AIRCRAFT NOISE IMPACTS RESEARCH

INFORMATION BRIEFS

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INTRODUCTION

Based on discussions at the FAA's August International Forum and the December Workshop on Aircraft Noise Impacts Research, and in preparation for the follow-on workshop in San Diego on March 4, 2010, key topics for information briefs were identified. The information briefs are one or two pages of text briefly describing the state of practice, state of knowledge, evidence on an important hypothesis, or gaps in the state of knowledge currently not in the roadmap or not discussed at the August and December meetings. The briefs discuss aspects of aircraft noise and its resulting effects on surveyed annoyance, public actions or on sleep disturbance. The papers are not intended as exhaustive treatment of the topics, and not necessarily consistent with one another. They are the views of the identified individual researchers, and are presented unedited.

Several researchers contributed briefs, some addressing more than one of the identified aircraft noise effects. We have divided them, or excerpts from them, into the two categories of Annoyance and Sleep, as shown below.

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A. ANNOYANCE

1. Vincent Mestre - Chapter 3: Annoyance and Aviation Noise, ACRP Synthesis 9 "Effects of Aircraft Noise: Research Update on Selected Topics"

(This report is available at: http://144.171.11.107/Main/Public/Blurbs/160286.aspx; see report for references)

Annoyance remains the single most significant effect associated with aviation noise. Community annoyance is the aggregate community response to long-term, steady-state exposure conditions. However, to adequately support government noise policy-making efforts, it is necessary to synthesize the large amount of data contained in journal articles and technical reports to develop a useful exposure-response relationship. In his seminal journal article, Schultz (1978) reviewed data from social surveys concerning the noise of aircraft, street and expressway traffic, and railroads. Going back to the original published data, the various survey noise ratings were translated to Day-Night Average Noise Level (DNL) and, where a choice was needed, an independent judgment was made as to which respondents should be counted as "highly annoyed." According to Schultz ". . . the basic rule adopted was to count as 'highly annoyed' the people who responded on the upper 27% to 29% of the annoyance scale . . ." (Schultz 1978).

For decades, environmental planners have relied heavily on the Schultz Curve for predicting the community annoyance produced by noise from transportation noise sources. Notwithstanding the methodological questions, errors in measurement of both noise exposure and reported annoyance, data interpretation differences, and the problem of community response bias, Schultz's recommended relationship has historically been the most widely accepted interpretation of the social survey literature on transportation noise-induced annoyance.

Beginning with the publication of this original exposure-response curve, work has continued in many countries to conduct new field studies, develop databases with the results of dozens of new social surveys, and explore whether separate curves are needed to describe community responses to aircraft, street traffic, and railway noise. Based on an updating of the Schultz curve by Fidell et al. (1991), the Technical Section of the Federal Interagency Committee on Noise (FICON), stated in 1992 that there were no new descriptors or metrics of sufficient scientific standing to substitute for the present DNL cumulative noise exposure metric (Federal Interagency Committee on Noise 1992). The dose-response relationship, as represented by DNL, and the percentage of persons "highly annoyed" remains the best available approach for analyzing overall health and welfare impacts for the vast majority of transportation noise analyses. In later years, Fidell goes on to criticize the use of this type of simplistic 10 curve such as the one in FICON, in light of the high data variability, the effect of low- and high-noise exposure levels on the curve fit, and the lack of consideration of other variables in community response to noise.

A comprehensive review and critique of the Fidell et al. update was later published by Fields (1994) that raises questions about the use of the synthesis data to develop the commonly used annoyance/DNL dose-response relationship. The report arrives at several conclusions, including "the curve is NOT a measurement of the relationship between DNL and the percentage of the population that would describe themselves as 'highly annoyed'" and "if it is necessary to estimate the dose/response relationship . . . a single constituent survey provides a better estimate" (Fields 1994).

Fidell et al.'s expansion of the existing community annoyance research database and their revised prediction curve provided a considerable extension of the original Schultz meta-analysis (Fidell et al. 1991). However, because there were several debatable methodological issues involved in this update, Finegold et al. (1994) reanalyzed the Fidell et al. data focusing primarily on the choice of screening criteria for selecting which studies to include in the final database and the choice of a data fitting algorithm.

Using the new data set, a new logistic fit curve as the prediction curve of choice was developed and adopted by FICON in 1992 for use by federal agencies in aircraft noise-related environmental impact analyses (Federal Interagency Committee on Noise 1992). It was also adopted as part of the American National Standards Institute (ANSI) Standard on community responses to environmental noises (Acoustical Society of American 2006). Finegold et al. (1994) showed that if the data are broken down into separate curves for various types of transportation noises (aircraft, roadway, and rail noise) aircraft noise appears to be more annoying at the same DNL than road or rail noise.

Over the past decade, Miedema and Vos (1998) have compiled the most comprehensive database of community annoyance data yet available, and several studies have been published on the results of their analyses. It is a comprehensive review of an issue—separate, non-identical curves for aircraft, road traffic, and railway noise—that has been the subject of much debate since Shultz published his data in 1978. Caution should be exercised, however, when drawing conclusions about the state of knowledge regarding the relationship between various transportation noise sources and community annoyance.

The European Commission position on annoyance is based on a report recommending the percentage of persons "highly annoyed" be used as the descriptor for noise annoyance. Similar to Miedema and Vos (1999) the report distinguishes between aircraft, road, and rail traffic noise; recommends use of a separate pair of curves ("annoyed" and "highly annoyed") for each; and clearly shows a tendency to treat aircraft, road, and rail noise as unique when estimating population that will be "annoyed" or "highly annoyed" by noise (Miedema and Vos 1999).

In their 1999 paper, Miedema and Vos further studied the effects of demographic variables (sex, age, education level, occupational status, size of household, dependency on the noise source, use of the noise source, etc.) and two attitudinal variables (noise sensitivity and fear of the noise source) on annoyance. The results are very interesting and suggest that fear and noise sensitivity has a large impact on annoyance. Additionally, in a 2002 report by Fidell et al., it is suggested that a good part of the excess annoyance is attributable to the net influence of non-acoustic factors.

Some of the most interesting research comes from Fidell's "The Schultz Curve 25 Years Later: A Research Perspective" (2003). It presents the argument that although federal adoption of an annoyance-based rationale for regulatory policy has made this approach a familiar one, it is only one of several historical perspectives, and not necessarily the most useful for all purposes. This tutorial article traces the development of the dosage-effect relationship on which FICON currently relies and identifies areas in which advances in genuine understanding might lead to improved means for predicting community response to transportation noise. It provides an important summary of how the annoyance synthesis was developed, and the inherent weakness of the DNL/dose-response relationship that was developed. Fidell is highly critical of U.S. policy that relies solely on the synthesized dose-response relationship.

Fidell and Silvati (2004) identified shortcomings of a fitting function endorsed by FICON for predicting annoyance in populations exposed to aircraft noise that are well-understood and well-documented. The authors argue that the U.S. National Environmental Policy Act (NEPA) (1969) requires the use of the best-available technology for disclosure of noise impacts of major federal actions, even though reliance on the FICON curve for meeting NEPA requirements does not use the best available technology.

To summarize, significant research has occurred since the 1985 aviation effects report was published. Although no current research suggests there is a better metric than DNL to relate to annoyance, there still remains significant controversy over the use of the dose-response annoyance curve first developed by Schultz and then updated by others. Further, investigations that report a distinct percentage of the populations that will be highly annoyed at a given DNL may be incorrectly interpreted as to having a more precise meaning than should be taken from the data. Lastly, a relatively new concept is that more research tends to support the idea that dose-response curves are different for aircraft, road, and rail noise sources. Areas of research that remain to be investigated include the relationship between single-event noise levels and annoyance. The expanding use of airport noise monitoring systems, flight-tracking systems, and geographic information systems may make the evaluation of annoyance and single-event noise rich for examination.

2. Fields, Personal Impact vs. Public Actions: Two Types of Community Response

(Prepared by Jim Fields, March 16, 2010)

Summary:

Two very different results from having aircraft noise in a community are often confused in discussions of "community response": private response (i.e. impact on residents) and public response (the public actions of residents). The impact on people is a private response to noise that is not directly observed by authorities or acousticians. The public response in the form of complaints or other public action is directly observed by authorities and becomes the basis for involving acousticians in noise issues. Many factors that have a strong effect on public actions may be largely irrelevant for gauging the number of community members who are impacted by noise. One consequence of this is that authorities and acousticians can easily form inaccurate views of the causes of noise impact on residents.

Two Types of Responses in Communities

Transportation noises in communities result in two separate, but related phenomena: residents are impacted and people take public action. The differences between the two phenomena are summarized in Table 1.

Private Response – Personal Impact: The impact of noise is a private, difficult-to-observe effect. Residents and other community members hear noise that they often do not want to hear and experience various disturbances in their normal lives such as speech interference or sleep disturbance. This results in a reduced quality of life. These private effects are directly measured through social surveys that ask people to describe their annoyance, disturbance, degree of activity interference, etc. The private effects are also known to occur because acoustical studies have identified the acoustical conditions that cause speech and other types of communication interference. The extent of these private effects can only be known through systematic, scientific research.

Public Response – Public Action: Although the public response is partly driven by the effects of noise on individuals, it is not a direct measure of the effect of noise on individuals. The public response is behavior that officials, members of communities, or acoustical consultants can observe directly such as: complaints to authorities, letters to the editor of newspapers, speeches by legislators, signatures on petitions, or attendance at public meetings.

Table 1: Differences between Personal Impact and Public Action

Type of community response	Who is impacted	Phenomena measured	Effect of noise that is directly measured	Method for measuring
Private response (Personal impact)	Residents and other members of communities	Effect on individuals	Reduced quality of life for residents and other people	• Social survey • Observation (sleep disturbance, etc.) • Controlled experiments (speech interference, etc)
Public response (Public action)	Public officials, airport operators	Behavior displayed publically	Increased actions in pubic that authorities address	• Counting complaints • Counting public actions (law suits, protests, petitions, etc.)

Factors Affecting Public Response (Public Actions)

One of the preconditions for public responses is some personal impact on residents. As a result the factors that lead to private responses and reduce the quality of life for residents will have some effect on the extent of public action. However, the public response also is affected by all the factors that can lead people to translate their feelings into visible action. These factors mean that observations of the public response may lead to erroneous conclusions about the levels and causes of noise impact and thus about the levels and causes of a reduced quality of life from noise. Table 2 summarizes some type of factors that could be major determinants of public action but have little or no effect on private welfare.

Table 2: Factors that May Affect Public Action but Have Little or No Effect on Personal Reactions

Type of variable	Hypotheses: Public actions will be especially high if::	Implications	Evidence that more important for actions than private impact
Motivation to take action	A person believes actions will affect policy or noise exposure	Communities with political influence are more likely to act	Logic
	A person has an investment in the community	Home owners are more likely to complain	Home ownership has a big effect on complaint rates but not on annoyance.
	The neighborhood does not have other more serious problems (for example high crime rates or poor public services)	Disadvantaged neighborhoods are less likely to act on noise	Social surveys show income has little or no effect on annoyance

Type of variable	Hypotheses: Public actions will be especially high if::	Implications	Evidence that more important for actions than private impact
	A person is confident about speaking with authorities	Highly educated residents are more likely to act	Social surveys show education has little or no effect on annoyance
	Unusual events provide a legitimate basis for the timing of the complaint	Actions are greater when there are unusual events or plans for changes.	Social survey evidence on reactions to changes is not consistent
	A person believes the basis for a complaint will be accepted as legitimate and credibly timed	People complain about sleep disturbance	Complainants do not say that noise is esthetically displeasing
Conditions facilitating public actions	Complaint processes are widely publicized	Complaint rates can vary widely with no change in private impact	Logic
	The authorities make it easy to register complaints	(see above)	Logic
	Community organizations make it easy for actions to be registered (for example by circulating petitions)	Previously well-organized communities complain more	Logic
Airport procedures affecting complaint statistics	Authorities systematically maintain data bases that track complain activity	Changes in data systems and recording forms may affect complaint statistics	Logic
	All personnel in contact with the public are able and prepared to record complaints	Many complaints may go unrecorded if only a formal complaint process is monitored	Logic
	Complaint personnel are trained to objectively record complaints	Poorly trained personnel may discourage complaint reports	Logic

Some of the motivational and organizational conditions that facilitate complaints are obviously of great relevance to complaints and action, but of little or no obvious relevance for private reactions. For example, whether the airport has a well maintained data base could not directly affect residents' annoyance. However, other variables' effects are not so obvious. Home owners have been found to be much more likely to complain, but to be only slightly more likely to be annoyed. One of the first surveys around London Heathrow airport found that high socio-economic status residents were not more annoyed than other residents, but were much more likely to complain (McKennell, 1970). The implications of using public actions as a measure of noise impact are clear from the table. Lower socio-economic status (SES), less politically connected communities could be incorrectly assumed to be unaffected by noise. In addition, airports that carefully accumulate complaint data could appear to have bigger noise problems than airports that ignore their communities.

Considerations for Research

Although there are scattered pieces of empirical evidence and theoretical bases for expecting the differences between personal impact (for example, annoyance) and public action, this subject has not been carefully or systematically studied for community noise. Secondary analyses of previously collected survey data could provide a firm empirical basis for comparing personal annoyance with respondents' reports of making complaints and participating in other public actions.

Progress in understanding public actions might be rapid since social theory about the formation of interest groups and the emergence of political action is available (Lesnick and Crowfoot, 1981, Fields, 1990). Although some insight could be gained by comparing respondent reports of annoyance and respondent reports of complaints, a broader understanding would require that social survey information be supplemented by measures of community level reactions such as meetings, organizational activity, media campaigns, and legal actions. The danger exists that such studies would provide the tools for the political system to control public action while ignoring the actual impact on the quality of life for the inactive community members. However, it is also possible that such knowledge would clarify the now-blurred distinction between personal annoyance and visible public action with the result that there would be a clearer focus on privately expressed annoyance. Community planners might also more clearly understand that they must plan both for the equitable management of noise as well as for the undeniable pressures from community action that could distort an equitable management plan. The knowledge might also confirm that community involvement in the evaluation and mitigation of impacts could reduce public actions.

