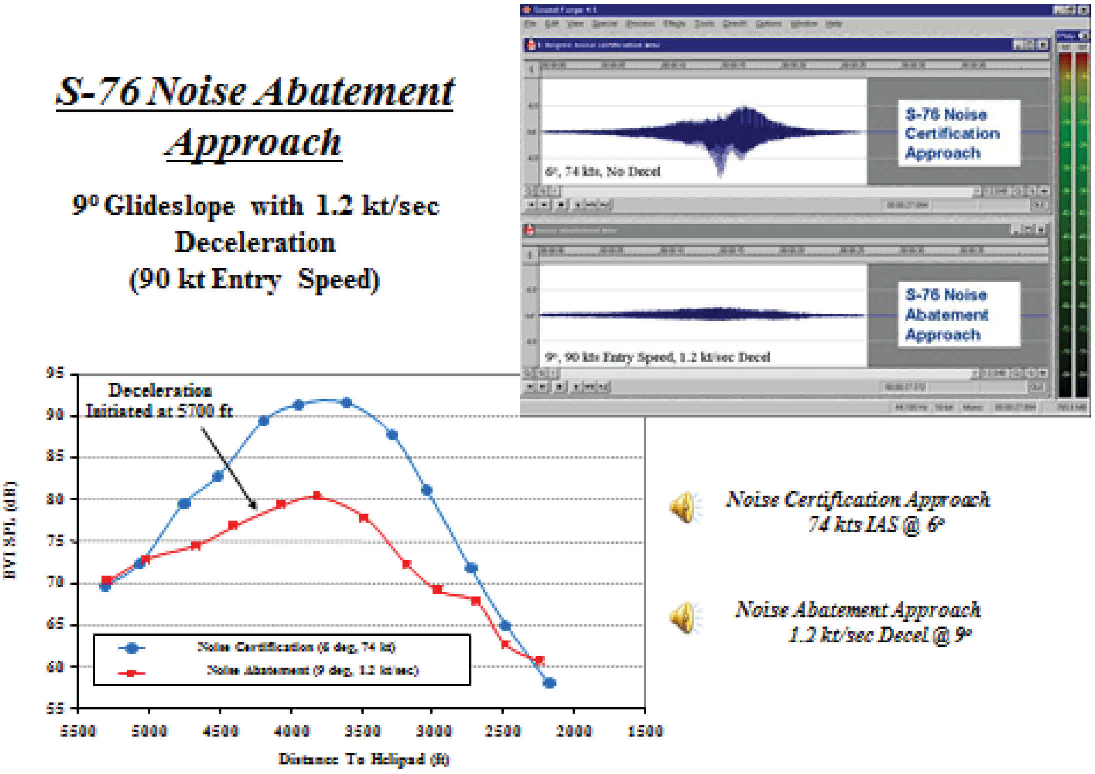


In-Flight Noise Measurement - Steady State Descent (cont' d)

- Variation of BVI noise with Rate-of-Sink Captured
- Must Account for Additional Drag due to Spray Boom

(Source: Schmitz, F. H. and Gapolan, G. – Sketch from HAI briefing, Las Vegas, NV 2004.)

Figure A-8. Sound frequency as function of climb rate and level flight.

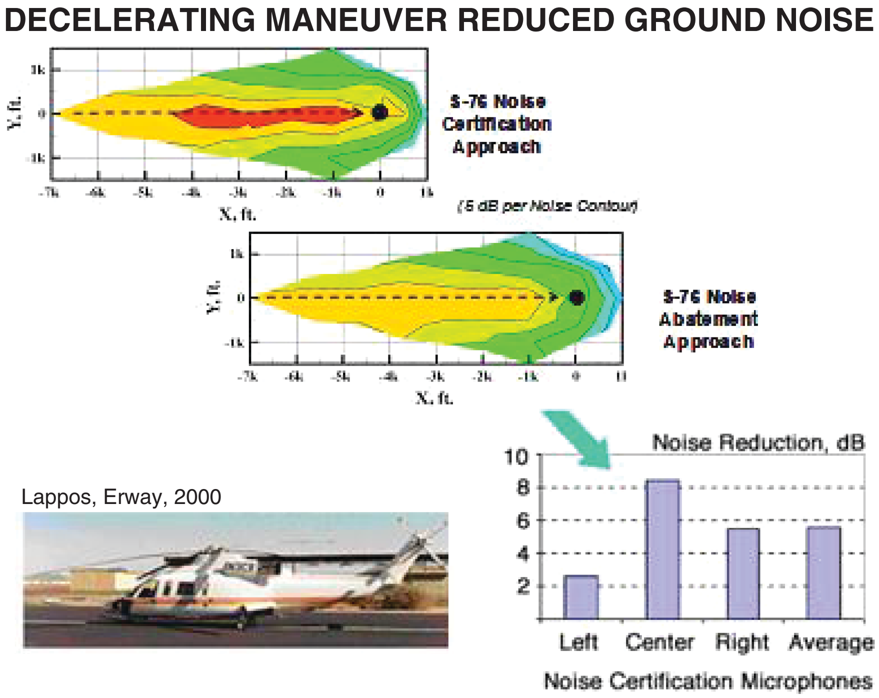


S-76 Noise Abatement Approach

9° Glideslope with 1.2 kt/sec Deceleration (90 kt Entry Speed)

(Source: Schmitz, F. H., *et. al.*, Measurement and Characterization of Helicopter Noise in Steady-State and Maneuvering Flight, presented at the AHS Annual Forum, 2007.)

Figure A-9. S-76 noise abatement approach.



(Source: Schmitz, F. H. and Gapolan, G. Sketch from HAI briefing, Las Vegas, NV 2004.)

Figure A-10. Reduced ground noise with modified approach procedure.

Table A-1 lists the helicopters that are currently included in the INM database. Note that FAA has published a long list of substitutions for helicopters not included in the database and a recommended helicopter from the database to use as a surrogate for that helicopter.

A.2.1 Helicopter Spectral Classes

INM helicopter spectral classes are representations of average spectra for groups of helicopters with common characteristics. Figure A-11 and Figure A-12 show two of INM's spectral class charts for the B212, BO150, and S70 helicopters (Figure A-11) and the SA335, S65, and H500D helicopters (Figure A-12). Note that the spectral class data are unavailable for frequencies lower than the one-third octave band centered at 50 Hz. The database structure allows for lower frequency information, but none is currently available.

A.2.2 Correlations Among Helicopter Noise Metrics

A hypothetical helicopter exposure case was constructed to examine the relationships among the noise metrics that INM computes. The purpose of the exercise was to inform the selection of noise metrics for the field measurements of this research project. The numbers and types of measurements required for the social survey and subsequent analyses can directly affect the cost and design of the research.

The hypothetical case modeled noise exposure for a generic heliport with a large number of operations. The first case studied featured simple straight-in and straight-out departure flight paths, using the standard profiles built into INM for the nine helicopters that have both A-weighted and PNL based NPD data. One hundred arrivals and one hundred departures were evaluated using an equal distribution of the following helicopter types: B206B3, B407, B427, B429, B430, EC130, R22, R44, and SC300C.

(Contour values 75 DNL to 55 DNL, Grid point spacing 0.1 nm.)

Table A-1. Helicopters included in INM v7.0d database.

HELICOPTER INM NAME	DESCRIPTION
A109	Agusta A-109
B206L	Bell 206L Long Ranger
B212	Bell 212 Huey (UH-1N) (CH-135)
B222	Bell 222
B206B3	Bell 206B-3
B407	Bell 407
B427	Bell 427
B429	Bell 429
B430	Bell 430
BO105	Bölkow BO-105
CH47D	Boeing Vertol 234 (CH-47D)
EC130	Eurocopter EC-130 w/Arriel 2B1
H500D	Hughes 500D
MD600N	McDonnell Douglas MD-600N w/ RR 250-C47M
R22	Robinson R22B w/Lycoming 0320
S61	Sikorsky S-61 (CH-3A)
S65	Sikorsky S-65 (CH-53)
S70	Sikorsky S-70 Blackhawk (UH-60A)
S76	Sikorsky S-76 Spirit
SA330J	Aérospatiale SA-330J Puma
SA341G	Aérospatiale SA-341G/342 Gazelle
SA350D	Aérospatiale SA-350D AStar (AS-350)
SA355F	Aérospatiale SA-355F Twin Star (AS-355)
R44	Robinson R44 Raven / Lycoming O-540-F1B5
SC300C	Schweizer 300C / Lycoming HIO-360-D1A
SA365N	Aérospatiale SA-365N Dauphin (AS-365N)

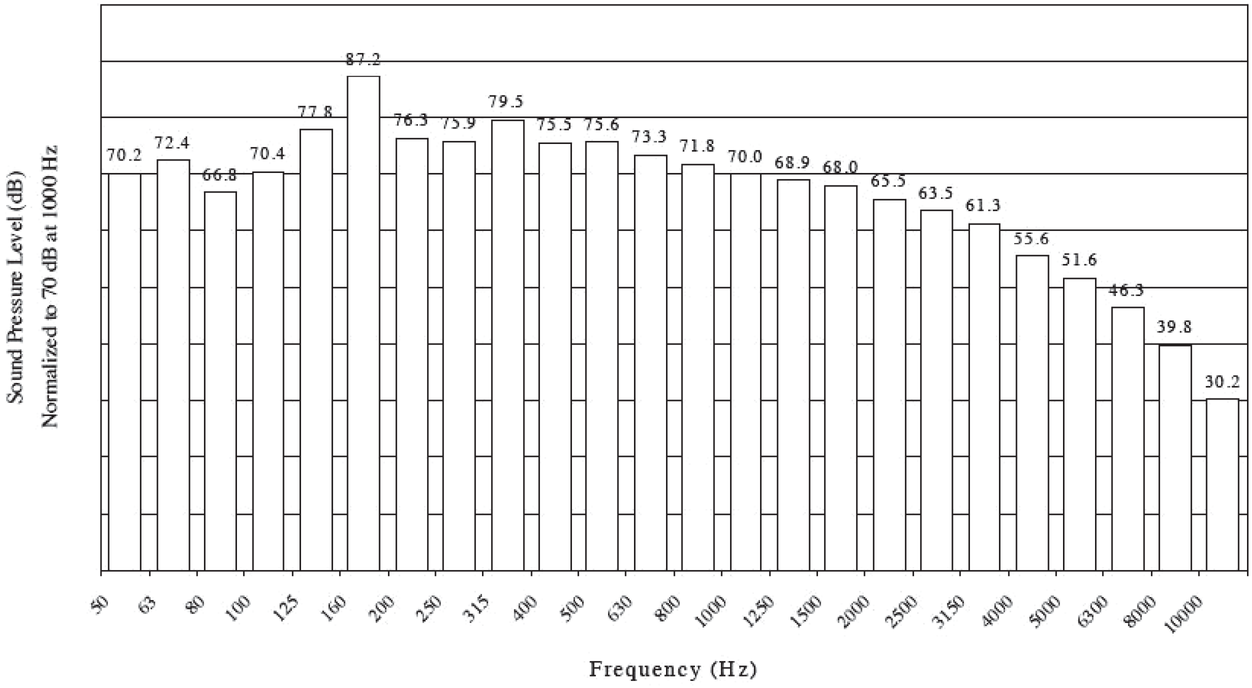


FIGURE 14. DEPARTURE SPECTRAL CLASS 114

INM Aircraft Descriptions:	Helicopter
INM Aircraft ID:	B212 BO150 S70

Figure A-11. Spectral class example 1.