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3. Fields, The place of annoyance in impact assessment and its validity

(Prepared by Jim Fields, March 16, 2010)

Summary

Models of noise impact in residential areas have been developed on the basis of explaining subjective reactions to noise that are characterized as "annoyance" as measured in social surveys. Such measures of subjective reactions are accepted as the most direct method for determining how residents in a community feel about the impact of noise on their lives. The available evidence shows that individuals differ greatly in their annoyance levels but that the annoyance levels reported in surveys appear to be an accurate report of feelings. Methodological experiments in surveys show that annoyance measures are internally consistent, consistently related to noise level and similar to other subjective measures in their stability over time. Annoyance consistently increases as noise levels increase. Noise levels only partially explain annoyance scores for a number of reasons: humans do not have objective rules for relating a questionnaire scale label to their subjective state, feelings of annoyance within a single person vary some from day to day, different people feel differently about the same noise exposure, and other attitudes have some effect on annoyance. Methodological experiments have found some evidence that this variability in annoyance is not caused by questionnaire construction or a desire of respondents to artificially distort their responses to inflate questionnaire results. These experiments find that annoyance is not distorted by position in a questionnaire, not distorted by the extent to which noise effects have been discussed in a questionnaire and not distorted by knowledge of the survey sponsor.

Measuring Noise Annoyance

Noise annoyance is generally measured by asking residents questions in social surveys. Two annoyance questions that are recommended by international bodies (Fields *et al.*, 2001, ISO (International Standards Organization), 2003) are now the most frequently recommended questions:

[ASK ALL RESPONDENTS]

Q.V "Thinking about the last (..12 months or so..), when you are here at home, how much does noise from (..noise source..) bother, disturb, or annoy you; Extremely, Very, Moderately, Slightly or Not at all?"

Q.N "Next is a zero to ten opinion scale for how much (..source..) noise bothers, disturbs or annoys you when you are here at home. If you are not at all annoyed choose zero, if you are extremely annoyed choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the last (..12 months or so..), what number from zero to ten best shows how much you are bothered, disturbed, or annoyed by (..source..) noise?"

The questionnaires that contain these questions are almost always introduced as "environmental" or "neighborhood condition" surveys by interviewers who have been trained to conduct interviews in a neutral unbiased manner. The noise annoyance questions almost always appear early in questionnaires before the respondent is asked enough questions to infer that the topic of the survey as a whole concerns a particular noise source.

Questionnaires have contained other questions about interference with specific activities (sleep, speech, listening, relaxing, concentration, etc.) or have asked for the ratings of the noise on scales such as “satisfaction”, “acceptability”, and “disturbance”. These and other more complex multi-item indices have been found to be no more highly related to noise level than the simple questions presented above, which highlight a generally negative reaction with the three words “bother, annoy or disturb”.

The Validity of Noise Annoyance Measures

As for the attitudinal questions in other types of public opinion surveys, these attitudinal noise annoyance questions are assumed to be the most direct, accurate, and economical measurement of people’s feelings as they would express them in words to a neutral observer. There is, of course, no method for directly measuring feelings. All we can measure is people’s statements about their feelings. The validity and reliability of the questions must therefore be assessed indirectly through examining the methods that are used for gathering the information, determining whether the answers are consistent over time, logically consistent with other measures, and not distorted by factors that would indicate that respondents were deliberately misreporting their feelings.

Validity is defined as the extent to which a question actually measures some “true” underlying annoyance. The reliability is the extent to which repeated measures of the same individual’s annoyance are consistent. An understanding of the causes of less than perfect reliability will provide a basis for realistically applying the results from social surveys. Confidence in the validity of the measurement of annoyance depends partly upon the quality of the social survey measurement process. Since the annoyance construct is a subjective one, measurement of annoyance follows guidelines that eliminate as many sources of potential bias as possible. Some standard practices are as follows. Surveys conceal the focus of the questionnaire from the respondent as long as possible by being presented as studies of general environmental problems. The primary annoyance questions are presented early in the questionnaire in the context of a list of other environmental disturbances. Interviewers are carefully trained to ask all questions exactly as printed in the questionnaire so that the interviewer will not bias the respondents' answers. Questions, such as the ones reprinted above are stated in a simple, unbiased manner. The selection of respondents is based on sampling techniques which ensure that interviewers’ feelings cannot bias the selection of respondents.

Methodological studies of the annoyance measures give further confidence that they are not biased by details of the interviewing process. British road traffic and railway surveys have found that answers are not affected by variations in the order of questions or the order in which the alternatives are presented (Fields and Walker, 1982b;Langdon, 1976b). A survey in Hamburg, Germany found that annoyance responses were not distorted by the length of the questionnaire or several characteristics of the interviewer (Guski, Wichmann, Rohrmann, and Finke, 1978). In post-interview debriefings it has been found that most people did not know about the subject of the questionnaire before beginning the interviews (Fields and Walker, 1982b;McKennell, 1963). A study around Roissy airport near Paris included a standardized scale which is designed to measure the extent to which a person generally tries to falsify results by choosing answers which are perceived to be socially acceptable (Francois, 1979a). No evidence was found for an upward distortion of annoyance ratings. In fact the respondents who scored the highest on the so-called “lie” scale were those with the lowest annoyance scores.

Other support for the validity of the annoyance measures comes from the fact that the annoyance responses correlate with other variables in a meaningful manner (McKennell, 1969). Annoyance responses are highly correlated with one another as well as with the somewhat more objective activity interferences, private behavior and public complaint reports. Annoyance is, of course, also related to noise level. The available research, therefore, indicates that social survey annoyance scales are valid, unbiased measures of annoyance.

The most important indicator of the validity of the annoyance measures is that they are related to noise in the way that is expected. Every large scale residential noise survey has found that there is the simple, reasonable relationship for a given situation: the lower the noise level, the less the average annoyance. The findings from surveys are consistent with the assumption that people would generally prefer that their home acoustical environment only includes the sounds they bring into their home while excluding transportation sounds, even of a low level. As long as a noise is present, some people would prefer a quieter environment, but the lower the level that noise becomes, the fewer the people who are annoyed. When 495 publications concerning 282 community surveys were examined, it was found that every one of the eight surveys that included at least a 10 dB range at low noise levels below 55 DNL found that annoyance continued to decrease as noise levels dropped to 45 DNL and below (Fields, 1992 p. 27). Very low noise levels have not been studied systematically to see whether there is a point at which annoyance completely disappears, although one survey in England of residents at least five miles from a railway line found that there was no annoyance with railway noise even though a few people reported hearing it (Hawkins, 1979b). Of course, the normal social survey of aircraft noise does not include residents from such low noise levels. It is thus to be expected that there will be some residents in these surveys who are annoyed at the lowest noise levels, that the noise level itself will explain only a modest amount of the variation in the differences between individuals’ answers to the subjective survey question, and that there will still be annoyed people at the lowest noise levels that can be found in an aircraft noise exposed community. Within these communities variation in annoyance question answers is to be expected because humans do not have objective rules for relating a questionnaire scale number to their subjective state, feelings of annoyance within a single person vary some from day to day, different people feel differently about the same noise exposure, and other attitudes have some effect on annoyance.

Measured annoyance scores have two characteristics which are inevitable in social science inquiries but which would indicate serious methodological errors in most physical science inquiries. Firstly, the annoyance responses to any single noise environment are highly variable and, secondly, the annoyance responses are affected by some aspects of the question wording. The amount of random variation in the answers to the questions is measured in terms of the reliability of the measures, i.e. the extent to which repeated measures of the same concept are correlated. Measures of the reliability of annoyance indices consisting of several questionnaire items have generally been found to meet or exceed the standard , accepted social science criteria of r = 0.80(Bullen and Hede, 1983b;Hall and Taylor, 1982). Even though standard reliability criteria are met there is still a great deal of variability. When the same individuals have been asked about their (unchanged) noise environments at intervals of from a month (Griffiths, Langdon, and Swan, 1980) to a year (Hall and Taylor, 1982) only about 35% of the variance in response ratings can be explained by their answers on the previous questionnaire. This level of reliability is not surprising if two aspects of the respondent's task are considered.

The first task is to consolidate immediately all of his diverse experiences and feelings about noise onto a single dimension. Without the opportunity to consider the problem carefully it is understandable that a purely random set of associations during the course of an interview could recall different experiences and feelings which lead to considerable random variation in the location that any one individual places himself or herself on an annoyance scale.

Even for respondents who are certain about their feeling there is still an equally difficult second task; the respondent must make a somewhat arbitrary choice between the words or numbers which the interviewer has offered. There are no objective rules that a respondent can draw on to determine whether the subjective feeling should be described as "very" or "moderately" annoyed or as "4" or "6" on an annoyance scale. Given these difficulties in measuring annoyance, it is to be expected that there will be considerable variation in the annoyance scores at any particular noise level and for the same person at different point in time.

The difficulties that respondents face in relating their complex feelings to a previously unseen survey scale explain the second important characteristic of the measurement of annoyance in the social surveys. That is, the number of people who are rated as "annoyed" depends on the form of the annoyance question. Since many people have difficulty in quickly organizing all of their thoughts on an open-ended question early in a questionnaire, fewer people indicate that they are annoyed by noise when asked to name any "things which bother you around here" than when they are specifically asked about an item (such as "road traffic noise") later in the questionnaire (McKennell, 1963; Kryter and Pearsons, 1963). The number of annoyance categories included in an annoyance question will affect answers because respondents use not only the words but also cues from the length of a scale to classify themselves. As a result the interpretations of the meaning of particular labels on annoyance questions must be made cautiously.

The Place of Noise Annoyance Measures

Objective measures of the effects of noise are important and could be more widely used than is common in community assessments and in discussions with communities about the implications of specific noise levels. The types of speech interference or sleep disturbance at different noise levels could be presented as relatively objective measures of the effects of noise in communities. This could provide a large set of valuable measures. However, the subjective annoyance measure provides some advantages that the "objective" measures lack because the annoyance measure gives the respondent's single, combined, weighted judgment of all the effects.

Even though the various speech interference and disturbance measures provide objective measures of impact they cannot determine which levels of impact are relevant without other subjective assumptions. For example, the amount of speech interference at three feet for normal conversation outdoors could be described. But we must still rely on a more-or-less subjective judgment from the acoustician as to whether the relevant speech interference is for indoors or outdoors, is for a distance of three feet or 20 feet, is for normal speaking levels or for low levels, etc.

In addition, though we can objectively describe each of these indicators we do not know what the relative importance of all the indicators is for the respondent. We do not know how the respondent weighs all these disturbances and thus how the objective indicators should be combined to represent the overall impact on an individual. In addition, the objective indicators still do not include some purely subjective judgment about how pleasant or unpleasant the sound is.

The annoyance measures, subjective though they are, provide important information because the respondent integrates all the effects to give an overall, balanced assessment of the total impact of the noise environment.

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(Note: The six-character abbreviation following many references is the identifier for the associated survey in a 2008 community response survey catalog.)

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(Prepared by Jim Fields, March 16, 2010)

Summary

Over 628 social surveys of residents' reactions to environmental noise have been conducted. Some of the larger surveys' complete social survey data sets have been deposited in data archives where they have been accessed by researchers who did not conducted the original survey. The findings from the 628 surveys have been reported upon in over 1,300 publications (Bassarab, Sharp, and Robinette, 2009). Researchers have attempted to consolidate the information from multiple surveys in a number of ways besides traditional, unstructured literature reviews. Meta-analyses have been conducted that examine publications to count the number of surveys that support or oppose various hypotheses (for example whether men are more annoyed than women). Secondary analyses have been conducted that access the combined acoustical/social-survey-questionnaire, respondent-level data sets and conduct new, identical parallel analyses of all data sets. The approach used by Schultz in 1978 (Schultz, 1978) was a hybrid in which only two variables were estimated for each survey (DNL and some measure of reaction) and the respondents' answers had been previously averaged into a category of noise exposure.

Discussion about the community response surveys and their data sets have often been confusing because key terms have not been consistently defined. In the discussion below, each term appears in bolded font the first time it is introduced.

Introduction and Definitions

Community Noise-response Surveys (often labeled "community response" or "annoyance" surveys) are social surveys that administer questionnaires to residents to measure residents' feelings about noise in their residential environments. These social surveys often, but not always, are accompanied by an **acoustical survey** that estimates the noise exposure from a noise source at the social survey respondent's residence.

The **respondent-level social survey dataset** contains a separate record for each respondent's questionnaire. The **original acoustical survey dataset** contains the most basic information about the noise levels and other characteristics of the noise events in the environment. The contents of this dataset vary greatly from study to study depending upon the strategy that is followed for estimating the long-term noise environment. Some studies measure exposure with a noise monitor that records all the relevant noises in a location. Other studies obtain operational information about the number of noise events of different types and then use models or samples of measurements to specify the acoustical characteristics of each event. The **derived acoustical survey dataset** contains estimates of characteristics of the noise environment that are summarized for some period of time for a particular location (for example, LAeq 24hr for the previous year at the center of a postal code area). A **social-survey/acoustical-survey linking procedure** uses geographic information about the residential locations to match each questionnaire with an estimated noise environment. The **combined respondent-level dataset** consists of a separate record for each respondent that has both the answers to that respondent's questionnaire as well as the estimated noise environment for that respondent's residence.

The information that has been captured in these studies is usually reported in one or more publications that discuss only the results from that study in a conference paper, journal article, or scientific report.

The Universe of Community Noise Response Surveys – A Survey Catalog

Several hundred noise response surveys, at least 628, have been conducted around the world since at least the 1940's. The most comprehensive list of these surveys appears in a series of successive catalogues that were supported by NASA (National Aeronautics and Space Administration) and then the FAA (Federal Aviation Administration) with the first catalog listing 200 surveys in 1980 (Fields, 1981) and the last catalog listing a cumulative total of 628 surveys through the year 2008 (Bassarab, Sharp, Robinette, 2009). The 628 surveys listed in the 2008 catalog are believed to represent all the surveys of residents' reactions to noise that were measured in a social survey and conducted in any language or country that produced reports in an English-language publication by December of 2008. Through the year 2000 catalog update (Fields, 2001) all such residential surveys were included. In the 2008 update, surveys of transportation noise sources continued to be added (e.g., aircraft, road, rail, etc.) but a smaller, unknown number of post-2000 surveys were not added which addressed industrial or other non-transportation noise sources.

The surveys vary greatly in the number of respondents, complexity, completeness of the reports and quality. The surveys vary enormously in the number of respondents with about 4% having fewer than 50 respondents and 40% having more than 1,000 respondents. Of the 628 surveys, approximately 78% estimated the noise exposure of their respondents' residences. The surveys also vary enormously in their complexity. The simplest are based on only 10 or 20 survey questions and included only a single noise metric (for example, DNL) while the more complex are based on 30-minute questionnaires that include over 100 survey questions that are combined with several 100 summary acoustical indices and, in some studies, observations about the characteristics of the residential environment (for example, housing conditions or relationship to a flight path). The survey publications range from four-page summary reports in Inter-noise conference proceedings (with little or no information about the survey data collection) to detailed several hundred-page reports which provide detailed methodological appendices. It is difficult to easily classify these studies by quality. Most are probably adequate for the purposes for which they were planned. However, uncertainties about details remain since the social surveys are often not conducted by social survey professionals and relevant statistics that link acoustical data to the estimates of the residential noise environment are not often reported.

The 2008 catalog of 628 surveys provides a convenient way to identify all the surveys for a given noise-source, country, year or sample size; to obtain some basic background on the methodological underpinnings; to locate all relevant methodological publications; and to determine whether publications are based on the same or different data sets. The main noise issues that were studied can also be identified for most surveys.

Storing Data from Surveys – Respondents – Archives – Multi-study Databases

Individual investigators analyze their respondent-level, combined social-survey/acoustical-survey data set to produce reports. Investigators differ in the extent to which they document their data sets and data set creation procedures for both the acoustical and social surveys. This in turn affects whether or not they could economically make their data sets available to others. Investigators also differ in whether or not they retain their respondent-level data file so that it can be used by others.

Different disciplines, including the social sciences, have tried to ensure that data will be available to others for future analyses. Several organizations have established **data archives** in which the respondent-level questionnaire datasets are deposited. For the social sciences such archives are expensive to maintain because they must not only store the information provided by investigators but also ensure that there is sufficient documentation for other researchers to understand and access the data. A number of large social survey archives operate around the world and, no doubt, contain some community noise-response surveys either with or without the accompanying derived acoustical summary measures which were not included in the questionnaire itself. An attempt was made in the 1980's to encourage noise researchers to deposit their combined social-acoustical-survey data sets in the SSRC Survey Archive in England, now named the UK Data Archive. There are currently 23 transportation-related noise surveys in the archive. However, the archive has not continued to acquire noise surveys – the most recent community noise-response survey in the archive was conducted in 1982. Data sets that are in an archive still require considerable effort to use since they are complex and may be difficult to understand.

If several surveys have been acquired, it is easier to conduct a unified analysis if a multi-survey data base is created. A **multi-survey database** is a single electronic file that contains data from multiple surveys with variables that are shared between the surveys. Such a multi-survey data base may contain only one or two variables or may contain a very large number of variables that are shared by many or all studies that are contained in the database. For social surveys generally, each record represents a separate respondent's questionnaire. These are more complex and information-rich data bases than Schultz and some others used with noise surveys where the each record represented an aggregate measure for a group of respondents.

The largest systematic, multi-survey database for community noise surveys has been constructed at TNO [Netherlands Organization for Applied Scientific Research (Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek)]. This database has data from more than 50 surveys for tens of thousands of respondents for over 50 variables. The database includes some data from all the surveys in the UK Data Archive. In order to create the data base the TNO researchers had to acquire the combined social/acoustical respondent-level data set from each country and thus, in effect, TNO also has a data archive. The TNO office is not, however, a public data archive and does not have the intake procedures, documentation, organization, staff, or budget to make data sets available to the public generally. It should be possible to work with TNO to utilize their data if a project was mutually agreed upon.

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5. Fields, Possible Future Research to Close Knowledge Gaps

(Prepared by Jim Fields March 16, 2010)

PERSONAL IMPACT RESEARCH (Annoyance, etc.)

Substantial progress might be made on a number of issues in the immediate future by secondary analyses of previous, respondent-level data sets. However, the steering group and workshop participants need to decide whether these reanalyses will provide sufficiently strong evidence to guide policy before the analyses are conducted. In some cases new surveys might be conducted to follow the reanalyses.

It is assumed that annoyance and other types of personal impact are important issues for only residential environments. Other projects would be recommended if it is important to examine the effects in workplace or outdoor recreation settings.

1. **Increased sensitivity to noise.** As described in the various FAA roadmap documents, one issue is whether dose/response planning curves need to be adjusted because the population has become more sensitive to noise in the last few decades.
   1) **Project A:** A reanalysis could make carefully controlled comparisons between the DNL/response relationships at two or more points of time around the same airport using the same method. Data sets are available that would permit such analyses with existing data around at least a few major airports. The possibility of including road traffic studies that have been conducted at different times in the same country should also be considered.
   2) **Project B:** Any new survey that is conducted around an airport that was previously surveyed should include a methodology that permits close comparisons with the previous survey.

2. E**qual energy principle in noise indices.** Discussion continues about whether or not LAeq adequately represents the relative importance of noise levels of individual noise events and the numbers of those events. Several types of projects might help to resolve this issue.
   a. **Project A**: Previously collected social surveys that measure both the numbers of aircraft and the levels (average levels) of the events could be reanalyzed. One major analysis was performed in the 1980's (Fields, 1984) but additional surveys have become available since then and new analysis techniques have emerged that are widely accepted. A part of such a project would be to develop a statistical tool that could determine whether a new survey could resolve this or other equal-energy index issues.
   b. **Project B:** New surveys could be conducted at multiple airports to provide better tests of the equal energy principle. This might be especially important if there are other types of aircraft noise environments that were not represented in previous studies. If a large number of suitable environments were located, more complex acoustical indices might be examined. Of course these and other surveys should not be conducted unless a statistical planning tool indicates that accurate estimates can be obtained from community surveys.

3. **Ambient noise impact.** A review of ambient noise studies found little or no effect of ambient noise on reactions to other noises. (Fields, 1998) Since that time additional studies have been conducted. Only a small amount of evidence was available at that time about reactions in rural areas.
    a. **Project A:** An updated meta-analysis of ambient noise studies could be conducted which would include an attempt to locate information about reactions in rural areas.
    b. P**roject B**: A new survey would be very likely to provide strong evidence on the effect of road traffic on reactions to aircraft noise. A survey might also be able to compare reactions to distant aircraft noise in remote suburban and urban environments.

4. **Reactions to changes in noise exposure:** Strong evidence is not available about the impact of step changes in aircraft noise on residents' annoyance. (But see Irene van Kamp and Lex Brown, Information Brief Excess Response in Annoyance from Step Changes & Policy Relevance). A NASA report provides a guideline for how to design a new survey, if suitable change situations can be identified far enough in advance of the change. (Fields, Ehrlich, and Zador, 2000)
    a. **Project A:** Plans for changes at airports could be monitored and new surveys could be conducted as opportunities arise. These studies should monitor both changes in annoyance and changes in public actions over the course of a noise-exposure change. If there will in fact be very few abrupt changes, it may be that studies should be conducted even if the changes are gradual and extend over several years.
    b. **Project B:** Reanalyses could be conducted of previous surveys of reactions to changes in aircraft and road traffic noise. This may not yield very much improvement in estimates of change effects for aircraft noise, but could provide additional information about the extent to which existing or future road traffic noise studies could provide evidence that is relevant for aircraft noise change studies.

5. **Aircraft-specific dose/response curve:** Reanalyses of existing survey data have consistently shown differences between reactions to different noise sources. (Fields and Walker, 1982, Miedema and Vos, 1998) Most comparisons show that aircraft are most annoying and railways least annoying, but Japanese studies display a different pattern. (Yano, Murakami, Kawai, and Sato, 1998;Yano, Sato, and Morihara, 2007) If it is concluded that new surveys in the United States are needed to update the aircraft relationship several projects would be useful.
    a. **Project A:** Reanalyzing the data from previous surveys could provide direct estimates of aircraft impacts and statistical parameters that would guide the design of new surveys
    b. **Project B:** New surveys around airports in the United States could provide convincing evidence for updating a dose/response relationship if the study was conducted in a large number of neighborhoods around many airports and the study examined characteristics of local areas that could affect reactions.

6. **Time-of-day weighting:** DNL has a nighttime penalty. If sleep disturbance were protected with another metric, it is not clear that a nighttime weighting can be justified on the basis of

survey data. However, such weightings are so widely used in noise indices that the FAA may not want to consider alternatives, especially when the evidence is not likely to be definitive.

   a. **Project:** At least two reanalyses of social survey data nighttime weightings have been conducted that came to different conclusions. (Fields, 1986;Fields, 1992, Miedema and Oudshoorn, 2001) Additional data have become available since those analyses. A new analysis might better evaluate the evidence for a time-of-day weighting and more clearly determine whether a new field survey would be useful.

CLEAR COMMUNICATION

7. **Communicating acoustical information:** This is a topic that has not been explored in previous noise research but might yield valuable results. It is sometimes assumed that the public cannot understand the equal energy principle and that the public will always be confused by DNL and other acoustical concepts. Communication experts who do not necessarily have acoustical expertise should direct or be heavily involved in defining such a project. Research perspectives from outside the acoustical community might discover that new, more effective approaches might be used such as some type of interactive, computer-based exercise. Communication experts might recommend programs such as the following:
   a. **Project A:** If studies have not been performed before, it would be useful to carefully examine public meetings and other public discourse on acoustical regulations to try and understand the major communication problems and possible solutions. It would also be useful to compare different acousticians' approaches to these problems.
   b. **Project B:** With the knowledge gained in Project A, new laboratory or small group research could be conducted to determine what types of presentations or other exercises are most effective at helping people understand acoustical concepts.

PUBLIC ACTION

8. **Comparison of annoyance (personal impact) and complaints (public action).** Some early surveys provided some evidence about the differences and similarities between personal impact and public action. New work could provide clearer and more definitive information.
   a. **Project A:** A reanalysis of some existing social survey data sets could determine to what extent complaints may represent or misrepresent the underlying impact of noise on residents. This analysis would compare the characteristics of respondents who reported annoyance with the characteristics of the respondents who reported having made complaints or otherwise engaged in public action. This information would help to determine what the strengths and weaknesses of complaint information may be.
   b. **Project B:** To further understand the relationship between complaints and underlying annoyance, the FAA might identify ongoing and previous annoyance surveys and then obtain records of complaint data for neighborhoods in the survey areas. This would provide another source of information about the conditions under which complaint actions are more or less accurate representations of the underlying annoyance experienced in a community.

9. **Community and acoustical factors that explain public actions.**
The factors that explain public actions against noise have not been systematically and scientifically studied. A frequently cited graph of community response by adjusted noise level from a 1950's Wyle study is not clearly based on sound scientific methods. (Wyle Laboratories, 1971) It is difficult to see just what objective, scientific coding scheme could have produced the graph. Nonetheless, a graph from this study is one of the most cited graphs in the entire noise control literature. It would be useful to design a scientifically sound, research project be to relate these, or similar measures of public actions to noise level for a statistically sound sample of airports.
    a. **Project:** As suggested above, new research could uniformly collect information about a wide range of community variables for all large airports in the United States and for a stratified random sample of smaller airports. This research would obtain community-level information from officials, knowledgeable informants, and documents. Acoustical data could also be examined, but it seems unlikely that this project would provide very much information about the effects of noise exposure itself because noise exposure varies greatly between subareas around airports while the actions themselves are not tied to a particular subarea. Research of this type requires very little acoustical knowledge, but should draw on areas of social science expertise that examine community conflicts and organization.

10. **Community /airport interactions.** Research projects have not systematically examined the methods for mediating community/airport conflicts.
    a. **Project A:** Conducting case studies of airport community relations could identify hypotheses about procedures that would most efficiently manage airport/community conflicts.
    b. **Project B:** Follow-on studies or real time monitoring of such conflicts might provide guidelines for managers' and communities' actions around airports. As with the previous topic, the primary expertise required for this work comes from the social sciences not from acoustics.

SLEEP DISTURBANCE

11. **Relationship between sleep disturbance measures.** If possible, we need estimates of the relationships between the different measures of sleep disturbance. This might help in choosing metrics for a FAA study, but more importantly could provide a basis for linking previous studies.
    a. **Project A:** Conduct meta-analysis of both noise studies and sleep disturbance studies generally to determine how accurately the values of different sleep disturbances can be estimated from other sleep disturbance measures. For example, what is the best estimate of ECG arousals from signaled awakenings (behavioral awakenings)?
    b. **Project B:** Acquire data sets and conduct secondary analyses of the relationship between different metrics for any studies that did not fully analyze such collected data.

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(Note: The six-character abbreviation following some references is the identifier for the associated survey in a 2008 community response survey catalog.)

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JPN-565

6. Van Kamp and Brown, Excess Response In Annoyance From Step Changes & Policy Relevance

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The Issue:

An extensive review of studies of human response to a change in transport noise (Brown and van Kamp, 2009a) suggests that response to a step change in exposure includes both an exposure effect and a change effect. The change effect is manifest as an excess response to the new noise exposure additional to the response that is predicted from steady-state exposure-response relationships. The excess response (the excess disbenefit arising from an increase in exposure, or the excess benefit arising from a reduction in exposure) can be greater, often much greater, than that due to the change in noise levels itself (as estimated from the exposure-response curves). The available evidence is that the effect is persistent—even years after the change.