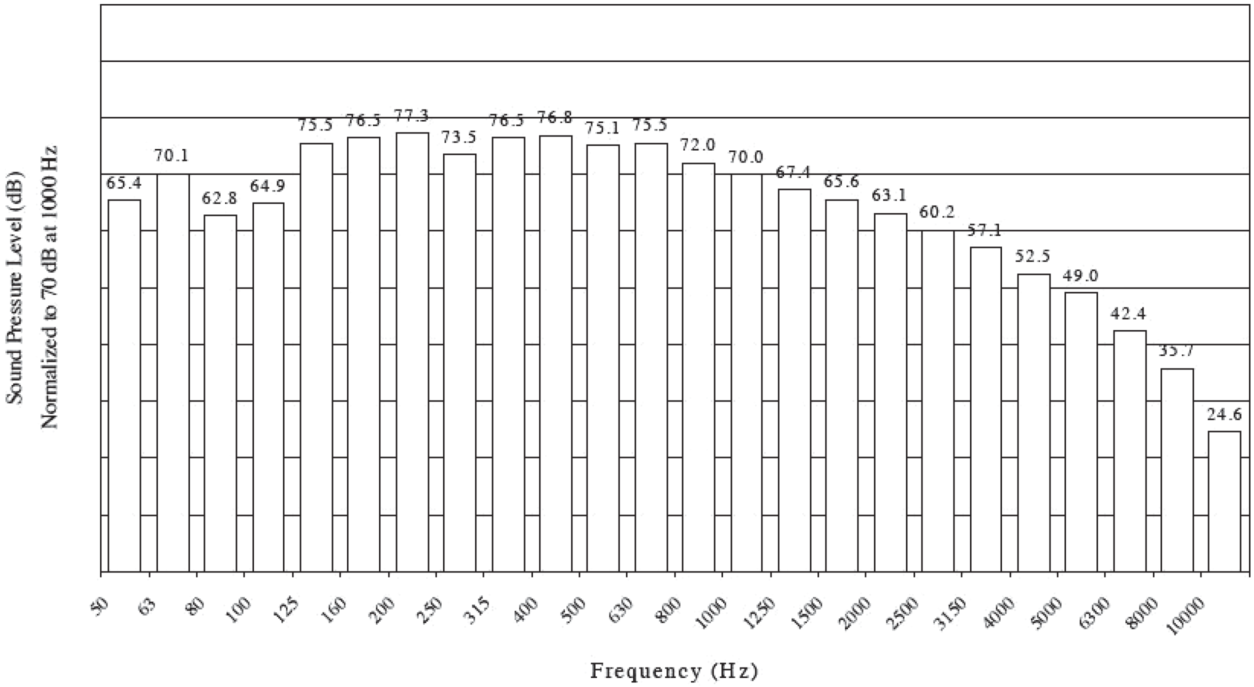


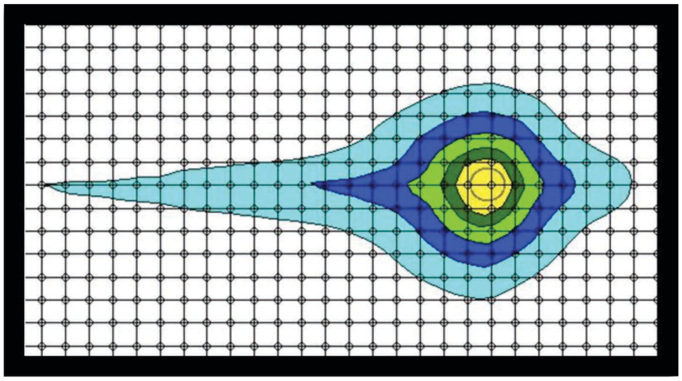
FIGURE 16. DEPARTURE SPECTRAL CLASS 116

INM Aircraft Descriptions:	Helicopter
INM Aircraft ID:	SA355 S65 H500D

Figure A-12. Spectral class example 2.

Figure A-13 shows the 55 through 75 DNL contours for this generic helicopter test case. The grid points shown are 0.1 nautical miles apart (approximately 608 feet). The resulting DNL contours are relatively small, even with 200 daily helicopter operations.

Figure A-14 and Figure A-15 compare the noise metrics that INM can compute relative to the DNL value at each of the grid points within a 4 nautical mile square grid with 0.1 nautical mile spacing. Figure A-14 shows the traditional level based metrics, while Figure A-15 shows the Time Above metrics.



(Contour values 75 DNL to 55 DNL, Grid point spacing 0.1 nm.)

Figure A-13. DNL contours for test case operations.

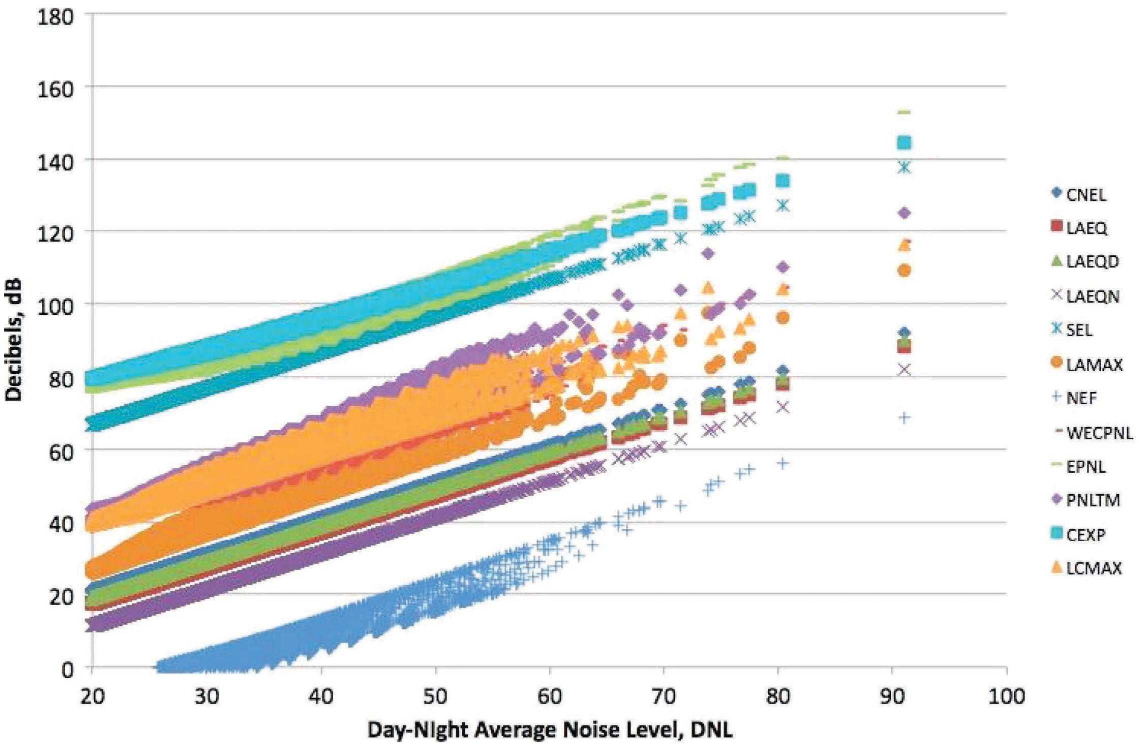


Figure A-14. Relationship of traditional level based noise metrics to DNL for an example heliport.

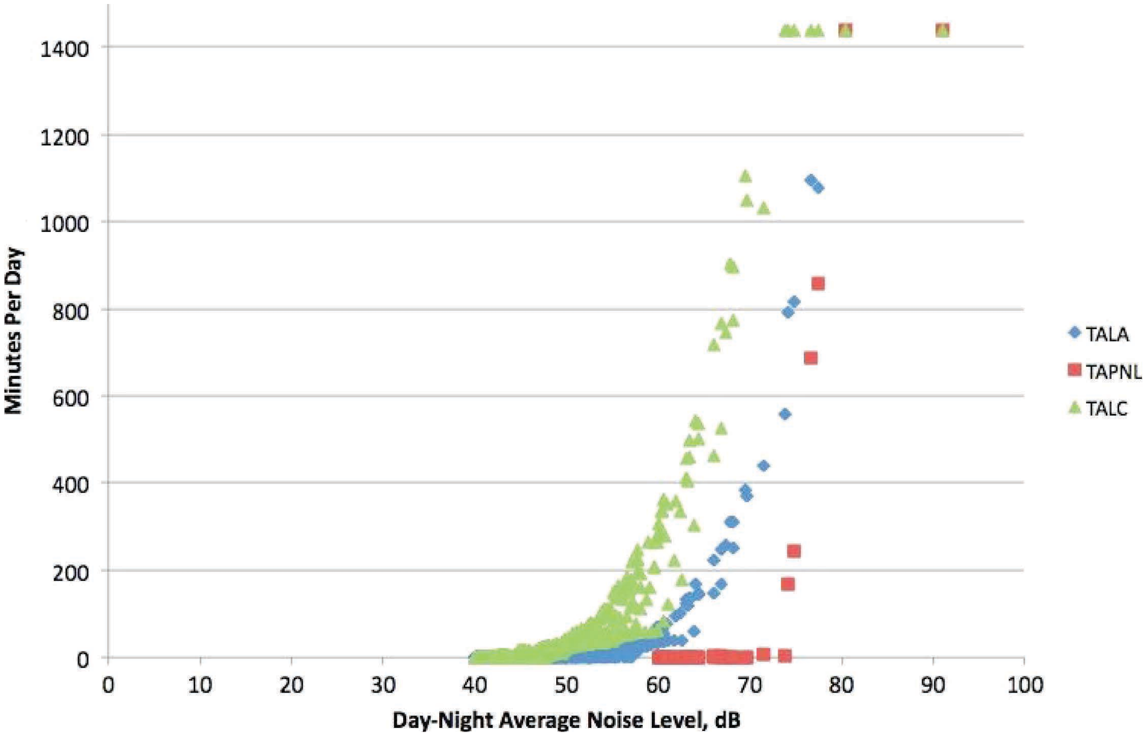


Figure A-15. Correlation of Time Above Metrics to DNL for an example heliport (threshold 65 dB for TALA and TALC and 95 dB TAPNL) (TALA – time above A-weighted SEL, TAPNL = time above PNL-weighted SEL, TALC = time above C-weighted SEL.)

Table A-2. Coefficients of determination (R^2) of noise metrics with DNL.