The studies reviewed included: road, air and rail sources; increments and decrements in level; the majority were step changes, but some were of gradual and even temporary changes. Many of the studies involved substantial changes in level (5 dB or more), though some considerably smaller changes. Part of the conflicting results from different analyses of change may result from the bundling together of studies in which the step change in level had been large and others where the changes has been minimal, temporary or gradual.

Significant change effects were observed in the roadway studies. These estimates of large excess responses to change have been confirmed in two large, recent studies around EU major airport, but overall no significant change effect was found in the airport studies.While this could be attributed to a difference in response to change between aircraft sources and roadway sources, the more likely explanation is that it is due to the limited nature of the changes available to date in most of the earlier airport studies (which have been small, gradual or temporary).

Policy Implications:

Should excess response to change be of concern to policymakers – and if so should it be addressed in environmental assessments of infrastructure projects? Secondly, are there implications of the different potential explanations of change effects for interpretation of existing exposure-response relationships for transportation noise?

Within the limitations of existing evidence that we have documented, the magnitude and persistence of a change effect over time (Brown and van Kamp, 2008a), and the existence of several plausible (though as yet inadequately tested) explanations for it (Brown and van Kamp, 2008b), suggest that it is a real effect that must be taken into account in assessing the response of communities where noise levels change. Communities that experience an increase in noise exposure are likely to experience much greater annoyance than is predicted from existing exposure-response relationships, and communities that experience a decrease in exposure experience greater benefit than predicted. Policy makers need to be informed of the likelihood of a change effect, particularly as situations in which noise levels may increase as a result of infrastructure changes are generally always contentious. To do otherwise would be to deny them important scientific information regarding the way in which a community is likely to respond in situations of change in levels.

If changing attitudes to the source/authorities proves to be the explanation of the change effect, there is the potential for considered interventions to be used as an instrument to reduce noise annoyance of affected populations in situations of change. Transparent information/communication about the noise changes could positively affect attitudes and expectations of the community. Evidence of the existence of a change effect demonstrates that this should not be perceived merely as manipulative public relations, but a bona fide and positive contribution to managing the magnitude of the annoyance responses of the community subject to the change.

A *differential response criteria* explanation has much wider implications. It raises the question that there may be measurement error across the generalized exposureresponse curves. The latter are always based on responses of people who have been exposed “in the steady-state” to particular noise levels. The explanation suggests that measurement error may be present in all steady-state situations, but revealed only in situations of change. The consequence, from the direction of the change effect, is that the gradient of an exposure-response curve adjusted for this purported error would be much steeper than that of currently used steady-state curves.

Further studies involving change at airports will be necessary to examine whether there might be any difference between response to change for different transport modes, although a difference in mechanisms is not deemed plausible. Our clarification of potential mechanisms for the change effect provides a structure for the design of future studies of change, and guidance as to what needs to be measured in longitudinal studies to overcome weaknesses in the existing set of studies/data in testing, not only to confirm the existence and durability of an excess-response change effect, but also the various hypotheses to explain it.

References (the following review papers cite an extensive list of relevant literature, including seven previous reviews of change studies):

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7. Fidell, Brief on Aircraft Noise-Induced Annoyance

Prepared by Sanford Fidell

Annoyance, a common reaction to the noise of aircraft operations, has been studied extensively for the last half century. Annoyance is known to be influenced by all of the primary physical characteristics of noise, such as sound level, duration, frequency content, and number and time of occurrence of noise events. Annoyance can also be influenced by a range of second-order characteristics (*e.g.*, tonality, impulsiveness, audibility, and rise time), not to mention by a range of non-acoustic factors, including novelty, control, and the identity and meaning of noise events.

In the laboratory, individual annoyance can be quantified by classical psychophysical and modern methods. In community – that is, residential – settings, transportation noise annoyance is assessed by self-report through social survey techniques. Relatively few of the hundreds of studies of the annoyance of transportation noise have been sufficiently well designed and documented to support systematic analyses of the annoyance of aircraft noise. Several well-known meta-analyses of these data have nonetheless been conducted, including those of Schultz (1978), Fidell *et al.* (1991), Miedema and Vos (1998), and Fidell and Silvati (2004).

Fields (1993) has shown that demographic factors such as age, sex, social status, income, education, home ownership, dwelling type, and length of residence have no reliable effect on reports of noise-induced annoyance. Brooker (2008) concludes that some indications can be found of increased sensitivity to transportation noise exposure over the last 25 years, but that the statistical evidence for an upward trend is weak, and may simply be due to sampling and/or methodological differences among studies.

In its 1992 report, the U.S. Federal Interagency Committee on Noise (FICON) identified annoyance as its preferred "summary measure of the general adverse reaction of people to noise," and described "the percentage of the area population characterized as 'highly annoyed' by long-term exposure to noise" as its preferred measure of annoyance. FICON (1992) also endorsed a specific dosage-effect relationship between a measure of long term noise exposure (Day-Night Average Sound Level) and the prevalence of high annoyance. This relationship permits community response to transportation noise to be treated, for policy purposes, simply as a particular transform of DNL: $100/(1+e^{(11.13-0.141\,L_{dn})}$.

FICON considered this relationship to be appropriate for assessing community noise impacts of all forms of transportation noise, and indicated that "the DNL methodology" (*i.e.*, its preferred dosage-effect relationship) was the basis for its judgments about the acceptability of noise exposure, as expressed in the agency's "land use compatibility" recommendations.

Several limitations of FICON's views have become evident in the years since publication of the FICON report. First, FICON's fitting function systematically underestimates the prevalence of high annoyance due specifically to aircraft noise (Miedema and Vos, 1998; Fidell, 2003; Fidell and Silvati, 2004), particularly in the range of noise exposure levels of greatest practical interest for regulatory purposes. Second, the relationship accounts for relatively little of the variance in the social survey data on which it is based (Fidell and Silvati, 2004). Third, it ignores the influences of non-acoustic factors on annoyance (Job, 1988; Fidell *et al.*, 1988). Further, because FICON's relationship lacks obvious inflection points, it is not self-interpreting for policy purposes. Definition of any particular value of noise exposure as a "significant" noise impact is thus inescapably arbitrary, and must be made on nontechnical grounds.

The International Standards Organization (ISO) is currently attempting to identify an improved method for predicting the prevalence of aircraft noise-induced annoyance. Two goals for this effort are 1) to increase the accuracy of prediction of annoyance prevalence rates, and 2) to quantify the precision of such estimates so that they can be used more appropriately in environmental impact assessment documents.

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8. Woodward & Mestre, "Is the Schultz Curve Still a Useful Measure of Community Annoyance with Aircraft Noise?"

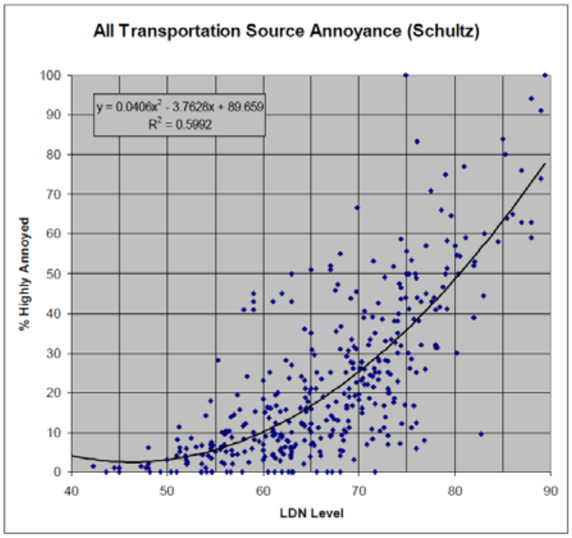
(An extended discussion of this topic by Woodward and Mestre will be made at the March 4, 2010 workshop.)

Jon M. Woodward and Vincent Mestre
December 8, 2009

When Theodore Schultz developed his synthesis of the literature addressing the relationship between noise generated by transportation sources and human annoyance[1], he was limited to studies conducted prior to 1976. Because the data was available in a variety of forms, using several different noise metrics, and different descriptions of the level of human annoyance found, Schultz normalized the data to provide a relationship between Ldn and percent of the population highly annoyed by noise. The resulting "Schultz curve" has become entrenched in the evaluation of aircraft noise impacts in US aviation evaluations since its publication in 1978. The Schultz data are presented in Figure 1 along with a second order polynomial curve fit (the original Schultz paper used a different curve fit to the data that is not shown here).

The Schultz curve incorporates data from aircraft, rail and highway noise sources. Consider that the noise data used in developing this dose-response relationship dates from the early 1960's through the mid 1970's. During this time the uncertainty associated with the noise exposure, whether by measurement or modeling, is unknown but would be quite large given the technology available at the time. When considering the Schultz curve, it is useful to keep in mind that the noise dose data may have uncertainty of 5 dB or greater.

Figure 1



[1] Theodore H. J. Schultz, "Synthesis of Social Surveys on Noise Annoyance," Journal of the Acoustic Society of America, Volume 64, pages 377-405 (August, 1978).

Research Questions Regarding Annoyance

Observation: Many decisions about noise abatement and management are being based on annoyance data that is more than 33 years old, does not reflect aviation noise exposure. When noise evaluations have been conducted in the last 30 years, only a few have evaluated the effect of noise at general aviation airports. Nonacoustics factors have been shown to have an influence on annoyance response[2,3] . These non-acoustics factors, such as fear of an aircraft accident and distrust of government may be as important as noise level in determining annoyance response and may be the reason that dose – response data show such a large amount of scatter.

Concern: If United States noise abatement policy and federal tax dollars are going to be expended to manage noise at United States airports, what justification is there to base policy decisions on non-aviation data, drawn largely from studies conducted outside the United States. Shouldn't U.S. policy be driven by U.S. conditions when that policy addresses U.S. mitigation of locally based concerns?

Proposal: We propose that a comprehensive survey of persons residing around American airports be conducted to determine an unbiased level of annoyance with aircraft noise. The proposed survey should include areas around airports that have experienced controversial development, as well as areas that have had stable environments and little controversy over the past decade. The survey airports should include airports of several sizes and missions. Noise level and number of aircraft operations should be treated as independent variables in evaluating dose – response relationships.

[2] Fields, J., "Effect of Personal and Situational Variables on Noise Annoyance: With Special Reference to Implications for En Route Noise," NASA and FAA, CR-189676 and DOT/FAA/EE-92/03, 1992.
[3] RIVM, "Geilenkirchen Air Base Perception Survey, Perceptions of Residents in The Netherlands," 2008.

9. Luz, Potential Role of In Situ Studies in the FAA Roadmap for Research on Aircraft Noise Annoyance

George A. Luz

Introduction: The following paper has been written in response to issues raised during a workshop held by the FAA in Washington DC on December 10-11, 2009. The intent is (1) to share the author's experience with *in situ* studies of noise annoyance and (2) suggest ways that an *in situ* study of aircraft noise annoyance could resolve questions which social surveys cannot.

Definition: An *in situ* study of noise annoyance differs from a social survey in that subjects are asked to provide feedback on the annoyance of individual sound events as they experience them (1) in their own home and (2) over a period of days. This paradigm differs from a social survey in which interviewees are usually asked to rate their annoyance of the past year. The paradigm differs from a laboratory study in which subjects provide feedback on the annoyance of individual events in an artificial setting.

Examples of *In Situ* Studies: I became interested in this type of study because my job with the U.S. Army required me to understand and predict community response to high intensity impulsive sound. This type of exposure differs from the exposure around airports in that (1) the daily number of intrusive sound events are fewer and (2) the day-to-day variability in the intensity of the sound events is greater. One of the early contributions to understanding this subject was a study of quarry blast annoyance funded by the U.S. Bureau of Mines to Bolt, Beranek and Newman (Fidell *et al*. 1982). In this report, the authors designed and tested a "real time annoyance study" in which instrumentation designed to measure the sound level of individual events was coupled with a computer-controlled interview. This concept was later picked up by U.S. Army researcher, Paul Schomer, in a study comparing the annoyance of helicopter noise with railroad noise among people exposed in their homes to both (Schomer and Wagner, 1996). I used this paradigm in a study of heavy weapons noise annoyance with four complainants living on the eastern shore of the Chesapeake Bay across from Aberdeen

Proving Ground (Luz *et al*. 1994). Currently, the U.S. Army Construction Engineering Research Laboratory is conducting an *in situ* study of blast noise annoyance which corrects the shortcomings of my 1994 study.

Advantages of *In Situ* Studies: An option being considered as part of the FAA road map is the analysis of existing social surveys of aircraft noise annoyance. In the past, I have been a proponent of this approach. However, after reading a relatively recent aircraft noise annoyance survey from Korea (Lim *et al*. 2008), I have come to realize that this approach can lead us to ignore important information. In this example, the important information concerns the role of ambient noise.

In 1992, I represented the Army Medical Department on the Federal Interagency Committee on Noise (FICON). In the course of that role, I was asked to write the section of the FICON report dealing with the importance of ambient noise on the annoyance of a given level of day-night average sound level (DNL). As stated in Appendix D of the US Environmental Protection Agency (USEPA) "Levels Document," the ambient background accounts for a twenty (20) decibel range in community response to a given level of DNL (USEPA, 1974). Consistent with the predictions of the model put forward by the USEPA was the community response from rural areas of New Jersey and New York to the FAA's Expanded East Coast Plan (Wesler, 1989).

As I was writing this section of the FICON report, I was also in possession of a draft meta-analysis of social surveys from Jim Fields in which the ambient background had little or no effect on annoyance. As stated in a later refereed publication of Fields' analysis, "*57,000 interview responses to 35 noise sources in 20 social surveys and reviews of publication for over 12,000 additional responses to 16 noise sources in 13 social surveys show that residents' reactions to an audible environmental noise source (a target noise) are only slightly reduced by the presence of another noise source (ambient noise) in residential environments*." "*A 20 dB increase in ambient noise exposure has no more impact than a 1 dB increase in target noise exposure* (Fields, 1998)".

Faced with this disparity between two measures of behavior – collective community action and personal annoyance – I wrote a section of the FICON report stating that ambient was important for community response but not important for annoyance. I then called the expert who had written Appendix D of the USEPA report, Ken Eldred, at his retirement home on the coast of Maine and read my proposed text for his approval. As a psychologist, I was uncomfortable with the disparity between community response and personal annoyance, but I had such great respect for the competence of both experts that I did not question the conclusion, at least not until the publication by Lim *et al,* 2008). In this Korean survey of aircraft noise, ambient background did have a statistically-significant effect on annoyance.

From this experience, I have come to the conclusion that meta-analysis can be insensitive to the subtle variables underlying aircraft noise annoyance. In particular, the survey is a rather poor way to understand the dynamics of the psychological processes which distinguish the person who is up in arms about aircraft noise and leading the charge against any expansion of operations at their local airport from a person who is relatively unconcerned about noise from their local airport.

Proposal for an *In Situ* Study of Individual Differences. One of the important unknowns in the study of noise annoyance is the psycho-physiological process by which the individual remembers annoyance. From studies of step-wise changes in average daily exposure at three general aviation airports, it is known that people can make orderly judgments of their annoyance over the past week and past year (Fidell *et al.* 1985), and from the controlled study of helicopter noise published by Fields and Powell (1987), it is known that people can make orderly judgments of annoyance over the past day. What is not known, however, are the rules by which individuals integrate the annoyance of each intrusive aircraft sound during the day to arrive at an experience which they recall when a interviewer asks them to rate their annoyance.

Within the U.S., we continue to operate on the assumption that the best rule is equal energy, and the Fields and Powell study of the annoyance of 1 to 32 daily helicopter flights confirms this rule. Another rule which has been put forward by a group of researchers at the University of Gothenberg is that people keep an unconscious tally of the number of aircraft events greater than 69 dBA during the course of their day. In a study at an airport where the daily numbers of operations were less than seventy, Rylander and Björkman (1997) demonstrated the validity of this rule. Their curves are just as orderly as those of Fields and Powell (1987).

Where the difference in these psycho-physiological models occurs is with environments where the daily number of events in excess of 69 dBA exceeds seventy per day. The University of Gothenberg group believe that there is a breakpoint where the typical person stops tallying the number of events and just remembers the noisiest events (Rylander and Björkman, 1988) The equivalent level model has no place for a breakpoint. On the surface, it might seem reasonable to conduct a "round robin" test between these two models using data from noise surveys. In practice, any differences between these two models are likely to be undetectable through social survey data because of variability in personal and situational variables (Fields, 1993), variability in the times when interviewees are actually at home to hear aircraft noise, and difficulties in specifying the true interior acoustic environment for each interviewee. Because an *in situ* study looks at only one individual at a time, the error variance associated with individual differences can be eliminated.

Refinements of *In Situ* Study In choosing a location to conduct such a study, it would be advisable to avoid communities where there is already a controversy over existing or proposed operations. Beyond that, it would be desirable to conduct the study with people who fall at the extremes of noise-sensitivity. One of the unknowns about noise sensitive people is whether they experience all intrusive noise events as more annoying than others or whether they are just more reactive to the noisiest events.

Application of Findings The proposed research falls under the category of applied research. It is not being proposed simply to collect academic knowledge. As suggested in a previous paper, there is a weakness in the current practice of presenting the public with a "one size fits all" noise contour (Luz, 2004). The fact that a house is located in an area where aircraft noise exposure is below DNL65 does not mean that everyone will be satisfied with the acoustic environment. By understanding the process by which people become annoyed, government will be in a better position to provide citizens with the information which they need in order to decide on whether to live in a noisy neighborhood.

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10. Hume, Rationale & Value for conducting research to develop a standardized complaint handling system (SCHS)

9 Feb 2010 (Dr Ken Hume)

The problem of aircraft noise disturbance involves a complex interaction of a number of physical, biological, psychological and sociological processes. The public response to noise disturbance is an equally complex issue. Complaining is usually accepted to be a result of focused annoyance and has been interpreted as a coping strategy to deal with the actual or perceived psychological harm of the stressor. However not all complaints are formalized by transmission to authorities who are either responsible for the production of the stressor eg. Airports, or can act on behalf of the complainant, eg. Politicians, media or environmental health agencies.

Across the world many thousands of formal complaints are generated every year about noise due to transportation systems particularly aircraft noise but there is no single methodology available to capture and evaluate this freely provided data stream in order to better understand the issues and mitigate the impact. Complaints give direct insights into the impact of airport operations on its community neighbours, particularly in terms of the level of annoyance and tolerance. Usually the complaint rate is the first and most obvious index of public action in response to the noise impact of airports, particularly in response to change.

There has been limited complaint research work carried out compared with social surveys which give more representative data from the community but are time specific ie. Snap shots. It is surprising that complaint analysis is limited as the numbers of complaints are frequently a major consideration in planning applications and legal proceedings. However, the raw number of complaints on their own is of questionable value and frequently there can be many interpretations made of the data depending on the standpoint and motivation of the reporter.

The value of conducting research into complaints systems which could produce industry (airports) standards for protocols and formats for systematically gathering, analyzing and reporting complaints is listed below. In essence, it is an attempt to extract the most information from this freely provided data with an aim to further understand annoyance and complaint motivations:

- Provides a continuous index / timeline of the level of disturbance/tolerance of the community from a given airport
- Provides rapid feed-back on operational nuisance in a specific area
- Provides relatively cost-effective (complaints offered free) feedback, but setting-up and running costs

- New technologies (GPS/GIS) are available to identify locations and spatial patterns of particular concern, and changes in patterns
- Provides a time-course with trends and peaks so the affect of operational changes (eg. Continuous descent approach) and initiatives can be assessed
- Allows comparison of noise (and other) impact within and between airports with the application of standardized metrics (eg. Complaints per ANE (aircraft noise event) per population over-flown)
- Acts as a community 'pressure valve' to vent frustration besides a source of information - allows residents a behavior that may help them to cope with the impact/nuisance
- By applying a standardized general methods for receiving and dealing with complaints and utilizing metrics which control for variations in eg. Number of flights, serial complainers, time of day of flights, noise level at ground level and number of people over-flown it may be possible to meaningfully compare the tolerance levels and changes at different airports
- By appropriate design of the complaint report (or follow-up) it should be possible to ascertain what aspect of the noise (eg. Vibration & rattle) and /or what behavioral affects (eg. Wake-up from sleep, interference with communication) has the most negative impact
- Use the SCHS to improve relationships and dialogue with the surrounding communities

This work could involve:

- Review of aircraft noise complaint literature
- Formation of scientific team with inputs from all stakeholder experts
- Survey of key airports (eg. Large, medium, small) current methods to ascertain views and requirements and build examples of 'good practice'
- Develop model based on above
- Trial model and refine
- Monitor operation, appraise and revalue

11. Fidell, Information Brief on Aircraft Noise Complaints

Prepared by Sanford Fidell

Large airports may receive thousands of annual aircraft noise complaints. Complaints typically concern acute or unusual noise events (*e.g.,* “extremely loud overflight”, “aircraft flying off-course/too low/too late/too early”, and the like). Complaints are also sometimes received, however, about cumulative noise exposure conditions (*e.g.,* “too much aircraft noise this morning”) as well.

On a day to day basis, airports are generally more concerned with this complaint behavior than with estimated annoyance rates. Nonetheless, the formal U.S. federal approach (*per* FICON, 1992) to assessing aircraft noise impacts is based on the predicted prevalence of noise-induced annoyance, as estimated from time-weighted average sound levels (DNL). The inconsistency between federal policy and local practice is exacerbated 1) by the lack of any predictive relationship between cumulative noise exposure and complaint behavior[4], and 2) by frequent complaints received from residents of federally-defined areas of “compatible” land use. The majority of complaints lodged with many airports are made by people who live beyond the L_{dn} = 65 dB noise exposure contour that is considered for federal purposes as the threshold of significant noise impact (GAO, 2001).

In reality, complaints and annoyance may simply be two sides of the same coin, since in practice, both are forms of self-report of adverse aircraft noise effects. Complaints are usually immediate, unsolicited self-reports, often about acute conditions[5]. Annoyance, as measured by questionnaire items which encourage respondents to consider cumulative exposure (as for example, by inquiring about annoyance “while you’ve been at home over the past year”), is a delayed form of solicited self-report.

Federal dismissal of complaints as a useful measure of adverse impacts of aircraft noise is based on FICON’s (1992) observation that “Annoyance can exist without complaints and, conversely, complaints may exist without high levels of annoyance.” It is just as true, however, that high levels of annoyance can exist at low levels of noise exposure, and low levels of annoyance can exist at high levels of noise exposure. Logically, the lack of a clear relationship between complaint rates and cumulative noise exposure is no more of an impediment than the great variability of annoyance prevalence rates for the same exposure levels to considering complaints as an indication of community response to aircraft noise.

Complaints are often regarded as unreliable indicators of community response to noise because small numbers of individuals can lodge large numbers of complaints. In reality, it has

[4] Since the prevalence of annoyance is, for all practical federal purposes, merely a mathematical transform of DNL, the lack of any relationship between complaints and DNL seems to imply a lack of any relationship between annoyance and complaints.

[5] This distinction may be somewhat strained, however, because although a single noise event may serve as the trigger for lodging a particular complaint, complainants may also be chronically annoyed by aircraft noise.

long been known that chronic complaining is the exception rather than the rule. The modal ratios of complaints to complainants in large complaint databases are quite modest – often on the order of one or two annual complaints per complainant (Fidell and Howe, 1998). Large numbers of complaints from a few complainants are easily identified outliers that may simply be excluded from analysis.

Despite the importance of complaints to airport administrations, airports typically make little systematic use of complaint information beyond plotting the locations of complainants' homes and periodically summarizing numbers and types. Modern airport noise and operations systems permit more insightful uses of complaint information, such as drawing of complaint density contours (*cf*. Fidell, 2003). These same databases can also support a range of sophisticated analyses of the dependence of noise complaints on numbers, times, and types of aircraft operations and flight path distributions (*e.g*., density, variability, altitude, *etc*.) with respect to geographically-weighted demographic information (*cf*. Fidell and Howe, 1998). Complaint information can also be used to independently estimate the non-acoustic component of reported annoyance with aircraft noise exposure, and to quantify the sensitivity of complaints and time constants of arousal and decay of complaints following operational changes that alter flight paths.

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B. SLEEP DISTURBANCE

12. Vincent Mestre - Chapter 4: Sleep Disturbance and Aviation Noise, ACRP Synthesis 9 "Effects of Aircraft Noise: Research Update on Selected Topics"

Most noise-exposed populations especially in the vicinity of airports cite sleep disturbance as a common complaint. Protection of a particular sleep period is necessary for overall quality of life. Sleep may be quite sensitive to environmental factors, especially noise, because external stimuli are still processed by the sleeper's sensory functions, although there may be no conscious perception of their presence.

The large amount of research published during the last 30 years has produced considerable variability and often controversial results. For example, in establishing the effect of aviation noise on health, the absence of one internationally accepted exposure-effect or dose-response relationship is largely the result of a lack of one obvious "best choice" research methodology, as well as to the complex interactions of many factors that influence sleep disturbance, including the differences of the noise source and the context of the living environment. Current exposure-response relationships use either awakenings or body movements to describe sleep disturbance.

Several studies suggest that either sound exposure level (SEL) or maximum noise level (Lmax) are better predictors of sleep disturbance than long-term weighted averages [equivalent sound level (Leq)], day-evening-night average noise levels (Lden), community noise equivalent level (CNEL), DNL, or equivalent noise level for night (Lnight). A survey of the literature also shows large differences between results from numerous laboratory studies and those from epidemiological or experimental studies made in real, in-home situations. The landmark study by Ollerhead et al. (1992) clearly identified a difference between laboratory and in-home studies of sleep disturbance, with the in-home data showing it takes considerably more noise to awaken people than data collected in the laboratory studies, and that the agreement between actimetrically determined arousals and electroencephalogram (EEG)-measured arousals were very good (Ollerhead et al 1992). It summarized by stating that "once asleep, very few people living near airports are at risk of any substantial sleep disturbance resulting from aircraft noise, even at the highest event noise levels."

Later studies by Horne et al. (1994) document a landmark in-home field study that demonstrated dose-response curves based on laboratory data greatly overestimated the actual awakening rates for aircraft noise events. In 1995, Fidell found that SELs of individual noise intrusions were much more 12 closely associated with awakenings than long-term noise exposures (Fidell et al. 1995). These findings do not resemble those of laboratory studies of noise-induced sleep interference, but agree with the results of other field studies. Importantly, the study also concludes the relationship observed

. . . between noise metrics and behavioral awakening responses suggest instead that noise induced awakening may be usefully viewed as an event-detection process. Put another way, an awakening can be viewed as the outcome of a de facto decision that a change of sufficient import

has occurred in the short-term noise environment to warrant a decision to awaken (Fidell et al. 1995).
This is an important observation that leads to suspicion of any assumption about the independence of noise events made in the pursuit of estimating total awakenings.

In 1989, a comprehensive database representing 25 years of both laboratory and field research on noise-induced sleep disturbance was the basis for an interim curve to predict the percent of exposed individuals awakened as a function of indoor A-weighted SEL (Finegold et al. 1992). This curve was adopted by FICON in 1992. Since publication of the FICON report (Federal Interagency Committee on Noise 1992), substantial field research in the area of sleep disturbance has been completed. The data from these studies show a consistent pattern, with considerably less percent of the exposed population expected to be behaviorally awakened than laboratory studies had demonstrated. As a result, the Federal Interagency Committee on Aviation Noise (FICAN) published a new recommendation in 1997. Interestingly, the FICAN curve does not represent a best fit of the study data, but rather is constructed to represent the out boundary of the data (FICAN 1997).