NOISE METRIC	R^2 RELATIVE TO DNL
CNEL	0.99997
LAEQ	1
LAEQD	0.99997
LAEQN	0.99997
SEL	0.99998
LAMAX	0.95152
NEF	0.92129
WECPNL	0.92128
EPNL	0.92126
PNLTM	0.92887
CEXP	0.99538
LCMAX	0.95927
TALA	0.86722
TALC	0.86848
TAPNL	0.6641

Table A-2 shows the variance accounted for (coefficients of determination) for each of the noise metrics with DNL. All of the metrics other than the Time Above metrics are highly correlated with DNL. For all practical purposes, if one of the equivalent energy metrics is known, all of the other equal energy metrics are also known (except for constants and scale factors.) These results are similar to the results for fixed-wing aircraft (Mestre et al. 2011).

The R2 values between DNL and individual metrics displayed in Table A-2 demonstrate that essentially all of the metrics modeled by INM are highly correlated with DNL. Note that in each case in Table A-2 the correlation of determination was based on a linear fit except for the Time Above metrics. For the Time Above metrics, a 2nd order polynomial fit was used. The choice of linear or 2nd order fit of DNL to the individual metrics was based on the shape of the data plot and the method that provided the best correlation. TAPNL is the metric most independent from DNL, albeit in a not particularly useful manner. Figure A-15 shows that the TAPNL data have a very narrow dynamic range, with a nearly vertical slope between DNL 75 and DNL 80. Time Above 95 PNL goes from nearly 0 to 1400 minutes within a range of only $L_{dn} = 5$ dB.

Note that none of the metrics, the traditional level based metrics nor Time Above, include any corrections or adjustments for impulse type noise that occurs as part of some helicopter operating modes. Note also that the spectral data used by INM to compute C-weighted and PNL metrics do not contain any information below the one-third octave band centered at 50 Hz.

APPENDIX B

Annotated Bibliography

The entries in the following bibliography are not intended to be comprehensive but rather to summarize interpretations of findings of some of the better-known studies of the annoyance of helicopter noise. They exclude studies intended mostly to measure helicopter noise emissions, and some laboratory studies of rotor noise whose findings have little direct bearing on the design of social surveys of the annoyance of helicopter noise. Although preference was given to annotating peer-reviewed studies, a number of technical reports are annotated as well.

Atkins, C., Brooker, P. and Critchley, J. (1983) ***1982 Helicopter Disturbance Study: Main Report*****. Civil Aviation Authority/Department of Transport/British Airports Authority.**

The authors report the results of a large-scale field study intended to evaluate attitudinal differences to fixed- and rotary-wing aircraft. Six interviewing areas were chosen with differing proportions of the two aircraft types, from none to exclusive. Areas near military installations were avoided in the belief that attitudes near such installations might differ from those of the general population. Each potential site received considerable pre-study qualification, including site visits to some and consultations with air traffic control and airport personnel. Exclusive helicopter exposure was found in areas where aircraft served North Sea oil platforms and helicopter passenger service.

Interviews were conducted in person. Interview areas were sized to encompass cumulative exposure ranges no greater than 5 dB. (All respondents within such areas were assumed to receive the same dose.) Questionnaire completion rates across interviewing areas ranged from 61 to 82 percent. Continuous sound level measurements were conducted for 10 or more days in each area. The measurements were largely unattended except in areas where varying source contributions or complex flight procedures were anticipated.

The survey instrument was quite lengthy, as it sought information about a large number of variables that might relate to respondent attitudes. The main questionnaire item about bother or annoyance used a four-point category scale. This question was asked only of those respondents who in an earlier question responded positively that they heard aircraft noise. An average of 30 percent of respondents expressed fear that an overhead aircraft might crash. The attitudinal response of bother or annoyance to aircraft noise was found to be positively correlated with crash fear: "On the whole, residents who feared a crash were more annoyed by aircraft noise than those who did not."

The authors noted that the scatter of dosage-response points about their trend line exhibited greater scatter than expected by chance alone. This scatter was somewhat reduced when respondent socio-economic group was factored into the analysis. Some neighborhoods differed markedly in the age of the population, however no age effect was found in the dosage-response analysis.

Edwards, B. (2002) ***Psychoacoustic Testing of Modulated Blade Spacing for Main Rotors.*** **NASA Contractor Report 2002-211651.**

Edwards reports the results of laboratory studies of the annoyance of noise created by a simulated 5-bladed main rotor with unevenly spaced rotors. Forty subjects assigned numeric ratings to the annoyance of various simulated blade configurations, and forty provided paired-comparison ratings. Edwards concludes that "No strong subjective differences among the predicted helicopter test sounds were found in either test. . . ." and that A-weighted measures of helicopter rotor noise are ". . . not strongly indicative of subjective response."

Federal Aviation Administration (2004) ***Report to Congress: Nonmilitary Helicopter Urban Noise Study.*** **Report of the Federal Aviation Administration to the United States Congress Pursuant to Section 747 of the Wendell H. Ford Aviation Investment and Reform Act for the 21st Century (AIR-21), Washington, D.C.**

FAA's review of the technical literature on the annoyance of helicopter noise in its Report to Congress cites eight (mostly laboratory) studies supporting the imposition of a blade slap "penalty" on A-weighted measurements of helicopter noise, and seven suggesting that such a penalty is not justified. The FAA report also cites two studies of "heightened reaction" to helicopter noise—presumably not associated with blade slap—by Schomer (1983) and by Atkins et al. (1983). Despite the inconsistency and ambiguity of these findings, the report repeats the common assertion that "helicopter noise may be more noticeable because of its periodic impulsive characteristic." The report also cites "the possible phenomena (sic) of 'virtual noise'" [see annotation for Leverton (2014) below], which it suggests may be due to attitudes and beliefs about the necessity of helicopter operations and fear of crashes.

The FAA report also includes brief discussions in Sections 3.5.5 through 3.5.8 of contentions that "helicopter noise is more annoying than fixed-wing aircraft noise"; that "helicopter sounds may be more readily noticeable than other sounds"; that attitudes such as fear of danger, beliefs about the importance of the noise source, and invasions of privacy may influence the annoyance of helicopter noise; and that rotary-wing flight capabilities such as prolonged hovering and proximity to residences may also heighten the annoyance of helicopter noise.

The primary conclusion of FAA's Report to Congress is that "models for characterizing the human response to helicopter noise should be pursued." The report also includes a wide range of recommendations, including some that are reflected in the current effort. For example, FAA recommends study of "nonacoustical effects," among which includes vibration and rattle, and "virtual noise," as described informally by Leverton (see below) and systematically by Fidell et al. (2011). The report also suggests that unique characteristics of helicopter noise emissions (notably including blade slap) may heighten community annoyance with helicopters; that evaluation of noise metrics other than DNL should be undertaken; and that "operational alternatives that mitigate noise should be examined." The latter specifically includes higher altitude flight and route planning to avoid noise sensitive areas.

Fidell, S., and Horonjeff, R. (1981) ***Detectability and Annoyance of Repetitive Impulse Sounds,*** **Proceedings of the 37th Annual Forum, American Helicopter Society, New Orleans, LA, pp. 515–521.**

The audibility of low-frequency rotor noise is of concern not only in residential settings, but also in military applications (where the element of surprise can be mission-critical) and airspace subject to special federal aviation regulations intended to protect natural quiet. In such applications, the main concern is prediction of the audibility of wavetrains of repetitive acoustic impulses, rather than of individual impulses. Fidell and Horonjeff (1981) demonstrated that over a range of observation intervals (0.25 to 2.00 seconds) and repetition rates (5 Hz to 40 Hz, corresponding to the range of fundamental and harmonics of blade passage rates of present interest) the audibility of impulse wavetrains is very closely predictable from the audibility of a single impulse. Under highly controlled listening conditions, participants determined when impulse wave trains of varying repetition rate and observation interval duration were just audible in white noise. The impulse was a 1000 Hz sinusoid. Test participants also listened for a single impulse randomly placed within a 500 msec observation interval.

Equation 1 shows a derived relationship between the energy ratio of a wave train divided by single impulse (left side of equation) and the repetition rate and observation interval (right side).

$$10\log_{10}(E_{ri}/N_0) - 10\log_{10}(E_{si}/N_0) = 5\log_{10}(RR) + 8\log_{10}(D) + 1.5 \qquad \text{Eq. 1}$$

where:

E_{ri}/N_0 = signal energy to noise power density ratio of impulse wave train
E_{si}/N_0 = signal energy to noise power density ratio of a single impulse
RR = impulse repetition rate (Hz)
D = observation interval (seconds)

Figure B-1 shows the resulting clustering of data points (each an average over all test subjects) when the energy ratio is plotted against repetition rate and the energy ratios have been adjusted for the duration term, 8 Log10(D) in Equation 1.

The tight fit of the data points to the line (plus or minus 0.3 dB) suggests a strong predictive relationship between repetition rate and observation interval (all for the same waveform) and the energy ratio of the wavetrain and single impulse. The positive slope of about 1.5 dB per

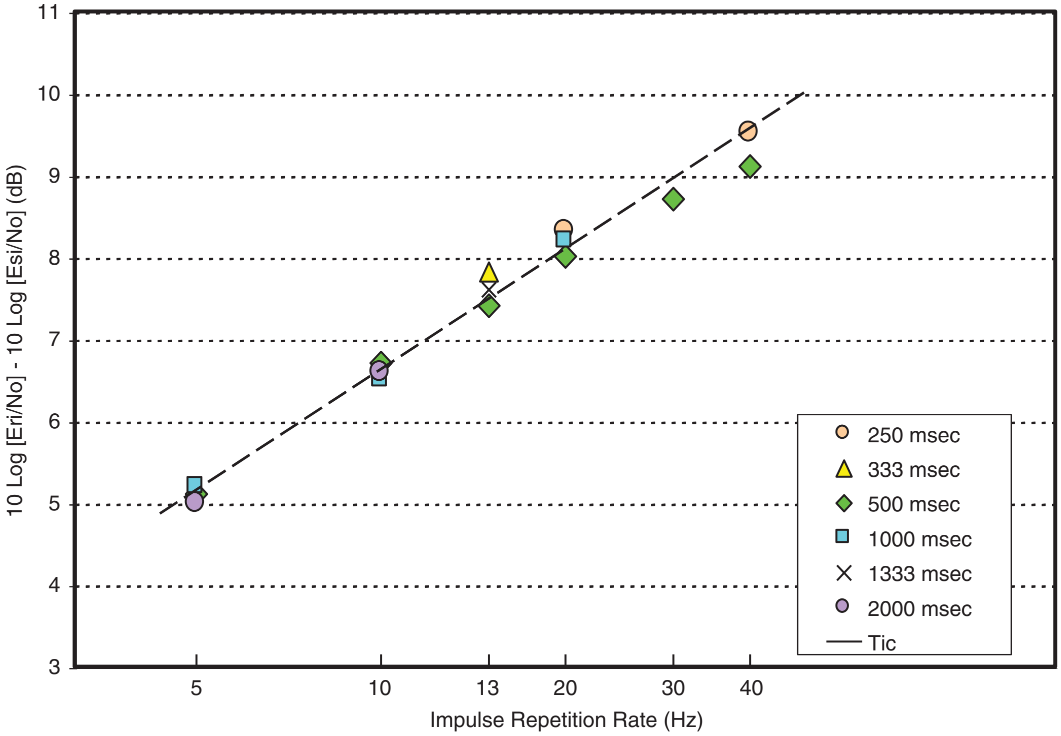


Figure B-1. Observed relative signal-to-noise ratios (10 log10[En/N0] – 10 log10 [Esi/N0]) of equally detectable impulse wavetrains as a function of impulse repetition rate collapsed over observation interval duration by 8 log10[D].

doubling of repetition rate (or 5 dB/decade) indicates that greater signal energy is needed at increasing repetition rates to maintain constant detection performance, and that these slopes are effectively independent of observation interval duration over the investigated range.