In summary, although the most common metrics for assessing the impacts of DNL, Lden, or CNEL already contain a 10-dB penalty for night-time noises, there are circumstances where a separate analysis of the impacts of night-time transportation noise is warranted. There are, however, different definitions of sleep disturbance and different ways to measure it, different exposure metrics that can be used, and consistent differences in the results of laboratory versus field studies. At the present time, very little is known about how, why, and how often people are awakened during the night, although it is generally acknowledged that the "meaning of the sound" to the individual, such as a child crying, is a strong predictor of awakening. Although different models can estimate various metrics, there is substantial controversy associated with how to apply and interpret these studies. Current research has focused on measuring in-home sleep disturbance using techniques not available in 1985. In-home sleep disturbance studies clearly demonstrate that it requires more noise to cause awakenings than was previously theorized based on laboratory sleep disturbance studies. Recent studies have cautioned about the over-interpretation of the data. This is contrasted with recent efforts to estimate the population that will be awakened by aircraft noise around airports. Research may not yet have sufficient specificity to estimate the population awakened for a specific airport environment or the difference in population awakened for a given change in an airport environment.

13. Griefahn and Basner, Aircraft noise effects on sleep

Prepared by Barbara Griefahn and Mathias Basner

1. Aircraft noise effects on sleep

a) Describes *evidence that aircraft noise affects sleep (i.e., sleep intensity, continuity, and/or duration) and models that have been developed to establish relationship between aircraft noise exposure and sleep; states sufficiency and policy relevance.*

Continuity. There is sufficient evidence shown in laboratory and in field studies due to which single aircraft noise events (ANE) evoke autonomic, motoric (movements) and cortical arousals, sleep stage changes and awakenings. Respective reports are numerous and go back to the 60s (e.g. Basner, Griefahn, Lukas, LeVere, Muzet, Passchier-Vermeer).

Several dose-response curves describing the probability in relation to the noise load expressed in LAmax or SEL were calculated. They are congruent insofar that increasing levels (SEL, LAmax) cause higher percentages of the effects in question. The steepness of the ascents of the dose-response curves deviate, however, in a wide range due to the various effects considered (EEG-awakening, behavioural awakening, motility) and the large variety of variables moderating the effects of noise on sleep. Nevertheless, as far as these curves are based on a sufficient number of observations (Basner - EEG awakenings, Passchier-Vermeer - motility) the dose-response relations can be taken as a basis for the definition of exposure limits. In the past these decisions were primarily done on the basis of the noise load. This is problematic as shown by Basner et al. (for example see Figure 1). If protection limits refer primarily to the effects i.e. the probability of awakening, than the protection areas differ considerably from those defined by integrated measures such as the equivalent noise level.

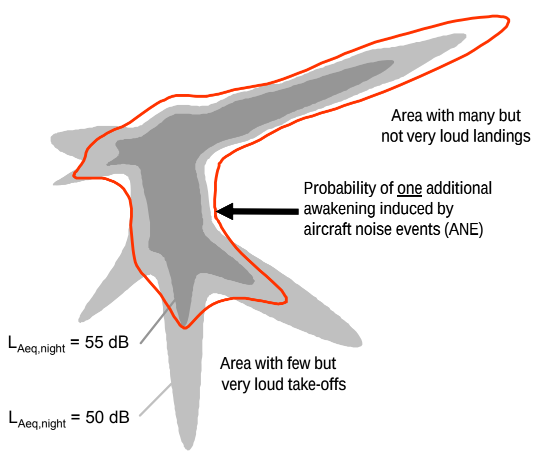

Figure 1: Protection areas defined by equivalent noise levels (L_{Aeq}: 50 dB, 55 dB) and by one additional awakening (Basner et al.).

Sleep intensity. The term 'sleep intensity' is here certainly understood as sleep depth. Alterations of sleep depth were more or less regularly reported in several studies. Deep sleep (slow-wave-sleep, SWS), that in young healthy adults amounts to about 20 % of the sleep period time is reduced due to nocturnal noise. The loss is, however, usually rather moderate, amounts to not more than a few minutes, and does not necessarily show a strict dose-response relation. In nights with indoor levels of aircraft noise varying between 39 and 50 dBA the average loss was for instance 2.5 minutes (see Table below, Griefahn et al.) This small decrease is in accordance with reports of other authors (e.g. Basner et al.).

Methodological remarks: The alterations of sleep depth as a criterion for the limitation of nocturnal noise are problematic. First, a major reason for this small effect might be related to the rules for sleep staging (Rechtschaffen & Kales). Deep sleep (sleep stages S3 and S4) is by definition reached if at least 20% of an epoch (30-s-period) consists of low frequency waves (≤2 cps) of high amplitudes (≥75 µV). So, if a person produces 100% of these Delta waves, a reduction of 80% would be dramatic but would not count as an alteration of sleep depth. (These alterations would be detected by alternative evaluation methods that base on frequency-amplitude analyses.) Second, deep sleep decreases with increasing age, meaning that aged people cannot loose much deep sleep due to nocturnal noise.

Sleep duration. Sleep duration as indicated by the time between sleep onset and final sleep offset (Sleep Period Time, SPT) is usually moderately affected. The difference is due to the increase of intermittent wakefulness somewhat greater when considering Total Sleep Time (TST = SPT minus intermittent wakefulness) but again rather moderate (Table 1).

Table 1: Alteration of some sleep parameters due to aircraft noise with L_{Aeq} from 39 to 50 dB (24 participants, 18-28 yrs. Griefahn et al.)

Variable	quiet	Noise	difference
Sleep period time (SPT, min)	455.3 ± 19.6	457.2 ± 7.7	-1.9 min
Total sleep time (TST, min)	425.3 ± 23.5	418.8 ± 21.4	-6.5
Slow wave sleep (SWS, min)	73.3 ± 25.6	70.8 ± 27.7	-2.5
REM-Sleep (min)	101.4 ± 16.7	103.1 ± 16.5	-
Sleep disturbance index	0.03 ± 0.95	0.57 ± 1.05	0.54

Though sleep intensity and sleep duration were ascertained in most studies on the effects of nocturnal noise on sleep, there are no dose-response relations that would allow a definition of protection limits.

Methodological remarks: Alterations of whole-nights sleep are difficult to interpret. In most laboratory studies, the time in bed (TIB) is eight hours which is more than the participants usually sleep at home (representative studies on sleep duration show usually not more than 7.5 hours sleep at home). Thus, the reduction of sleep duration is difficult to interpret and certainly less important than the same reduction in the field situation. On the other hand alterations of sleep structure (including sleep duration etc.) are difficult to evaluate in the field due to the fact that there is often no control situation, i.e. at airports with nocturnal traffic nights without any air traffic are rare. Moreover, it is conceivable to assume that bedtimes and rising times of residents near airports are in an attempt to cope with noise influenced by the schedule of air traffic.

b) *Describes noise metrics used in models that establish relationship between aircraft noise exposure and sleep; states strengths and weaknesses of different metrics.*

Models that relate noise metrics with the effects on sleep concern the prediction of EEG-awakenings (Basner et al., Marks et al.), of behavioral (signalled) awakenings (FICAN, Elias & Finegold, Anderson & Miller) or motoric arousals (body movements, Passchier-Vermeer). Noise metrics used in these models were either Lmax (Basner et al., Marks et al.) or SEL (FICAN, Elias & Finegold, Ollerhead, Passchier-Vermeer). It is difficult to discuss the strengths and weaknesses of both these acoustic measures as they were used for the prediction of different effects. Moreover, the moderator variables differ between studies.

Lukas (1975) was the first who tried to summarize the results from a few studies and came to the conclusion that the EPNdB would be the best predictor of sleep disturbances caused by aircraft noise. Pearsons et al. (1995) who pooled the data from various studies related awakening frequencies to LAmax and SEL and found that the ascent for SEL was lower than for LAmax, whereas the p-values were similar. This means that both measures can be almost equally applied. However, when it comes to explaining this to the residents in the vicinity of airports, it might be advantageous to use a metric than can be 'heard', namely the LAmax, and thereby better understood.

c) *Compares severity of aircraft-noise-induced sleep disturbance relative to other known causes of sleep disturbance.*

There are only a few attempts to compare sleep disturbances caused by aircraft noise with those related to other reasons (apart from noise).

Two attempts were made to compare noise-induced sleep disturbances with sleep disturbances of other reasons quantitatively. For this, the Sleep Disturbance Index was applied (SDI: this measure considers sleep structure by integrating 7 sleep parameters, Griefahn et al.). The index increases – as expected – gradually with age in noise-free nights as shown in Figure 2 (192 persons, 18-68 years). This figure shows also the SDI calculated for nights with equivalent noise levels of 44 (orange line) and of 50 dBA (green line) of young persons (18-28 years). The elevation of the SDI (as compared to the regression line showing the increase of the SDI with age) corresponds to an SDI that would be found in about 10 years older persons.

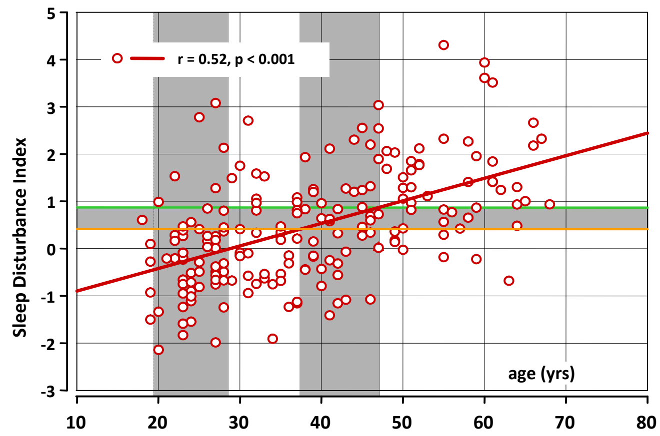

Figure 2: Sleep disturbance index in persons 18 to 68 years old (red circles). The orange and green lines indicate the SDI in noisy nights with LAeq of 44 and 50 dB in 18-28 years old persons. The cut-points with the regression line indicate the age range for which this sleep behavior would have been expected during quiet nights.

Another comparison based on the SDI concerned patients with Obstructive Sleep Apnea (OSA-patients). Figure 3 shows the SDI of healthy young persons in nights with equivalent noise levels of 39, 44, and 50 dBA and of OSA-patients in noise-free nights. The SDI increases with the severity of the OSA symptoms (Apnea-Hypopnea-Index AHI).

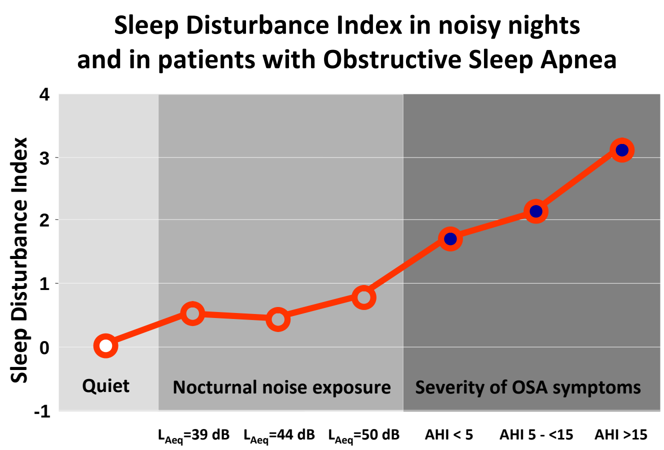

Figure 3: Sleep Disturbance Index (SDI) in quiet and in noisy nights and in persons with Obstructive Sleep Apnea of different severity.

These observations clearly indicate that nocturnal noise might have adverse effects and contribute in the long run to the genesis of health disorders. These findings are, however, certainly not enough to state a chronic health effect or to define protection limits.

2. Short-term after-effects of sleep disturbances

a) *Describes evidence of short-term effects of sleep disturbance (irrespective of cause) and whether relationships have been established between effects and indicators of sleep disturbance such as continuity, intensity, duration; states its sufficiency and policy relevance.*

A precise differentiation between 'short-term' and 'long-term' effects is almost impossible. Both indicate after-effects (secondary effects) to noise induced sleep disturbances (primary effect) where the short-term effects certainly contribute to the development of long-term effects. Short-term after-effects occur immediately or soon after nights with noise exposure and usually disappear after the cessation of nocturnal noise exposure. These effects comprise (1) subjectively assessed alterations (sleep quality, mood, annoyance, sleepiness), (2) objectively assessed alterations (sleepiness, performance) and (3) coping strategies (closing windows etc.).

Subjectively assessed alterations

– Subjective sleep quality. This parameter has been ascertained in almost all studies on the effects of noise on sleep and was usually found to be worse after noisy than after quiet nights. Sleep quality is as a rule related to some sleep parameters of the previous night (time to fall asleep, intermittent wakefulness etc). Significant but rather low correlation coefficients ($p \leq 0.01$) were found in several studies (usually $r < 0.3$).

  Though the decrease of subjective sleep quality is a consistent finding in almost any study on noise-induced sleep disturbances and though sleep quality decreases systematically with increasing nocturnal noise load, the results are not easy to pool for meta-analyses because sleep quality is differently ascertained. Some authors merely ask a single question, others have several indicators integrated to a single value (Griefahn et al.). Dose-response relations based on several laboratory studies were only presented for road traffic noise (Öhrström). Corresponding relations are not yet available for aircraft noise.

– Sleepiness. The best instruments to measure sleepiness are the Stanford Sleepiness Scale (SSS) and the Karolinska Sleepiness Scale (KSS) that correlate significantly with each other. These variables are only occasionally ascertained but seem to increase with nocturnal noise exposure. In a recently performed, however, not yet published study (Griefahn and Marks) it has been shown that sleepiness remains after noisy nights higher throughout a consecutive 8-hour experimental work shift than after sleep in quiet conditions (Figure 4). This has been shown for surface transport but the same is expected for aircraft noise as well.