Fields, J., and Powell, A. (1987) Community Reactions to Helicopter Noise: Results from an Experimental Study. *J. Acoust. Soc. Am.*, 82(2), 479–492.

Noting the characteristically small numbers of helicopter overflights in many residential exposure settings, Fields and Powell focus on "the applicability of the equivalent energy assumptions about the relative importance of noise level and number of noise events." They devised a controlled-listening field study in which the same 330 respondents were paid $40 to complete repeated interviews on the evenings of 22 days about their annoyance with late morning and early afternoon weekday helicopter noise.

The study area, in close proximity to an army helicopter training base, was a strip 500 meters long, containing 861 dwellings, in a "quiet, well-maintained, middle-class suburban area" with high military employment. The residents were thoroughly habituated to helicopter overflight noise. Large percentages of respondents considered helicopters "very important" (64%), believed that "pilots or other authorities" could not do anything to reduce helicopter noise (62%), and were not afraid that a helicopter might crash nearby (67%).

The daily interview lasted only about four minutes and was confined to determining the times at which respondents were at home during the day, what noise sources they heard, and how annoyed they were by them. Noise measurements were limited to those made at one fixed site at the end of the exposure area, and two roving mobile sites.

Fields and Powell found that respondents' annoyance ratings of helicopter noise increased with both number and level of noise exposure. The average annoyance scores were almost all below 4 on a ten-point scale, indicating that few, if any, respondents were highly annoyed by helicopter noise in the target population. They also found only minor differences in annoyance scores for long-term exposure to more or less impulsive noise: "annoyance, in general, was slightly higher" for exposure to more impulsive noise (UH-1H). Correlations between noise exposure levels and annoyance scores accounted for less than 10% of the variance in the relationship.

Leverton, J. Helicopter Noise: What is the Problem? *Vertiflite*, Vol. 60, No. 2, March/April 2014, pp. 12–15. (See also Leverton and Pike, 2007 and 2009)

The standard measure of adverse public reaction to transportation noise exposure is the prevalence of a consequential degree of noise-induced annoyance (FICON 1992; ISO 2016). Leverton (2014) asserts that vigorous adverse community reaction to helicopter noise "is a little difficult to understand because most helicopters generate less noise than the noise certification standards [for fixed-wing aircraft]. . . ."[20] He infers from this observation that "there appears to be something different about the way in which helicopters are perceived."

Leverton expands the concept of "something different" about the perception of helicopter noise into the concept of "virtual noise." He offers somewhat contradictory definitions of virtual noise, however. On the one hand, Leverton states that virtual noise is nonacoustic in nature. This is a plausible belief, since the annoyance of an unwanted noise intrusion is, after all, a property of an unwilling listener, not of a noise source per se. A sound level meter measures sound pressures, not annoyance. Absent a reliable dosage-response relationship, useful inferences cannot be drawn from noise levels alone about the prevalence of annoyance with transportation noise in noise-exposed communities.

On the other hand, Leverton believes that even though virtual noise is not directly related "either to the absolute level or to the character of the noise generated by helicopters," it is nonetheless "triggered by the direct acoustic signal." As Leverton puts it, "Virtual noise is dependent on a wide range of inputs but is triggered initially by any distinctive feature of the acoustic signature and, to a far lesser extent, the absolute noise level." In other words, adverse community reaction to helicopter noise is conditioned on two sets of factors other than the conventionally measured, A-weighted acoustic energy of helicopter noise emissions. The first component of virtual noise is the noticeability of distinctive features of helicopter noise emissions, such as HSI, tail rotor (TR) noise, main rotor/tail rotor interaction (TRI) noise, and BVI. In Leverton's view, the second component of "virtual noise" is entirely nonacoustic.

Leverton's concept of virtual noise has several limitations. First, it does not consider the possibility that certain characteristics of helicopter noise could be highly annoying at levels that do not control a helicopter's total A-weighted noise emissions. Second, it does not clearly distinguish between the influences of acoustic and nonacoustic factors on the annoyance of helicopter noise, nor offer any quantitative guidance about the relationships between them. Third, it does not provide any operational definition or methods of quantifying the nonacoustic aspects of virtual noise.

The major contribution of this publication is that it reinforces the notion that factors other than those that can be measured with a sound level meter may somehow affect the annoyance of helicopters.

Magliozzi, B., Metzger, F., Bausch, W., and King, R. (1975) *A comprehensive review of helicopter noise literature.* FAA-RD-75-79.

The "comprehensive review" of Magliozzi et al. (1975) is more of a summary of early field measurements of helicopter noise than a critical review. It focuses more on noise emissions and noise control concerns than on the subjective effects of helicopter noise on individuals or communities. Some of the reasoning is specious, as for example, when the authors conclude "Spectrum analyses of helicopter noise show that the main rotor, tail rotor, and engine sources contribute significantly to annoyance." Merely because rotating noise sources contribute conspicuously to a spectrogram does not mean that they are "significant" sources of annoyance.

Likewise, Magliozzi et al. (1975) repeat the views that a need for "a new noise unit" for measuring helicopter noise is required, and assert that a "modification of the Day-Night Noise Level (sic) . . . shows promise" for assessing community acceptance of helicopter noise.

Molino, J. A., (1982) Should Helicopter Noise Be Measured Differently From Other Aircraft Noise?—A Review of the Psychoacoustic Literature, NASA Contractor Report 3609.

Molino's review describes the many differences between fixed- and rotary-wing aircraft noise but pays most attention to the impulsive nature of helicopter BVI noise ("blade slap"). He reviewed 34 studies of the noisiness of helicopter blade slap, many of which were non-peer-reviewed conference papers or technical reports, which yielded conflicting if not contradictory findings. His conclusion that "there is apparently no need to measure helicopter noise any differently from other aircraft noise" is based largely on the lack of consistent empirical findings about the "excessive" (with respect to the annoyance of fixed-wing aircraft noise) annoyance of impulsiveness per se.

The zeitgeist of the early 1980s, particularly ISO's attempts to recommend noise metrics appropriate for certification of helicopter noise, appears to have influenced Molino's analyses. Several national helicopter industries had proposed methods for assessing the annoyance of helicopter noise. Each disproportionately penalized the noise emissions of competitors' products. Aérospatiale, for example, proposed a "correction" to helicopter noise that heavily penalized even slight short-term temporal variation in noise levels. "Corrections" proposed by British sources, on the other hand, heavily penalized tonal components of helicopter noise, such as those produced by Sud Aviation's (subsequently Aérospatiale, Eurocopter, and now Airbus Helicopters) high-speed, ducted fan ("Fenestron") tail rotor.

Molino's report goes into considerable detail about the acoustic characteristics of helicopter noise emissions and into variability in noise emissions associated with various helicopter types and operating conditions. He notes that relationships between operating mode, engine power, and airspeed in helicopters are not as straightforward as they are for fixed-wing aircraft. For example, Molino observes that unlike fixed-wing aircraft, "helicopters generally produce a minimum sound level at some intermediate airspeed, with higher sound levels at lower and higher airspeeds." He also observes that "for the same airspeed, helicopters often exhibit different sound spectra for approach versus level flight."

The psychoacoustic research reviewed by Molino consists mostly of 1970s-era studies, with a smattering of earlier and later studies. A major part of Molino's review addresses the methodological advantages and disadvantages of varying forms of signal presentation, listening contexts, and annoyance-rating scales for controlled-listening tests. He ultimately speculates that 1) "the source of . . . [discrepancies among empirical findings] . . . may lie in the methodologies and approaches selected by the experimenters," rather than in bona fide differences in the annoyance of helicopter noise and 2) that inadequate experimental treatment of the complexity of helicopter noise may obscure the annoyance of helicopter noise. For example, Molino notes "The presence of blade slap, in and of itself recognized as contributing to increased annoyance, produces changes in other acoustic parameters that can compensate for or account for the increased annoyance caused by the presence of blade slap."

Molino concludes from the contradictory and inconclusive nature of the findings of laboratory studies about the annoyance of helicopter noise that "there is apparently no need to measure helicopter noise any differently from other aircraft noise." The logic and universality of Molino's conclusion are open to question given the limited nature of comparisons that Molino describes among the findings of different forms of laboratory studies of the annoyance of helicopter noise.

Another major limitation of Molino's review is that he confines his review to the direct annoyance of airborne acoustic energy produced by helicopters, and does not take into account the potential contributions to annoyance of secondary emissions (audible rattle and sensible vibration) produced by helicopter flight operations inside residences. To the extent that any excess annoyance of helicopter noise is related to the annoyance of secondary emissions, Molino's conclusion about the sufficiency of A-weighted measurements is premature.

More, S. R., (2011) *Aircraft Noise Characteristics and Metrics.* Purdue University Doctoral Thesis and Report No. PARTNER-COE-2011-004.

More's thesis reports the findings of laboratory studies of second-order effects, such as "sharpness" (spectral balance of low and high frequency energy), tonality (presence of prominent tones), slow fluctuations in loudness (fluctuation "strength"), and "roughness" (rapid fluctuations in loudness) on absolute judgments of the annoyance of single-event, fixed-wing aircraft noise presentations. (The reported work does not address the effects of rattle and vibration, or the annoyance of cumulative noise exposure.) Although More's interests did not specifically extend to the annoyance of helicopter noise, some of the factors that he studied are more characteristic of complex rotary-wing noise emissions than those of simpler, broadband fixed-wing aircraft.

The laboratory judgments did not demonstrate any clear contributions of sharpness, roughness, and fluctuation strength to judgments of the annoyance of aircraft noise. Loudness remained the major determinant of judged annoyance, with a clear contribution of tonality.

Munch, C. and King, R. (1974), *Community acceptance of helicopter noise: criteria and application.*National Aeronautics and Space Administration, NASA-CR-132430.

Because assumptions made by the authors have not withstood the passage of time, the reasoning in this 40-year old study—dating from the era prior to FICON's recognition of the prevalence of a consequential degree of annoyance as a preferred measure of adverse impact of transportation noise—is largely irrelevant to modern analyses of the effects of helicopter noise exposure on communities.

For example, the authors loosely define "community noise acceptance criteria" in terms of "a noise exposure acceptable to the average member of the community." Further, they interpret EPA's recommendation of a DNL of 60 dB as a level consistent with "requirements for human compatibility in the areas of annoyance, speech interference, and hearing damage risk" as a basis for regulating aircraft noise. They also assume that A-weighted noise levels 2 dB lower than ambient levels are completely acceptable, and that ambient noise levels in inhabited places will decrease "over the years due to stricter controls on noise sources other than aircraft." Neither assumption is correct. The audibility of aircraft noise cannot be reliably predicted from A-weighted noise levels, and Schomer et al. (2011) has shown that the slope of the relationship between population density and cumulative noise exposure has remained unchanged for about 40 years.

The authors also report an informal study of the noticeability of blade slap, from which they estimate that notice of blade slap occurs at a crest factor of 13 dB. This figure is little greater than the crest factor of many urban ambient noise environments. Although the authors repeatedly emphasize that understanding of the annoyance of blade slap is "sketchy," "inadequate," "very limited," "inconsistent," etc., they nonetheless conclude that a "penalty" is required to account for the annoyance of repetitive impulsive aircraft noise. The magnitude of the recommended penalty in units of perceived noise level is 4 to 6 dB, or 8 to 13 dB in A-weighted units.

Namba, S., Kuwano, S., and Koyasu, M. (1993) The Measurement of Temporal Stream by Hearing by Continuous Judgments—In the Case of the Evaluation of Helicopter Noise, *J. Acoust. Soc. Jpn.*, 14, 5.

Namba et al. (1993) suggest that the practice of calculating equivalent energy metrics for time-varying environmental noises (such as those produced in the course of helicopter flight operations) can misestimate their annoyance because they do not take into consideration the temporal context of noise intrusions.[21] They propose instead a method of continuous judgment, such that the annoyance of helicopter and other ". . . fluctuating sounds [can be measured] by pressing a key on a response box . . .", in real time. The authors found marked differences in the momentary annoyance of helicopter takeoffs, overflights, and landings.

Ollerhead, J. B. (1982) *Laboratory Studies of Scales for Measuring Helicopter Noise.* NASA Contractor Report 3610.

Ollerhead solicited absolute judgments from scores of test subjects of the annoyance of tape recorded helicopter sounds presented both over headphones and via loudspeaker in a series of laboratory studies. A set of preliminary investigations was conducted to pilot-test the annoyance-rating and signal presentation methods. A set of "main" tests followed, in which six undergraduates at a time rated the annoyance of the sounds of 89 helicopters (mostly level flyovers) and 30 fixed-wing aircraft heard through headphones. The headphone presentation results were generally replicated in subsequent free-field testing at NASA Langley Research Center.

Ollerhead concludes that tone-corrected effective (that is, duration-adjusted) Perceived Noise Level predicts the annoyance of helicopter noise better than does A-weighted sound pressure level, and that any putative effects of impulsiveness per se may be equally attributed to increases in helicopter noise level and duration.

Ollerhead, J. B., (1985) *Rotorcraft Noise*. Loughborough University of Technology, Leicestershire, England.

Ollerhead's review addresses "subjective impact" (individual and community response to exposure to helicopter noise), mechanisms of helicopter noise generation, and potential helicopter noise control measures, with greater emphasis accorded to the latter two topics.[22] Like most other review articles, Ollerhead's article deals at length with differences between rotary- and fixed-wing noise emissions. Among other salient differences, Ollerhead notes that unlike fixed-wing aircraft, "helicopters are usually confined to low altitudes," and that "many helicopters radiate maximum noise in a forward direction," so that "an approaching helicopter can often be heard for as long as five minutes."

Ollerhead's review of subjective impacts of helicopter noise deals with statements attributed to Molino (1982). Like Molino, Ollerhead draws attention to contradictory findings and to apparent discrepancies between the findings of field studies and laboratory studies. Ollerhead notes, for example, that his own 1971 finding "that the very long attention-arresting sound of an approaching helicopter did not affect annoyance responses in the laboratory experiments" conflicts with "hearsay evidence of complainants near heliports that [duration of audibility] may be a particular source of aggravation to people at home."

Patterson, J., Mozo, B., Schomer, P., and Camp, R. (1977) *Subjective Ratings of Annoyance Produced by Rotary-Wing Aircraft Noise*. Bioacoustics Division, US Army Aeromedical Research Laboratory, Fort Rucker, Alabama, USAARL Report No. 77-12, May 1977.

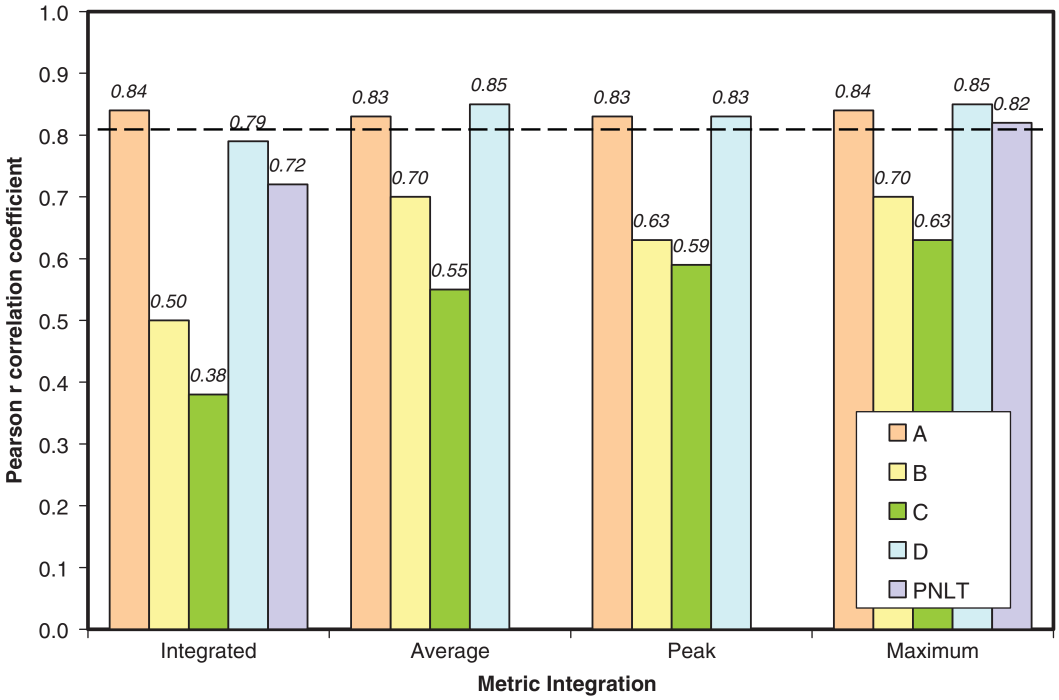
Patterson et al. (1977) describe an outdoor noisiness magnitude estimation test in which a panel of 25 audiometrically screened participants rated the sounds of actual rotary-wing aircraft passbys relative to that of a fixed-wing C-47 propeller-driven aircraft. The goals of the study were fourfold with regard to determining a metric that would best predict subjective annoyance: (1) which spectral weighting function(s) are most appropriate? (2) what type of temporal integration should be used? (3) is an impulsive blade slap correction factor necessary? and (4) do present fixed-wing annoyance predictors underestimate annoyance from rotary-wing aircraft?

To evoke differing spectral and temporal characteristics, the listening test involved nine different rotary-wing aircraft each flying six different flight maneuvers: (1) level flyover, (2) nap-of-the-earth, (3) ascent, (4) decent, (5) left turn, and (6) right turn. During each passby the sound pressure level signature was FM-recorded on magnetic tape for subsequent analysis into one-third octave bands. Observers recorded their noisiness rating relative to the C-47 at the end of each passby.

In the subsequent analysis five broadband frequency-weighted metrics were considered: A-weighted sound level, B-weighted sound level, C-weighted sound level, D-weighted sound level, and tone-corrected perceived noise level (per Federal Aviation Regulation Part 36). For each, four different temporal treatments were examined: the maximum sound level, the peak sound level, the average sound level over the passby, and the time-integrated level over the passby. The Pearson product moment correlations (r), relating noisiness to all frequency weightings and temporal considerations are shown in Powell, C. A. (1981) *Subjective Field Study of Response To Impulsive Helicopter Noise*, NASA Technical Paper 1833.

Figure B-2 plots the correlations in four groups of differing temporal considerations. Within each group the four different frequency weightings are shown.

The figure reveals that the A-weighted and D-weighted sound levels and the tone-corrected perceived noise level all performed equally well as noisiness predictors regardless of the time integration method employed. The dashed horizontal line plots the average value of all the



Powell, C.A. (1981) *Subjective Field Study of Response To Impulsive Helicopter Noise*, NASA Technical Paper 1833.

Figure B-2. Subjective noisiness correlations with four frequency weighting functions and four temporal integration measures.

coefficients for these metrics (0.81). In addition, the figure shows that B-weighted and C-weighted sound levels performed demonstrably more poorly. However, the maximum level was a better predictor of annoyance for both the C-weighted sound level and tone-corrected perceived noise level than was a temporal integration of these measures. These correlations notwithstanding, the authors found that on average the rotary-wing aircraft were rated an equivalent of 2 decibels more annoying than the fixed-wing C-47. This difference represents only about one-third of the scatter in sound level observed for any given relative annoyance rating but this difference is probably significantly different from zero (not determined by the authors).

The authors note that the similar performance of the A, D, and tone-corrected metrics was largely due to the high correlation between the metrics themselves. The correlations (r) were largely independent of temporal consideration and ranged from 0.91 to 0.98. The authors thus concluded “The high correlation among these predictors of annoyance makes any attempt to show the superiority of one over another unlikely to succeed.”

The authors also explored two measures of impulsivity to determine whether either improved the correlation. These were (1) the crest factor (peak minus root mean square) and (2) a novel adjunct to crest factor that measured the root mean square level between blade slaps and subtracted this value from the peak level. No improvement was found using crest factor. However, some modest improvement was found using the second method, but the authors concluded the method was too cumbersome to be used in practice.

Powell, C. A. (1981) *Subjective Field Study of Response to Impulsive Helicopter Noise*. NASA Technical Paper 1833.

Powell conducted two controlled-listening studies in which 91 test participants located both indoors and outdoors judged the noisiness of 72 helicopter and propeller-driven, fixed-wing aircraft flybys. After noting the "very diverse" character of helicopter noise, Powell comments on the inconclusiveness of studies intended to ascertain whether an impulsiveness correction is useful for predicting the noisiness of helicopter noise. One purpose of the current investigation was to determine whether highly impulsive helicopter overflights are judged to be noisier than less impulsive helicopter overflights at constant EPNL values. The other purpose was to determine the utility of ISO's then recent suggestion of an impulsiveness correction to EPNL.

Powell's findings were counter-intuitive and in direct contrast to the common assumption (cf. Sternfeld and Doyle, 1978) that the impulsiveness of helicopter noise accounts for much of its annoyance. Powell found that "at equal effective perceived noise levels (EPNL), the more impulsive helicopter was judged less noisy than the less impulsive helicopter." Powell also found that ISO's proposed impulsiveness correction, based on measurements of A-weighted crest factors, failed to improve the ability of EPNL to predict helicopter noisiness judgments. Powell concluded that ". . . some characteristic [of helicopter noise] related to impulsiveness is perceivable by subjects but is not accounted for by either EPNL or [ISO's] proposed impulsiveness correction."

Schomer, P. D., Hoover, B. D., and Wagner, L. R. (1991) *Human Response to Helicopter Noise: A Test of A-weighting*. U.S. Army Corps of Engineers, USACERL Technical Report N-91/13.