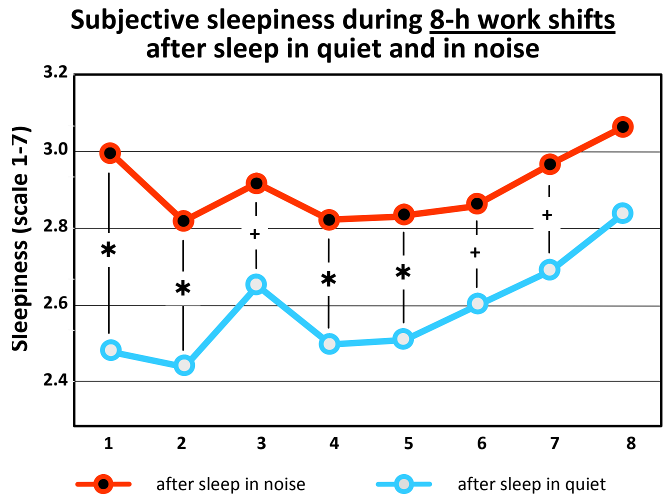

Figure 4: Sleep quality and sleepiness due to traffic noise.

– Annoyance. In studies designed to investigate the effects of nocturnal noise annoyance was rather occasionally than systematically ascertained. Annoyance has, however, been shown to increase gradually with the equivalent noise level (see in Figure 5, Quehl and Basner).

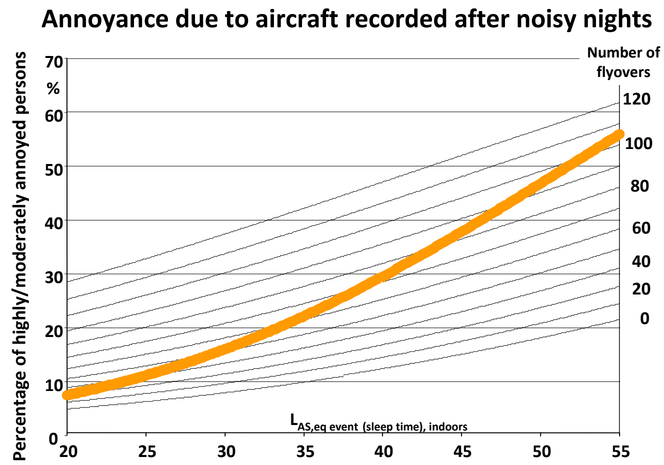

Figure 5: Annoyance related to the equivalent noise level.

Whether annoyance is - as assumed by the partners in the HYENA project - taken as a surrogate for sleep quality is not clear, though both variables increase with noise load (Babisch).

Methodological remark: Subjective assessments (sleep quality, sleepiness, annoyance) might be particularly problematic in field studies where the participants are still exposed to noise while they rate these parameters. This might disturb them more than during sleep and might thus influence the judgement, in particular as air traffic becomes heavier in the morning as compared to the night.

Subjective assessments (sleep quality, sleepiness, annoyance) are usually systematically related to noise load. However, dose-response relations were apart from only one study concerning annoyance not systematically published in the context of aircraft noise. Here, it would be advantageous to pool the data from as many studies as possible and to perform a meta-analysis that, however, has to take in account that these variables are often ascertained with different methods.

Objectively assessed alterations

- Sleepiness. Where subjective sleep quality is on the physiological level verified by sleep parameters that are recorded with the polysomnogram (PSG), sleepiness can be verified with the Pupillographic Sleepiness Test (PST). There is, however, only one study (Basner et al.) where this method was successfully applied and where a dose-response relation with nocturnal noise was found. Another objective method for the verification of sleepiness is the Multiple Sleep Latency Test (MSLT) that, however, has not yet been applied in studies on the effects of noise on sleep. The current knowledge is, however, insufficient to justify the derivation of applicable limits.
- Performance. According to numerous studies on partial or on complete sleep deprivation it was generally hypothesized that performance degrades after nocturnal noise exposure. Therefore, many studies included at least one performance test that was executed soon after getting up in the morning. However, there are only a few studies where one and the same performance test was applied (LeVere - Öhrström, Basner - Griefahn) and the majority of studies did not reveal any alteration due to noise applied in the previous night. Whether the tests were inadequate or whether the extent of sleep disturbances was insufficient to cause performance decrements is uncertain. Also sleep inertia, a state of dizziness and disorientation within the first minutes to even one hour post-awakening, may play a decisive role and determine actual performance. Most stable are performance decrements that show up as prolongations of reaction times by, however, only a few milliseconds (Basner, Marks) and if a task demands a high amount of working memory (LeVere, Öhrström). Relations to previous sleep were scarcely calculated (an attempt was made by Griefahn who calculated significant correlations between reaction time and SWS: $r = -.38$ and with the SDI: $r = 0.26$). A recently performed not yet published study showed that performance in terms of reaction time in several tests was prolonged throughout a consecutive experimental 8-hour work shift. A dose-response relation was found by Basner but this does not yet allow the derivation of thresholds or upper limits.

Other sources. Degraded performance has been shown in numerous experiments where sleep was at least partially deprived. The extent of sleep loss in these studies is, however, much greater than the disturbances evoked by aircraft noise and thus comparisons are not useful.

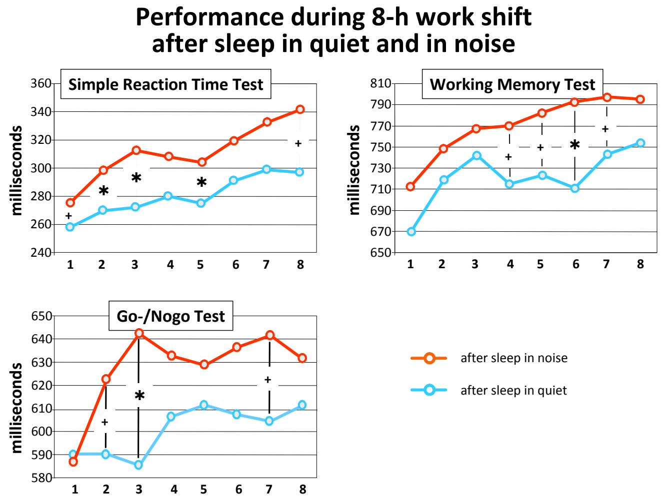

Figure 6: Annoyance related to the equivalent noise level.

Coping strategies

- Closing windows, using ear plugs
- Consumption of sleeping pills, tranquilizers, alcohol etc.

Though it is conceivable to assume that coping strategies are applied the more often the greater the nocturnal noise load is, this behavior has not yet been sufficiently studied.

b) *Describes evidence of short-term effects of aircraft-noise-induced sleep disturbance and places it in context with other causes of sleep disturbance*.
This is already included in topic with a) (irrespective of cause)

3. Long-term effects

a) *Describes evidence of long-term effects of sleep disturbance (irrespective of cause) and whether relationships have been established between effects and indicators of sleep disturbance such as continuity, intensity, duration; states its sufficiency and policy relevance.*

Long-term effects appear with a certain delay after the onset of long lasting (chronic) nocturnal noise exposure and they outlast even the cessation of noise exposure. Long-term effects concern health disorders as well as chronic alterations of behavior.

- Hypertension and myocardial infarction (including medication prescriptions)
- Behavioral alterations
- Chronic alterations affecting the immune and endocrine system

The majority of studies on the effects of noise on health concerned daytime exposure or 24-h exposures. None of the studies performed so far were designed to evaluate the relation between nocturnal noise and long-term effects (LARES, NAROMI-Study, Spandauer Gesundheitssurvey, HYENA-Study). Nocturnal noise was only occasionally regarded insofar that the effects in question were correlated with noise loads of different time periods during the day and during the night.

These studies are without exception cross-sectional and thus can merely reveal statistical associations, however, not causalities. Further, the data ascertained in these studies are usually rather weak. Noise loads were usually not measured in or calculated for the individuals' homes but measured or calculated for representative places around which these homes are located. Moreover, the effect variables are often not well quantified. Interviewees e.g. report whether they have a diagnosed disease or not, or whether they are on medication etc. Concerning the individual medications as documented by the health insurance companies the individual consumption of the remedies is not known (Greiser). Another weakness of some of these studies is that the authors correlate the effect data with as many noise indicators as possible until a significant correlation occurs (which is the more likely the higher the number of calculations is). The great value of these studies is, however, that they contribute to the formulation of solid hypotheses for future research. The latter must focus on individual data (individual noise load, quantified individual effects).

None of these epidemiological or field studies provide either thresholds or upper limits for nocturnal noise exposure.

b) *Describes evidence of short-term effects of aircraft-noise-induced sleep disturbance and places it in context with other causes of sleep disturbance.*

4. Methodological aspects

Describes options for assessing sleep and acquiring corresponding aircraft noise exposure; assesses relative suitability for different study applications from small laboratory to large-scale field study.

Methodological aspects were discussed in many papers since the earliest studies performed by Lukas, Griefahn, and Muzet and were recently summarized by Basner et al. and already presented within the context of the FAA initiative. Moreover, methodological aspects were considered under the topics 1 to 3.

5. Analyses of existing data.

a) *Summarizes data sets from research on sleep-related effects of aircraft noise.*

b) *Describes prospects for conducting meta-analysis of data from existing data sets.*

c) *Identifies ongoing sleep research with potential for incorporating addition of aircraft noise effects; assesses feasibility.*

Since the 60s many studies have been performed on the effects of noise. A meta-analysis is certainly desirable but seems not to be very promising

6. Research gaps

Describes aircraft-noise-induced sleep disturbance research needs and study approaches not discussed at August 2009 international forum or December 2009 roadmap, explains needs and policy relevance.

14. McGuire, Sleep Disturbance Information Brief

Sarah McGuire, Ray W. Herrick Laboratories, Purdue University

Existing Data

a) *Summary of data sets from research on sleep-related effects of aircraft noise*

A literature search was conducted in order to identify studies that examined the effects of aircraft noise on sleep. While not exhaustive, the result was that 12 laboratory [1-12] and 12 field studies [1,6,13-22] were identified. The reports for each study were examined to determine what methods were used to measure awakenings and what additional measurements were made; the results are in Table 1. Most field studies had more than 20 subjects. However, a wide variety of methods for measuring awakenings was used. Few field studies used polysomnography, the most sensitive measure of awakenings. All of the recent U.S. field studies [17,18] measured disturbance using behavioral awakenings.

Table 1: The number of studies out of 12 laboratory and 12 field studies that used the listed measurement techniques and measured the listed variables

	Laboratory	Field
> than 20 subjects	3	11
Social Survey	0	5
am/pm Questionnaires	7	7
Behavioral Awakenings	3	4
Actimetry	3	6
Motility-Other	1	1
Polysomnography	12	3
ECG	7	2
Blood Pressure	1	1
Hormone Levels	3	1
Objective Sleepiness	2	0
Subjective Sleepiness, Fatigue or Tiredness	6	8
Performance	5	3

b) *Prospects for conducting a meta-analysis*

It would be useful if, in addition to the many literature reviews conducted on noise and sleep, a more systematic analysis were performed. Due to the limited number of studies, in order to conduct a meta-analysis, it would likely be necessary to also examine studies on the effects of road and train noise on sleep. However, sound characteristics for each type of transportation mode are different, which causes different degrees of sleep disturbance [2,12]. This may affect the results of any combined analysis.

One topic in which a meta-analysis would be useful is on next day effects such as sleepiness. While it would be preferable to examine objective measurements of sleepiness, only two laboratory studies were found to perform these measurements. Both studies also used different methods. One measured sleepiness using the Multiple Sleep Latency Test which involves measuring the time it takes for an individual to fall asleep [6]. The other study used the Pupillographic Sleepiness Test (PST). PST involves measuring the oscillations in pupil size, which will be small for alert subjects and large for sleepy subjects [23].

Due to the limited number of studies which measured sleepiness objectively, for a meta-analysis subjective measures would need to be examined. Many studies have used morning questionnaires or social surveys. Eight out of the 12 field studies that were identified did ask questions on sleepiness, tiredness or fatigue. Also some subjective measures have been found to correlate to objective measures of sleepiness [24]. Due to the differences in study designs and the use of different questions the results between studies though may not be comparable. In addition to sleepiness, other possible topics for a meta-analysis on short-term effects would be to examine subjective responses on mood, or annoyance caused by sleep disturbance.

It would also be desirable to examine whether there is consistent evidence that nighttime noise causes a change in blood pressure, hormone levels or other physiological measurements other then awakenings. These parameters may be useful when trying to determine whether sleep disturbance caused by noise could lead to health effects. From the small literature review that was conducted, few studies examined these effects. For example, out of the 24 studies that have been identified only 4 measured hormone levels and only 2 measured blood pressure.

Overall the primary challenges in conducting a meta-analysis on noise-induced sleep disturbance are that there are a limited number of studies, and there are large differences in methods that were used. It seems that the most promising topics would be to examine subjective responses on next day effects due to the larger quantity of data that may be available. However, until a detailed list is compiled of studies that examined each effect and the methods used, it is difficult to determine whether a meta-analysis, that would improve the current state of knowledge, could be conducted.

Research Gaps

Short Term Objective: To understand the number of awakenings that occurs in communities around U.S. airports and the resulting next-day effects

a) *Given the current state of knowledge examine the impact of noise on sleep in communities around U.S. airports*

The degree of sleep disturbance that has been found needs to be placed in context in terms of DNL. While the same DNL level could result in different numbers of awakenings, it would be useful to use the model developed by Basner et al. [25] to create contours for U.S. airports indicating the area in which 1 additional awakening will occur and compare them to the 65 dB(A) DNL contours. An estimate of the populations that are within the awakening contour and not the 65 dB(A) DNL contour should also be made. Similarly it would be useful to calculate L_{night} contours around several airports and examine the difference in the 55 dB(A) L_{night} contour and the 65 dB(A) DNL contour. Above an outdoor L_{night} level of 55 dB(A), health effects caused by noise may often occur as stated in the Night Noise Guidelines for Europe [26].

b) *Examine literature on existing studies to determine whether a meta-analysis can be conducted on next day effects such as sleepiness, mood, or performance*

In order to determine whether there is sufficient data to examine these effects, a literature review of all studies on noise-induced sleep disturbance needs to be performed. A list of information contained in each study should be created. While it is questionable whether a useful meta-analysis can be conducted this review would provide a more complete picture of the research that has been done. If it is determined that an analysis can be conducted, models on sleepiness, performance or other next day effects should be developed.

Long Term Objective: To understand the effect of noise-induced sleep disturbance on health

a) *Determine whether aircraft noise impacts sleep enough to lead to long term health effects*

From the studies that have been conducted it is evident that the number of awakenings increase with noise level however, what is not well understood is what the effects of these additional awakenings are. To improve the understanding of the effect that nighttime noise has on health, one topic that should be further investigated is the non-dipping of blood pressure. A person is classified as a “dipper” if blood pressure during the night drops by more than 10%. The non-dipping of blood pressure may increase the risk for developing cardiovascular problems. An association between blood pressure level and the number of arousals has been found [27]. In order to determine whether nighttime noise around U. S. airports could lead to non-dipping, a literature review should be conducted to determine the number of arousals that is associated with non-dipping and compare it to the number of arousals caused by aircraft noise.

b) *Develop and verify models to predict changes in sleep that may lead to long-term health effects*

Most sleep disturbance models are based on behavioral awakenings and only predict the percent awakened. It needs to be determined which changes in sleep (e.g. time awake, reduction in rapid eye movement sleep, reduction in slow wave sleep) are the best indicators of long term health effects and then develop and validate models to predict these changes.

c) *Conduct additional studies*

There is a limited number of existing field studies in which the data could be used to develop and validate more complex sleep models. Also there is a need for additional studies to examine the link between nighttime noise and health. Therefore new studies should be conducted around U. S. airports. Research into the design and feasibility of conducting these studies should be completed.

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15. Basner, Information Brief - Sleep Disturbance – Methodology

Prepared by Mathias Basner

This information brief describes options for assessing sleep and acquiring corresponding aircraft noise exposure. It assesses the relative suitability for different study applications from small laboratory to large scale field studies.

The human organism recognizes, evaluates and reacts to environmental sounds even while asleep [1, 2]. Traffic noise may therefore disturb or fragment sleep and impair recuperation. Arousals of the central nervous system (CNS) occur frequently throughout the night and they are not specific for noise, i.e. many internal and external stimuli other than noise may induce an arousal (termed 'spontaneous' in Figure 1).

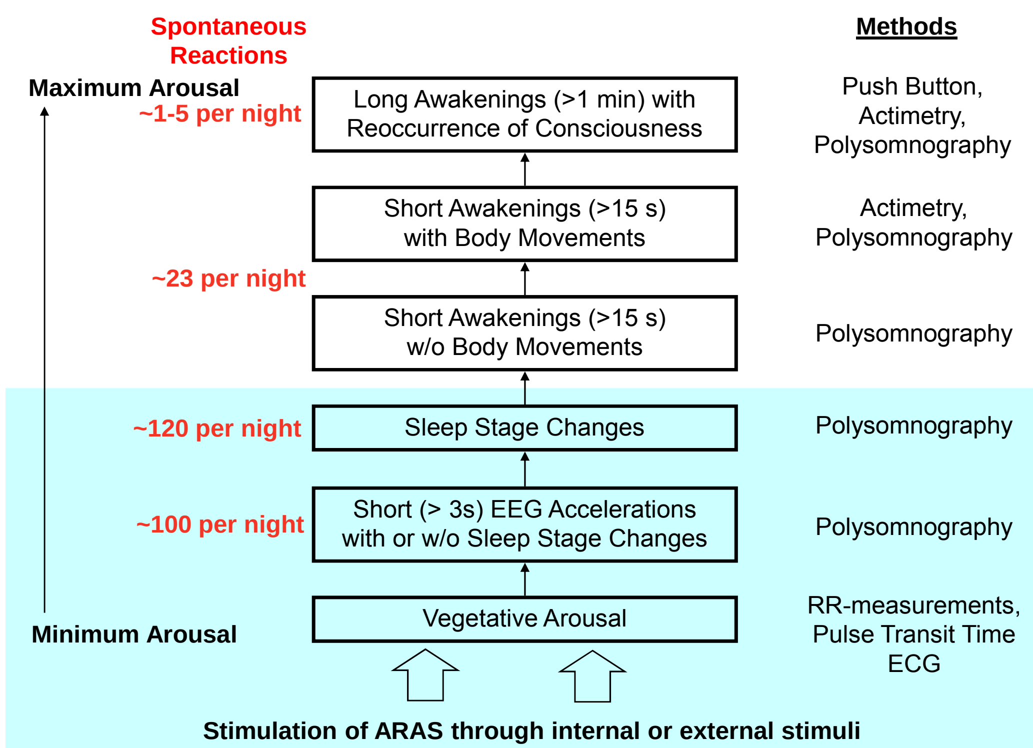

Figure 1: Different degrees of central nervous system arousal induced by stimulation of the Ascending Reticular Arousal System (ARAS) through internal or external stimuli and methods suitable for assessing the different arousals. Red numbers represent spontaneous frequencies for different reactions in a noise-free night with eight hours time in bed.

Polysomnography, i.e. the simultaneous recording of the electroencephalogram (EEG), the electrooculogram (EOG), and the electromyogram (EMG) remains the gold standard for measuring sleep. According to specific conventions [3, 4], the night is divided into wake and different stages of sleep (light sleep stages S1 and S2, deep sleep stages S3 and S4, and rapid eye movement (REM) sleep). Deep and REM sleep seem to be very important for restoration and memory consolidation during sleep [5]. Wake and S1 are typical indicators of disturbed or fragmented sleep, and they do not (or only very little) contribute to the recuperative value of sleep [6]. Even shorter activations (≥ 3 s) in the EEG and EMG, so-called *arousals*, that would not qualify to be scored as an awakening can be detected with the polysomnogram [3, 7]. These arousals are usually accompanied by cardiac activations (see below) that may be responsible for long-term adverse health effects of noise on the cardiovascular system [8, 9, 10]. Polysomnography is very sensitive in detecting even subtle physiological changes induced by traffic noise. However, polysomnography also has some disadvantages. EEG, EOG, and EMG electrodes and wires are somewhat invasive and may therefore influence sleep. The instrumentation of subjects is cumbersome and cannot be done by the subjects themselves. Finally, sleep stage classification requires trained personnel, and is known to have high inter- and intra-observer variabilities [11, 12]. Hence, only a few polysomnographic noise effects studies have been conducted with relatively small sample sizes in the past [13].

Several other methods can be used to measure sleep and the influence of noise on sleep. The easiest way to gather information on sleep is via ***questionnaires***. However, the validity of this method is at least questionable, as during most of the night the sleeper is unconscious and not aware of the surroundings. Only the process of falling asleep and longer wake periods during the night contribute to subjective estimates of sleep quality and quantity, which may therefore differ substantially from objective measures [14]. Also, subjective assessments are prone to manipulation. Nevertheless, subjective measures of noise induced sleep disturbance are still important, as both objective and subjective criteria should be addressed by noise mitigation measures.

Several studies investigated the influence of traffic noise on ***signaled awakenings*** (also called *behavioral awakenings*) [15, 16]. Here, the subject has to give an agreed-upon signal (e.g. pressing a button) to indicate the awakening. The method is easy to use and very inexpensive. However, it also has a low sensitivity and reliability, and the results depend strongly on what instructions were given to the subjects how. Consciousness is only regained during prolonged wake periods, and relevant activations of the CNS may be missed. By demanding an active cooperation of the subject, the importance of the signal, reaction probability, and sleep itself may be altered [17, 18]. On the other hand, subjects may forget to give the signal or they may be too tired or languid to give the signal.

Actigraphs are watch-sized accelerometers that record body movements during sleep and are usually worn at the wrist of the non-dominant arm. They are easy to use and less invasive and expansive than polysomnography. They have been widely used for the assessment of sleep-wake patterns [19]. However, both hardware and analysis algorithms are poorly standardized, and therefore the comparability of results derived from different actigraphs is restricted. Actigraphy has been used to measure body movements during sleep in noise-effects research [20, 21]. Although the number of EEG awakenings and the number of body movements are correlated, prolonged periods of wakefulness without body movements and awakenings not accompanied by body movements may be wrongly classified as sleep, whereas body movements without relevant activations of the central nervous system (CNS) may be wrongly classified as wake or a sleep disturbance, limiting the validity of actigraphy.

Noise induces ***activations of the autonomic nervous system***, like increases in blood pressure and heart rate, which can be measured easily with electrocardiography (ECG) or plethysmography [22, 23]. Repeated noise induced autonomic activations may play a key role in the genesis of hypertension and associated cardiovascular diseases. However, as of today there is no generally accepted convention on what exactly constitutes a cardiac arousal, e.g., how strong a heart rate increase must be in order to be classified as a relevant cardiac activation. Although Martin et al. [24] suggest that daytime functioning may be impaired by increases in the number of subcortical arousals alone, this has been questioned by Wesensten et al. [6], as the procedure used by Martin et al. inevitably also induced cortical arousals and changes in sleep structure beside autonomic activations. Recent findings of a carefully designed experiment by

Guilleminault et al. [25] support the thesis that EEG arousals are a prerequisite for the detrimental effects of sleep fragmentation on daytime functioning. Basner et al. developed an ECG-based algorithm for the automatic detection of cortical arousals, and validated it in a laboratory study on the effects of aircraft noise on sleep [10, 22]. After further validation, this inexpensive, objective, and non-invasive method may facilitate large scale field studies on the effects of traffic noise on sleep.

In conclusion, there is no consensus on what is the 'best' or 'preferred' method to investigate noise effects on sleep in general. It is absolutely legitimate to use methods other than the gold standard polysomnography in order to gather information on the effects of noise on sleep. All methods differ in instrumentation and data analysis expense, but also in their sensitivity and specificity for detecting noise-induced arousals of the CNS (see Figure 1). The choice of method therefore crucially depends on the research goal, the investigated population, and on the available funds. In the future, the research community should try to increase the knowledge on the interrelations of different measures of noise-induced sleep disturbance.

Acoustic measurements

Traffic densities are usually low during the night, and the sleeper reacts to single noise events rather than to a constant background noise. The reaction of the sleeper will therefore depend on the acoustic properties of single noise events (beside other moderating factors). In order to establish an event-related analysis [10], it is advantageous to record both acoustic and physiologic signals using a common timeline (or trigger signals to establish a common timeline). If this is not possible, the internal clocks of all measurement equipment should be re-adjusted before each measurement period, and the time-drift of each device should be established.

Acoustic measurements should always be performed with suitable and calibrated equipment (e.g. class-1 sound level meters). Inside sound pressure levels (SPL) should preferentially be measured, as the sleeper primarily reacts to the sound levels inside the bedroom. If this is not feasible, they may be calculated from SPL measurements made outside the bedroom, if the outside-inside SPL attenuation is known. The placement of the microphones should always be documented.

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16. Fidell, Brief on Noise-Induced Sleep Disturbance

Prepared by Sanford Fidell

Self-reported, behavioral, and physiological measurements of noise-induced sleep disturbance (such as those of Basner and Samel, 2006, and of Fidell *et al.*, 2000, among many others) have been made in both laboratory and field settings. The practical implications of these measurements for aircraft noise regulation are uncertain for several reasons. For example, matters as basic as what constitutes sleep disturbance, and the relative amounts of sleep disturbance attributable to noise and to other factors, remain unsettled. Further, the findings of sleep disturbance studies are difficult to compare systematically and to interpret in consistent ways. If, upon awakening, people declare they had a good night's sleep, can their reports be trusted if their brain wave and motility responses seem to indicate otherwise?

Sleep is a complex physiological process affected in both subtle and obvious ways, not only by noise, but by many other factors as well. Some effects of disturbed sleep remain noticeable the next day, and seem linked to the degree of sleep disturbance during prior nights. Unfortunately, useful quantitative understanding of noise-induced sleep disturbance does not extend much beyond these generalities. In particular, although the acute health consequences of extreme sleep deprivation are clear, the meaningfulness of health effects of occasional intrusions of aircraft noise into sleeping quarters remains debatable.

At a non-conscious level, nighttime noise may affect brainwave, cardiovascular, and endocrine activity. However, very short arousals occur routinely and frequently throughout the night, even in the absence of noise. These do not rise to the level of full waking consciousness, and are unlikely to be remembered the next morning. Further, shifts from one sleep stage to another, as well as slight, transient elevations in heart rate and blood pressure, may simply be signs of normal autonomic responses to ever-changing environmental conditions.

Noise in sleeping quarters can also create more readily observable effects, such as bodily movements and behaviorally-confirmed awakenings. They occur much less often than shifts in sleep stages and short term physiological arousals, and not solely during or shortly after noise intrusions.

Recent reviews of the noise-induced sleep disturbance literature (*e.g,*, that of Michaud *et al.*, 2007), conclude that findings about noise-induced sleep disturbance differ considerably both with respect to measures of sleep disturbance and by study. They also indicate that non-aircraft related awakenings are more common than aircraft noise-induced awakenings in airport neighborhoods, and that only small percentages of habitually exposed people in familiar sleeping quarters are regularly awakened by aircraft noise intrusions.

Half a dozen relationships between indoor sound exposure levels of nighttime noises and predicted awakening, such as that of ANSI (2008), have been derived in recent years. They account for little variance in the association between sleep disturbance and behaviorally-confirmed awakening, and have very shallow slopes. They are therefore not very reliable, and offer little guidance for regulatory purposes. Attempts to predict the probability of at least one awakening per night from numbers, times of occurrence, and sound levels of intruding noises also account for very little variance, depend on questionable statistical assumptions, and are more sensitive to total time spent in bed and customary airport operating schedules than to the sound levels of aircraft overflights.

Additional laboratory and field studies of the usual sort (*cf*. those of Basner and Samel, 2006; Fidell *et al*., 2000; Ollerhead *et al*., 1992; Pearsons *et al.*, 1995) are not likely to greatly improve understanding of the extent and meaning of aircraft noise on health. Due in part to their expense, such studies tend to be of relatively small scale, short duration, and simple design. New field studies and analytic approaches of greater sophistication must systematically account for non-acoustic influences on sleep (including as the source and meaning of noise intrusions and sleepers' familiarity with them), and must provide a context for distinguishing between incidence rates of spontaneous (non-noise related) and prevalence rates of *bona fide* noise-induced sleep disturbance.

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