Schomer, P. D., and Neathammer, R. D. (1987) The role of helicopter noise-induced vibration and rattle in human response. *J. Acoust. Soc. Am.*, 81(4), pp. 966–976.

Schomer et al. (1991) describe this study as a continuation of a field study ("jury test") conducted by Schomer and Neathammer (1987). The former study solicited individual paired-comparison judgments of the annoyance of helicopter flybys with respect to a single broadband noise from groups of paid test participants seated in a house, a tent, and a mobile home. Schomer and Neathammer (1987) concluded that A-weighted measurements of helicopter flyby noise did not adequately predict differences in annoyance between the flyby noise and the control signal, and that the level of secondary emissions (helicopter-induced rattle) in the listening environment influenced the annoyance judgments. The annoyance judgments were solicited in a field setting rather than in a laboratory because "the very low-frequency sounds, the rattles, and the vibrations characteristic of helicopter noise would be too hard to simulate realistically in a laboratory. . . ."

Neither A-weighted nor C-weighted measurements of helicopter noise were able to predict offsets between objective measurements of sound levels produced by helicopter flybys and the comparison sounds when heard at subjectively equally annoying levels. The differences between A-weighted and C-weighted levels of helicopters and equally annoying broadband noise varied from 10 dB (for helicopters with two bladed main rotors) to 8 dB for helicopters with greater numbers of rotor blades.

In other words, Schomer et al. (1987, 1991) found that exposure to helicopter noise depended in part on its impulsive characteristics (blade passage frequency and/or repetition rate) and the rattle induced by repetitive impulsive signals in residences. This finding directly contradicts Molino's interpretation a decade earlier of the (largely laboratory-based) research findings that "there is apparently no need to measure helicopter noise any differently from other aircraft noise."

Note, however, that the Schomer et al. (1987, 1991) studies included no direct comparisons of the annoyance of exposure to rotary- and fixed-wing aircraft sounds. Because these studies included no direct empirical comparisons of helicopter noise with fixed-wing aircraft noise, they do not clarify whether the observed "excess" (that is, greater than A-weighted) annoyance of helicopter noise also holds with respect to fixed-wing aircraft noise.[23]

Schomer, P., and Wagner, L. (1996) On The Contribution Of Noticeability of Environmental Sounds to Noise Annoyance. *Noise Control Eng. J.,* 44 (6), 294–305.

Schomer and Wagner provided modest numbers of paid volunteers at three locations with portable (palm-top) computers to self-report prompt annoyance judgments for naturally occurring outdoor noises that they noticed while at home. The computers administered a brief questionnaire that asked respondents to identify the source of the annoying sound (e.g., rotary- or fixed-wing aircraft) and their degree of annoyance with it. Unattended outdoor noise measurements were made at locations near the test participants' homes.

The authors analyzed both the per event annoyance ratings and the rate of notice of noise events. They found only minor differences in the per event annoyance ratings of fixed- and rotary-wing aircraft noise of comparable A-weighted SELs. In fact, for some of the test participants, the annoyance ratings varied little with SELs. Mere detection of noise events seemed to suffice to annoy these participants.

However, the authors also found that the rate of notice of helicopter noise was three times as great as the rate of notice of fixed-wing aircraft noise. They speculate that the greater rate of notice of helicopter noise was due to the "distinct sound character" of rotary—wing aircraft. Since the participants were exposed to notably fewer helicopter than fixed-wing overflights, it is also possible that they were less habituated to helicopter noise than to fixed-wing aircraft noise.

Sternfeld, H., and Doyle, L. B. (1978) *Evaluation of the Annoyance Due to Helicopter Rotor Noise.* NASA Contractor Report 3001, NASA Langley Research Center Contract NAS1-14192.

Sternfeld and Doyle conducted controlled (laboratory environment) listening tests in which 25 volunteer listeners adjusted the annoyance of three degrees of rotor impulsiveness, heard at four blade passage (repetition) rates, to the annoyance of a single broadband noise. Like virtually all other publications in this research area, Sternfeld and Doyle characterize helicopter noise as "unusually complex." They assert, however, without further elaboration, "It is the more impulsive types of rotor noise which are responsible for most of the noise complaints against helicopters." Sternfeld and Doyle did not match the annoyance of broadband noise with that of fixed-wing aircraft noise.

The experimentation conducted by Sternfeld and Doyle was premised on the assumption that main rotor impulsiveness controls the annoyance of helicopter noise. The authors therefore did not study the potential contributions of other sources of helicopter noise to annoyance judgments. Sounds presented to test participants for annoyance judgments were reproduced by headphones, rather than in free-field settings and consisted entirely of synthesized signals. On the continuum of compromise between face validity and precision of control, the work of Sternfeld and Doyle sacrifices nearly all claims to face validity to a desire for very high precision of control of signal presentation.

The authors concluded that their findings permit designers of helicopter rotor systems "to trade off rotor design parameters" to minimize their annoyance, but note certain limitations of the generalizability and practicality of their findings. They were also puzzled (1) by an "apparent inconsistence that when different rotor sounds were adjusted to be equally annoying as a broadband reference sound, subsequent subjective ratings of the rotor sounds were not equal to each other, or to the broadband reference sound," and about (2) "the apparent relative insensitivity to the rotor blade passage period." They conjecture that headphone presentation of signals for annoyance judgments deprived test participants of the sensations of high-level, near-infrasonic harmonics on body surfaces.

Sternfeld, H., Spencer, R., and Ziegenbein, P. (1995) ***Evaluation of The Impact of Noise Metrics On Tiltrotor Aircraft Design.*** **NASA Contractor Report 198240.**

Sternfeld et al. (1995) introduce their indoor, controlled-listening study of the judged annoyance of simulated rotor noise by re-capping the inappropriateness of the A-weighting network as applied to rotary-wing aircraft noise, which characteristically includes large amounts of low-frequency, if not infrasonic, acoustic energy associated with the fundamental blade passage frequency of a main rotor and its harmonics. Although the work is motivated by concerns about noise produced by a hovering tiltrotor, the arguments apply generally to other rotary-wing aircraft.

Forty test subjects rated the annoyance of 145 outdoor and 145 indoor simulated rotor noise sounds. The sounds varied in A-weighted and overall sound pressure level from 72 to 96 dB, and in fundamental blade passage rates from 15 to 35 Hz. The spectra and presentation levels of the test sounds were arranged such that the overall sound pressure levels of the test sounds always exceeded A-weighted levels by 6 dB. Sounds intended to represent indoor listening conditions were accompanied by a projection of an indoor scene, while sounds intended to represent outdoor listening conditions were accompanied by a projection of an outdoor scene.

Sternfeld et al. (1995) concluded that A-weighted measurements of the sounds rated by the test subjects were inferior predictors of the annoyance ratings because they were insufficiently sensitive to low-frequency rotor harmonics. They also concluded:

1. That a combination of A-weighted and overall sound pressure level measurements provided improved prediction of the annoyance ratings;
2. That annoyance predictions based on a combination of the two metrics were at least as good as, if not superior to, predictions made from Stevens Mark VII method of predicting perceived sound levels; and
3. That including blade passage frequency as a predictor of annoyance judgments improves matters yet further.

The differences in correlations between predicted and observed ratings for the various prediction schemes were quite small in some cases. For example, adding blade passage frequency to perceived level increased the variance accounted for in outdoor judgments by only 2%, from $R^2 = 0.87$ to $R^2 = 0.89$. Considering the marginal size of many of the observed differences, and that the ISO standard for low-frequency equal loudness curves has changed since the conduct of the Sternfeld et al. analyses, the authors' conclusions are best regarded as suggestive rather than definitive.

Sutherland, L., and Burke, R. (1979) ***Annoyance, Loudness, and Measurement of Repetitive Type Noise Sources.*** **EPA 550/8-79-103.**

This report evaluated "subjective and objective aspects of moderate levels of noise from impulsive sources," such as truck-mounted garbage compactors, drop hammers, two-stroke motorcycle engines, and rock drills. The report specifically excludes consideration of high-energy impulses (sonic booms, weapons fire, and quarry blasting), and treats helicopter blade slap as a special case. Sutherland and Burke's summary of early findings about the annoyance of blade slap may be paraphrased as follows:

- The mean observed blade slap correction or penalty factor was 3.3 ±2.7 dB for 11 (laboratory) studies that measured this quantity directly. However, three of these 11 studies found essentially a zero or negative correction. The maximum correction for moderate blade slap (i.e., crest level of 10 to 15 dB) was about 6 dB. The maximum correction for severe blade slap *(i.e.*, crest level about 20 dB) was 13 dB, comparable to the values measured for a variety of non-helicopter sounds.

- The methods proposed [by ICAO in the late 1970s] to objectively compute a blade slap correction factor do not appear to agree consistently with the correction factors measured subjectively to account for annoyance of blade slap.
- Improved results are obtained if [ICAO's proposed methods] are modified to account for variations in the frequency of the blade slap. Adjustments of 2 dB (for a blade slap repetition rate of 10 Hz) to 7 dB (for a blade slap rate of 30 Hz] might be appropriate. (These findings are discussed above in the annotation for Fidell and Horonjeff.) The dependency on repetition rates in this frequency range suggests that a blade slap "correction factor" may arise from inherent errors in perceived noise level computations for signals with significant energy below 50 Hz. The latter inference is not fully consistent with the observations of Fidell and Horonjeff (see above.)
- ICAO's proposed methods for predicting a subjective correction factor depend on some means of measuring the relative impulsiveness. These methods vary from a simple measurement of the crest level of A-weighted noise levels to more complex procedures involving sampling the detected signal (e.g., instantaneous A-weighted level) at a high rate (~5000 Hz) and computing a measure of mean square fluctuation level from these samples.

APPENDIX C

Systematic Analysis of Nonacoustic Influences on Annoyance

A long-standing approach to the problem of accounting for variability in judgments of the annoyance of fixed-wing aircraft noise has been to develop new noise metrics. This approach has produced a veritable alphabet soup of noise metrics, but no appreciable improvement in understanding or predictability of annoyance caused by fixed-wing aircraft noise. Nonetheless, it remains plausible that some improvement in predicting the annoyance of helicopter noise can be achieved via more complex noise metrics alone. After all, helicopter noise can be far more complex than the noise of fixed-wing aircraft.

For practical purposes, a technically defensible answer to the question “Are people more annoyed by helicopter than by fixed-wing aircraft noise?” requires answers to several further questions. Assuming for purposes of discussion that all other things being equal, helicopter noise *is* more annoying than aircraft noise, the first of these additional questions is whether any observed differences in annoyance prevalence rates are due to acoustic or nonacoustic factors.

Given the extent to which communities differ in their opinions about the annoyance of exposure to fixed-wing aircraft noise, it is likely that they also differ widely in their opinions about the annoyance of exposure to rotary-wing aircraft noise. Figure C-1 shows the scatter in prior measurements of the relationship between aircraft noise exposure and the prevalence of a consequential degree of annoyance in communities. Each data point shows the percentage of survey respondents who described themselves as “highly” annoyed (usually, “very” or “extremely” annoyed) by aircraft noise.

The range in noise exposure levels that give rise to the same prevalence of annoyance is on the order of 60 dB. The range in annoyance prevalence rates for the same exposure level across all transportation modes extends from none to about 90%. Figure C-2 shows that the correlation is particularly poor in the range of greatest regulatory interest, from 55 to 75 dB.

C.1 Definition of Community Tolerance Level

Fidell et al. (2011) have shown that a nonacoustic measure known as the CTL, in conjunction with cumulative noise exposure *per se*, accounts for half again as much of the variance in aircraft noise-induced annoyance prevalence rates from one community to the next as noise exposure alone. CTL is formally defined in a Final Draft International Standard 1996-1, shortly to be adopted as an ISO standard. A CTL value is a level of DNL at which half of a community is highly annoyed by noise exposure, and half is not. Since field studies of the prevalence of noise-induced annoyance in communities do not often directly measure DNL values at which half of a community is highly annoyed, it is necessary to estimate CTL values in another way.

CTL-based predictions of annoyance prevalence rates are based on the observation that the annoyance of transportation noise exposure grows at a rate very similar to the rate of growth of

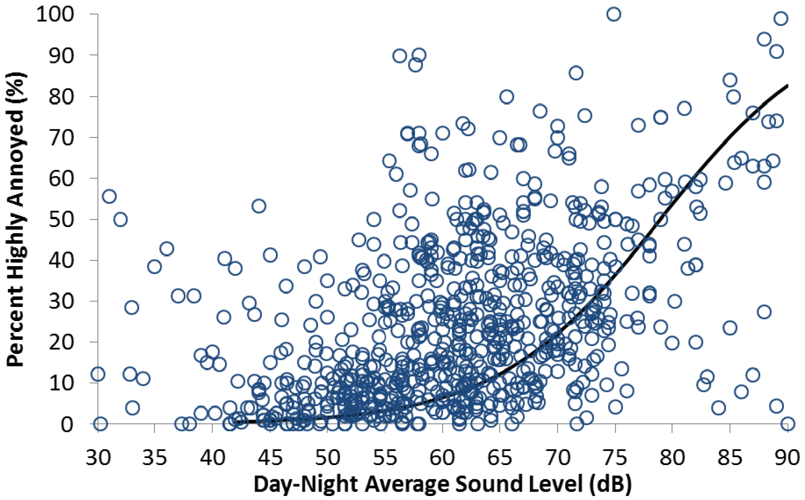


Figure C-1. Relationship between FICON curve and field measurements of DNL and the prevalence of high annoyance for all modes of transportation noise.

duration-adjusted ("effective") loudness with sound level. Fidell et al. (2011) and Schomer et al. (2012) show that the fits of social survey data sets to effective loudness predictions can be found by first converting DNL values for interviewing sites in the same community into a noise dose, m, calculated as $m = (10^{(\mathrm{DNL}/10)})^{0.3}$.

Annoyance prevalence rates for the calculated dose are then predicted as $p(\mathrm{HA}) = e^{-(A/m)}$, where A is a nonacoustic decision criterion originally defined by Fidell, Schultz, and Green (1988). The dose parameter, m, controls the rate of growth of annoyance on the ordinate of a dosage-response relationship, while the decision criterion parameter, A, translates the growth function along the abscissa. The value of A for a given community is estimated by minimizing

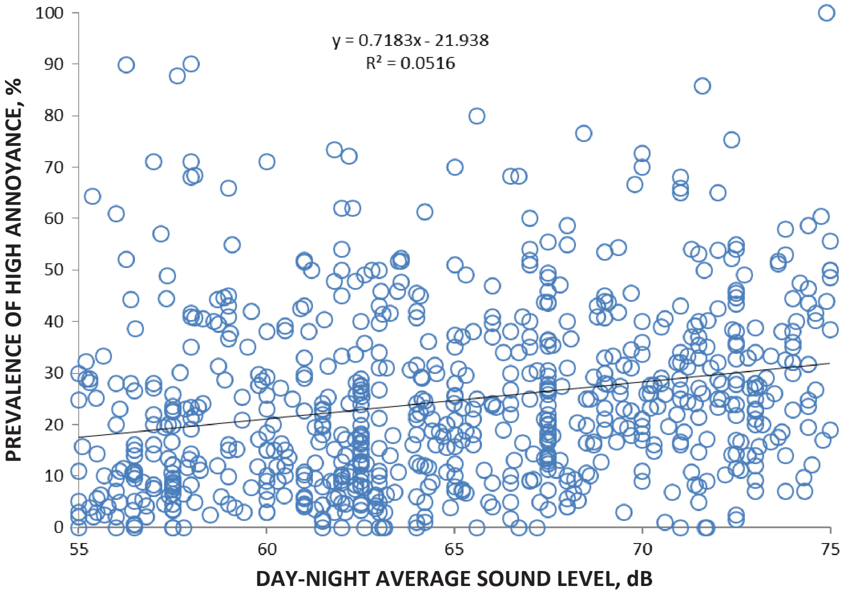


Figure C-2. Poor correlation between exposure and response in exposure range of greatest pragmatic concern.

the root-mean-square error between observed and predicted percentages of highly annoyed survey respondents (Green and Fidell, 1991; Fidell et al., 2011).

C.2 Communities Form Unique Attitudes About Noise

Communities exposed to similar aircraft noise show a wide variance in attitudes about that noise. It is from this observation that the conclusion is made that the focus of understanding annoyance is better done on the community level rather than the individual level. The panels of Figure C-3 (Fidell, 2011) display the fit of the findings of several social surveys to the effective loudness function. Each data point shown in these panels represents a paired observation of the prevalence of high annoyance among respondents at an interviewing site with the site's aircraft noise exposure level. The solid portion of the effective loudness function in each panel of Figure C-3 is the range of primary interest for policy and regulatory purposes. The dashed extensions show the behavior of the function outside the range of primary interest. Not all of the data sets fit the effective loudness function as well as the examples shown in Figure C-3 panels a–f. On average, however, the effective loudness function built into the CTL calculation

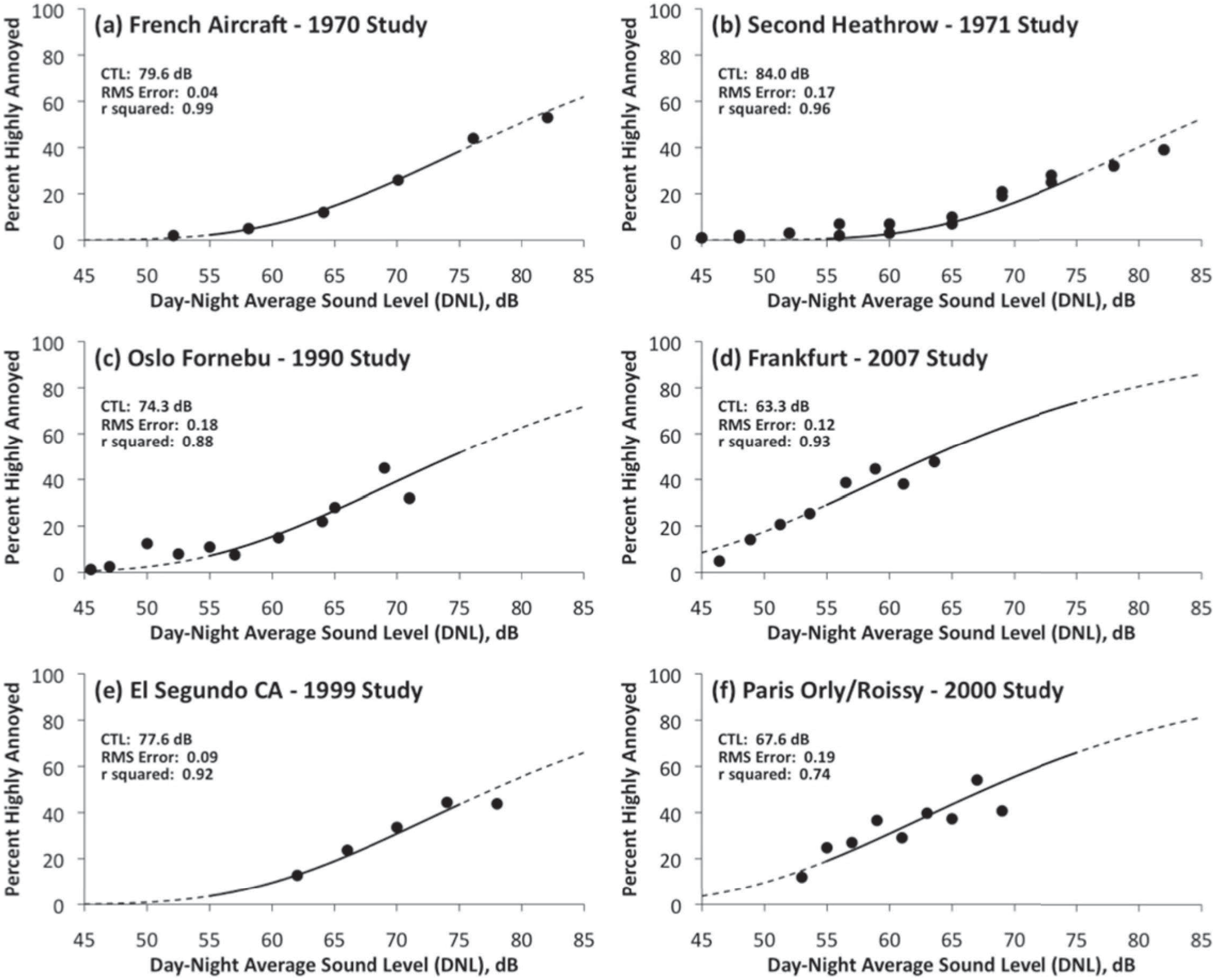


Figure C-3. A comparison of CTL values for six airports showing that at similar noise exposure levels the rate of annoyance varies over a wide range.

accounts for two-thirds of the variance in the association of observed and predicted annoyance prevalence rates.

C.3 Application of CTL Analysis to Annoyance of Exposure to Helicopter Noise

CTL values directly comparable to those calculated for the Fidell et al. (2011) surveys can also be calculated for interviewing sites that are exposed to a range of helicopter noise exposure conditions. Calculating CTL values for the proposed sites would make it possible to make consistent comparisons of the annoyance of rotary- with fixed-wing aircraft noise. These comparisons could be made both with respect to new social survey findings, and with respect to the Fidell et al. (2011) database for aircraft and the Schomer et al. (2012) database for road and rail noise.[24]

APPENDIX D

Noise Measurement Protocol

The noise monitoring for this study was performed using four identical systems of two sound level meters (SLMs). Each system consisted of one Larson Davis (LD) 831 Sound Level Meter and one LD 824 Sound Level Meter connected to a Zoom H4 recorder. Table D-1 presents a list of the SLM used along with the microphone and preamplifier used with each SLM and their serial numbers.

The LD 831 SLMs were set to record the overall A-weighted and C-Weighted L_{eq} and maximum noise levels as well as 1/3 octave band L_{eq} noise levels every second. The LD824 SLMs were set to record the overall A-weighted and C-weighted L_{eq} noise levels and maximum level every second. The audio output of the LD824 SLM was connected to the input of the Zoom H2 digital recorders which were set to record uncompressed WAV audio files at a sampling rate of 44.1 kHz and a bit rate of 16 bits/sample.

Prior to the commencement of monitoring, the performance of each SLM, preamplifier, and microphone combination was verified using a Brüel and Kjær (B&K) 4231 calibrator producing a 1 kHz test tone at 93.8 dB (Serial Number 2528535) and a B&K 4420 pistonphone producing a 250 Hz test tone at 124.0 dB (Serial Number 147402). Certificates of Performance showing the measured calibration levels for each of the SLM systems prior to each measurement period are attached. The calibrator and pistonphone were calibrated by Odin Metrology using standards with values traceable to the National Institute of Standards and Technology. Calibration certificates for these units are attached.

At the commencement of each measurement period, one system, consisting of two SLMs and a Zoom audio recorder, were set up at each measurement location. The SLMs and audio recorder were located in weather resistant cases with access ports for microphone cables and power. The microphones were placed on tripods to mount them at a height of approximately five feet AGL. The microphone tripods were located near the center of the yards at least 10 feet away from any building or wall.

Each SLM was calibrated using the B&K 4231 calibrator in the field prior to starting each measurement period and calibration levels recorded. Data capture on the SLMs was started along with the Zoom audio recording. A calibration tone was recorded to the Zoom recorder and an audible time stamp was recorded. The systems were locked within their cases, and left unattended.

Data storage limitations on the LD 824 SLM and Zoom H4 recorders required downloading of data from the units every other day. Data from the LD 831 SLM were generally downloaded every fourth day. Upon approaching the meters, an audible time stamp was recorded to the Zoom audio file. Data capture on the LD 824 and audio recording on the Zoom were paused and their data was transferred to a portable hard drive. This process was generally repeated for the LD831 SLM on every other visit. After the data was downloaded from the SLMs, the calibration

Table D-1. Sound level monitoring equipment.

	COMPONENT	MANUFACTURER	MODEL	SERIAL #
System A - Monitor 1				
	SLM	Larson Davis	831	2564
	Preamplifier	Larson Davis	PRM831	12422
	Microphone	GRAS	40AQ	83680
System A - Monitor 2				
	SLM	Larson Davis	831	A1460
	Pre-Amp.	Larson Davis	PRM902	1983
	Mic.	Larson Davis	2551	178
System B - Monitor 1				
	SLM	Larson Davis	831	2562
	Preamplifier	Larson Davis	PRM831	15267
	Microphone	GRAS	40AQ	101907
System B - Monitor 2				
	SLM	Larson Davis	831	A1459
	Preamplifier	Larson Davis	PRM902	1987
	Microphone	Brüel & Kjær	4176	2316550
System C - Monitor 1				
	SLM	Larson Davis	831	2565
	Preamplifier	Larson Davis	PRM831	15268
	Microphone	GRAS	40AQ	101963
System C - Monitor 2				
	SLM	Larson Davis	831	A1458
	Preamplifier	Larson Davis	PRM902	1976
	Microphone	Brüel & Kjær	2551	2316551
System D - Monitor 1				
	SLM	Larson Davis	831	2566
	Pre-Amp.	Larson Davis	PRM831	15270
	Mic.	GRAS	40AQ	101912
System D - Monitor 2				
	SLM	Larson Davis	831	A1457
	Pre-Amp.	Larson Davis	PRM902	1989
	Mic.	Larson Davis	2551	177

was checked and recorded using the B&K 4231 calibrator. The SLMs were recalibrated if the measured level differed from the calibration level by more than 0.4 dB. After this process was completed, data capture on the SLMs and recording on the Zoom were restarted. A calibration tone and audible time stamp were recorded on the audio file. The time the technician approached and departed each measurement site was recorded along with file names, measurement start and stop times, and calibration levels.

At the end of each measurement period an audible time stamp was recorded to the Zoom audio file as the meters were initially approached. Audio file recording and SLM data capture were paused and transferred to a portable hard drive. Calibration levels were checked using the Brüel and Kjaer calibrator and recorded.

The calibration checks for the SLMs are attached.

Endnotes

1. Fidell (2003) presents a broader tutorial on the findings, interpretations, and practical implications of community noise research.
2. Note that these nonacoustic influences are more productively addressed at the community, rather than individual, level. As described in the paper on Community Tolerance Level, CTL, (Fidell et al. 2011) communities form unique attitudes about noise. Decades of efforts (e.g., Job 1988; Fields 1993) to quantify individual differences in sensitivity to aircraft noise have produced little information useful for prediction of annoyance prevalence rates, or for regulation of aviation noise.
3. The lowermost curve is FICON's dosage-response relationship for the prevalence of annoyance for all forms of transportation noise. The Miedema and Vos (1998) curve is that of the European Noise Directive.
4. "Final Rule," The New York North Shore Helicopter Route, 77 Fed. Reg., pp. 39,911–39,913.
5. FAA's endorsement of A-weighted noise measurements for assessment of community noise impacts is in large part based on limitations of field-portable, analog-era sound level meters. Lacking the capacity for combining one-third octave band sound level measurements and identifying tonal signal components, it was not possible decades ago to directly measure PNL(T) values in the field.
6. Readers interested in additional detail about these frequency-weighting networks and noise metrics are referred to Mestre et al. (2011).
7. Idealized conditions include a stable and still atmosphere, close adherence to published flight paths and procedures, and ideal pilot technique. Because relatively few helicopter operations are likely to occur under all of these conditions, and because of the great sensitivity of helicopter noise emissions to minor changes in operating conditions, actual noise emissions in the vicinity of helipads may diverge considerably from predicted noise emissions.
8. Truncating the range of a predictor variable such as noise exposure level reduces the magnitude of any observable correlation with a predicted variable such as the prevalence of annoyance.
9. This is particularly true in areas orthogonal to runway centerlines, where the sideline noise exposure gradients for fixed-wing aircraft can be as steep as 10 dB per thousand feet. At airports with midfield helipads, this means that fixed-wing aircraft noise exposure levels are likely to decrease far more rapidly with distance from the runway than rotary-wing aircraft noise exposure levels.
10. Fidell et al. (2011) have suggested one potential solution to this problem—reliance on an assumed shape for the dosage-response relationship.
11. ISO Technical Specification 15666 ("Assessment of noise annoyance by means of social and socio-acoustic surveys") does not recommend screening questions, but also notes that ". . . specific requirements and protocols of some social and socio-acoustic studies may not permit the use of some or all of the present specifications. This Technical Specification in no way lessens the merit, value or validity of such research studies."
12. Proprietary databases, constructed from multiple (e.g., credit bureau, census, telephone, etc.) sources, may nonetheless be useful for present purposes if they permit geocoding and sampling based on areas enclosed by vertices of polygons that can be defined by noise exposure modeling.
13. More recent methods of interviewing (e.g., smartphone- and Internet-based) are not as likely to yield population-representative samples of opinions, since they either permit respondents to self-select for participation in the survey and/or attract primarily respondents with prior interests in the subject matter of the interview.
14. Note that the width of the confidence interval varies not only with sample size, but also with the absolute value of the proportion estimated. The values shown in Figure 3.12 are based on a normal approximation to a binomial distribution, and should not be extrapolated beyond the plotted range.
15. INM 7.0d was released prior to AEDT 2b, but produces identical noise exposure predictions for identical inputs. Note that AEDT 2c was published after the technical work was completed for this study.

16. In broad stokes, landline and wireless sampling frames are developed using a combination of public records and self-reported information. The starting point for compilation for the landline sampling frame is telephone white page directories. These directories are scanned, manually entered, and compared for accuracy. Public record sources, such as birth and mortgage records, are used to enrich this data wherever available. Enhanced-Wireless™ is based upon a self-reported sampling database of approximately 125,000,000 wireless phones. Using Enhanced-Wireless™, samples can be targeted to specific demographic groups, including age, income, gender, presence of children, and ethnic groups—just to name a few. Enhanced-Wireless™ was developed by STS using a proprietary set of databases that includes product purchase data, warranty card information, survey data, and many similar sources of information. Enhanced-Wireless™ is not a panel. Its consumers are not opt-in, instead, it is very much like a landline listings sample—except for covering the wireless universe.
17. Site 4 is a special case. Noise levels measured at Sites 1, 2, and 3 were dominated by a police helicopter that circled and crisscrossed the area above those sites many times at low altitude at 1 AM. Site 4 (north of Sites 1, 2, and 3) was shielded from this operation by a converted garage about 15 feet from the microphone location. Site 4 recorded appreciably lower noise levels for this series of events than did the other sites.
18. The concern over revised flight tracks, known as the "Metroplex Project" was not anticipated at the time of site selection. While the project was known, the concern that it would generate was not known. The FAA had determined that no significant impact would take place. In hindsight, it is clear that Metroplex projects around the U.S. generated more concern than was anticipated. It is still unclear if the concern was in fact a noise issue or whether the mere announcement of the changes or some other nonacoustic effect generated the adverse response. In any event, Washington, D.C., was the only place where we had overlapping fixed-wing and helicopter operations in significant numbers.
19. The current version of INM, version 7.0d (FAA 2007), will be replaced by the Airport Environmental Design Tool (AEDT) Version 2b by the end of the current calendar year. Prior to INM Version 6, helicopter noise was modeled with the Helicopter Noise Model, HNM (Volpe 1994). The helicopter noise computation model from HNM was incorporated into INM beginning with INM Version 6.
20. This assertion assumes that compliance with ICAO standards for fixed-wing aircraft noise certification precludes vigorous adverse reaction in aircraft noise-exposed communities near airports. ICAO's recommendations are consensus standards for noise levels that may not be exceeded by aircraft offered for sale in those member states who chose to adopt ICAO's recommendations. ICAO's noise certification standards are not intended to, and do not, in fact, preclude adverse community reaction to aircraft noise exposure. Indeed, it is commonplace for communities near airports served by large fleets of ICAO-compliant aircraft to oppose continued, unmitigated airport operation and expansion.
21. The influence of meaning on annoyance judgments was also demonstrated by Fidell et al. (2002b), who solicited annoyance judgments under highly controlled listening conditions to sounds with identical duration and power spectra, but differing phase spectra. Large differences were documented between meaningful sounds and the same sounds with scrambled phase spectra.
22. For example, Ollerhead's conclusions include no mention of the subjective impact of helicopter noise.
23. It is possible, for example, that rattle and vibration produced by fixed-wing aircraft at the relatively short ranges of the controlled helicopter flybys would also have created "excess" annoyance.
24. Descriptive statistical tools such as regression may also be used in some cases to estimate values of DNL that highly annoy half of the population at a given interview site. Such estimates do not offer all of the advantages of CTL analysis, however. The slopes of regression-derived estimates of DNL values that highly annoy half of survey respondents are not directly comparable in multiple communities, and levels of annoyance that annoy half of a sample of respondents often do not reach 50% at common levels of helicopter noise exposure.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation