SUMMARY REPORT
OF THE
WORKSHOP ON
AIRCRAFT NOISE IMPACTS RESEARCH

WASHINGTON, DC, DECEMBER 10-11, 2009

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INTRODUCTION

The FAA continues to work towards providing the safest, most efficient aviation system in the world that operates in an environmentally sound manner. Contours of annual average noise exposure for long-established U.S. airport communities have decreased because of continuing reductions in the amount of noise emitted by individual aircraft and other noise mitigation measures, despite an over 50 percent increase in passenger enplanements since 1990. Nevertheless, airport communities remain concerned about aircraft noise, as illustrated by the public's response to aircraft operations from the recently opened runways at Chicago O'Hare and Seattle-Tacoma airports.[1] Improving efficiency through airspace redesign, airport capacity expansion, and other initiatives of the FAA Next Generation Air Transportation System (NextGen), may be hampered without an aggressive program to address the environmental consequences of aviation noise.

The FAA Office of Environment and Energy seeks to develop a comprehensive research roadmap addressing critical noise impacts research needs, in collaboration with and participation of researchers across numerous disciplines and around the world, as well as with the broad community of aviation stakeholders including the public. Such a roadmap will enable FAA and interested parties to define systematic, focused, and complementary research programs, in which limited resources could be pooled to advance the scientific knowledge on how best to address the impacts of aviation noise on society.

To advance the roadmap design, the FAA held a two-day workshop in Washington, D.C. with the purpose of soliciting expertise and opinions about the effects of noise on humans and communities, focusing on sleep disturbance and annoyance.[2] The FAA began the meeting with an overview of the need for the research, a discussion of the roadmap development process, and an outline of the draft roadmap.[3] A considerable number of people attended representing a wide range of aviation stakeholders (Attachment 1[4]), and provided useful critiques. This report summarizes the introductory presentations that were made for annoyance and sleep, and outlines key issues and associated research projects derived from these discussions in Washington, the international forum in Ottawa, Canada[5], and work by two expert panels (Attachment 2). This workshop report together

[1] "New Runway Causing New Noise Problems", THE JOURNAL & TOPICS NEWSPAPERS | THURSDAY, NOVEMBER 27, 2008, http://www.journal-topics.com/eg/08/eg081127.3.html; "New O'Hare runway seeing tons of traffic, and nearby residents not keeping quiet"; Chicago Tribune, Friday, December 05, 2008, http://archives.chicagotribune.com/2008/dec/05/local/chi-ohare-noise_05dec05; "Sea-Tac neighbors feel duped over 3rd-runway noise", The Seattle Times, December 11, 2008, http://seattletimes.nwsource.com/html/localnews/2008493979_runway11m.html

[2] Meeting agenda is available: http://www.fican.org/pdf/faa/FAA_Noise_Research_Agenga-1209.pdf

[3] http://www.fican.org/pdf/faa/2009-12FAA_Workshop.pdf

[4] Any attendees not included in the list are encouraged to contact FAA (Patricia.friesenhahn@faa.gov) so that their name can be added.

[5] A summary report of the Ottawa forum is available at http://www.fican.org/pdf/faa/IntlForumSummaryReport-11-19-09.pdf

with the Ottawa forum report documents the roadmap development process and progress. As a starting point for the discussions, a draft research roadmap was distributed prior to the workshop (Attachment 3).

ANNOYANCE DISCUSSION

The annoyance roadmap aims to seek improvements to the current first-order approximation model used by FAA for a relationship between noise exposure and annoyance, shown below.

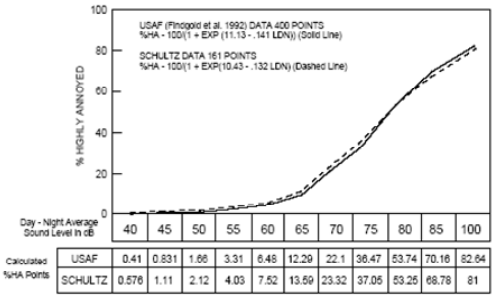
Simple model for annoyance

•Equivalent energy principle with time of day weighting
- ❑No. events
- ❑Time of day
- ❑A-weighted sound level

DNL → Long-term annoyance

Assumptions and/or have sufficient evidence

•Relationship bet. DNL & %HA works as a **first-order approximation** of annoyance from long-term aircraft noise exposure



Day - Night Average Sound Level in dB	40	45	50	55	60	65	70	75	80	85	100
Calculated %HA Points USAF	0.41	0.831	1.66	3.31	6.48	12.29	22.1	36.47	53.74	70.16	82.64
SCHULTZ	0.576	1.11	2.12	4.03	7.52	13.59	23.32	37.05	53.25	68.78	81

[FICON 1992, Federal Agency Review of Selected Airport Noise Analysis Issues]

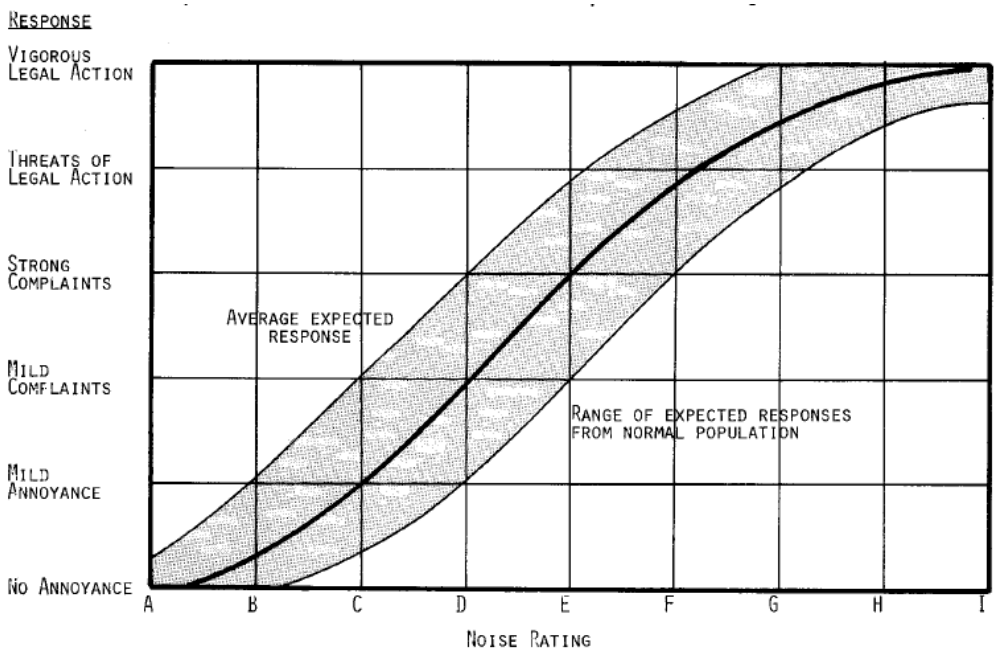
The roadmap follows a path that starts with the simple model above and identifies issues that should be researched either with existing data or with follow-on field studies to improve upon the model (or develop multiple models) to better capture the relationship between noise exposure and annoyance. Improvements to the model(s) would provide FAA a scientific basis by which to update its policy on what it considers significant noise impact for environmental studies, how it establishes criteria for airport-compatible land use, when to adopt noise mitigation measures, and how best to reduce the effects of noise.

The annoyance discussions began with a presentation by Ken Plotkin of Wyle Laboratories summarizing the history of aircraft noise metrics and the origin of using 65 Ldn/DNL in determining land use compatibility. The history includes the early efforts to respond to legislative and regulatory requirements to limit the adverse effects of noise when very little scientific research was available. Hence, the presentation of some information, such as the relationship of Response or Community Reaction to Noise Rating or to Outdoor Day-Night Average Sound Level does not mean that their use has been accepted by the science community.

Ken Plotkin's Presentation: Aviation Noise Impact: A Historical Perspective

The presentation provided a review of the history of aviation noise impact metrics. Early work by Fletcher and Munson determined frequency dependent curves that defined equal loudness levels as a function of frequency. These curves were used to define the three weightings, A, B and C, with the original intent that the A-weighting be applied to low levels, B to medium levels, and C to high levels. The A-weighting was found of the three weightings to best correlate with human perceptions of the loudness of aircraft noise; however a somewhat more complicated metric, Perceived Noise Level (PNL) correlated even better.

In the 1950s, a metric was developed that could relate both annoyance and community reaction (complaints, legal action, etc.) to aircraft sound. The Composite Noise Rating (CNR) included both the number of aircraft events and noise level, (using PNL) and was correlated with annoyance and community response:



Source: Kryter, K. D. Human Reactions to Sound from Aircraft. J. Acoust. Soc. Am. 31: 1415-1429. 1959.

In the 1960s, the duration of the events as well as tonal adjustments were included in the Noise Exposure Forecast (NEF). NEF was computed from the Effective Perceived Noise Level (EPNL) which in turn used PNL with a correction for event duration and pure tone content. The Department of Housing and Urban Development (HUD) linked acceptability for residential development to NEF values:

TABLE I.

SITE EXPOSURE TO AIRCRAFT NOISE

Distance from Site to the Center of the Area Covered by the Principal Runways	Acceptability Category
Outside the NEF-30 (CNR-100) contour, at a distance greater than or equal to the distance between the NEF-30 and NEF-40 (CNR-100, CNR-115) contours	Clearly Acceptable
Outside the NEF-30 (CNR-100) contour, at a distance less than the distance between the NEF-30 and NEF-40 (CNR-100, CNR-115) contours	Normally Acceptable
Between the NEF-30 and NEF-40 (CNR-100, CNR-115) contours	Normally Unacceptable
Within the NEF-40 (CNR-115) contour	Clearly Unacceptable

Source: HUD Noise Assessment Guidelines, BBN Report 2176, August 1971
(For aircraft noise exposure)
(Note: DNL or Ldn ~ NEF + 35)

In the late 1960s and early 1970s, with the tones produced by most jet aircraft significantly reduced, tone corrections were less important, and A-weighted levels became widely used, in part because, unlike NEF or EPNL, they could be easily determined through direct measurement with available sound monitoring equipment. The Community Noise Equivalent Level (CNEL) was based on A-weighted levels and used by the state of California in 1970 to set limits for aircraft noise in residential communities. A criterion level of 65 dB CNEL was established effective January 1986.

In response to the Noise Control Act of 1972, the U.S. EPA identified "noise levels requisite to protect public health and welfare with an adequate margin of safety," and established the Day-Night Average Noise Level, Ldn or DNL as the noise metric:

Table 1
SUMMARY OF NOISE LEVELS IDENTIFIED AS REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY
(see Table 4 for detailed description)

EFFECT	LEVEL	AREA
Hearing Loss	$L_{eq(24)} \leq 70$ dB	All areas
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

Source: EPA Levels Document EPA 550/9-74-004, March 1974

Succeeding federal committees (Federal Interagency Committee on Urban Noise (FICUN), Federal Interagency Committee on Noise (FICON), and Federal Interagency on Aviation Noise (FICAN) carried on the HUD and California traditions of using 65 dB, in terms of DNL, as the criteria/guideline for the limit of aircraft noise acceptable for residential areas.

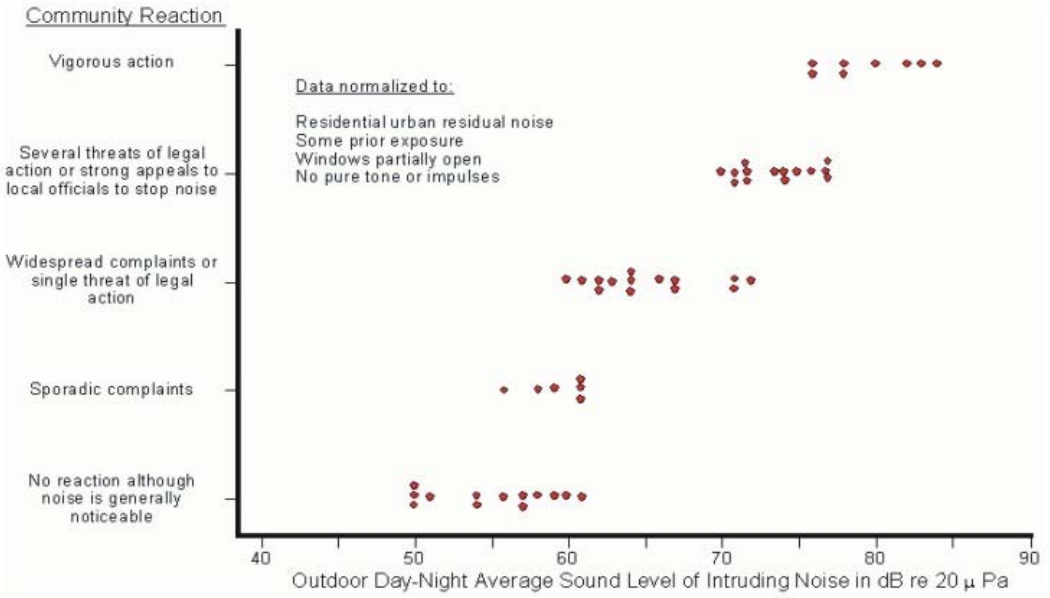
The use of DNL meant that the concept of "equal energy" prevailed; the sound level of events and the number of events were interchangeable, with a doubling or halving of the number of events equating to increasing or decreasing DNL by 3 dB. Many quieter events would produce the same value of DNL as would fewer loud events. Further, combining events of different durations and levels was computationally easy. However, it is not completely true that individuals' and communities' responses to noise exposure always correlate well with this trade-off of number and level.

Nevertheless, there have been continuing efforts to relate community reactions to DNL. At first, these efforts included adjustment factors to better predict community reaction:

CORRECTION FACTORS FOR NORMALIZING COMMUNITY NOISE CASES TO A SINGLE MAGNITUDE SCALE

Type of Correction	Description	Amount of Correction to the Measured Noise Levels, dBA
Seasonal Correction	Summer (Year-around operations)	0
	Winter only	-5
Time of Day	Daytime	0
	Evening	+5
	Nighttime	+10
Correction for Background Noise	Very quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Residential urban community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban community (near relatively busy roads or industrial areas)	-5
Correction for Previous Exposure and Community Attitudes	Community has had some previous exposure to aircraft noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to aircraft noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to aircraft noise, and airport relations with the community are good.	-5
	This correction can be applied for an operation of limited duration and under emergency circumstances; it cannot be applied for an indefinite period.	-10

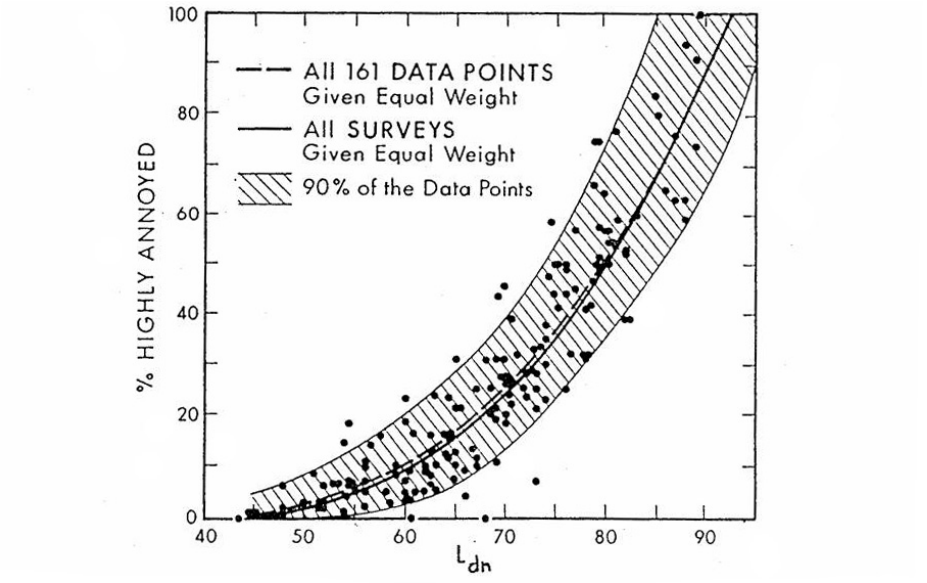
and for some early data from the 1970s these worked fairly well:



Source: EPA Levels Document EPA 550/9-74-004, March 1974

Use of these adjustments, probably due to the complexity of applying these to entire communities where different adjustments might apply at different locations, have largely fallen out of use.

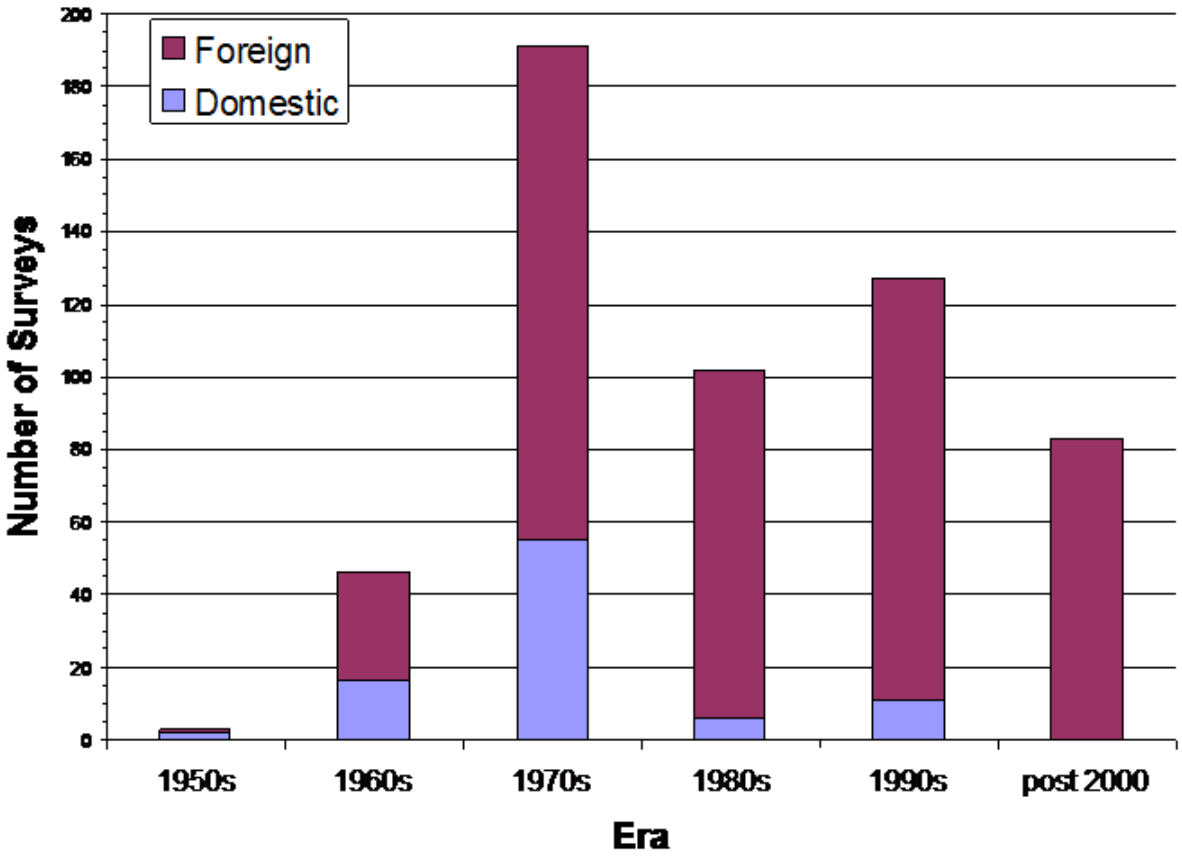
In 1978, Ted Schultz published "Synthesis of social surveys on noise annoyance," J. Acoustical Society of America, Vol. 64, No. 2 August 1978, and provided the following relationship:



After this article, “percent highly annoyed,” (%HA), became the way to view noise impact. In other words, aircraft noise became judged more by its effects on the public than on public reactions to aircraft noise. It should be noted that, contrary to occasionally expressed opinions, DNL 65 as a land use compatibility guideline pre-dated the %HA relationship, so that the fact that %HA is about 13% at DNL 65 is a result of Schultz’ analysis, not a reason for selecting DNL 65 as a land use criterion.

The relationship of %HA to DNL has been re-worked several times, most notably by separating data (and curves) for aircraft, rail and highway noise. The scatter of data is large and many researchers have pointed out that the use of DNL accounts for only a small portion (perhaps about 20%) of the scatter. Adding another survey or changing the curve will likely add little to improving the relationship/reducing the scatter.

In terms of using the survey data on which the relationship is based for U.S. airports, it should be noted that most surveys since the 1960s have been conducted around non-U.S. (foreign) airports:



Data from: Bassarab, R., Sharp, B., and Robinette, B., “An Updated Catalog of Social Surveys of Residents’ Reaction to Environmental Noise,” Wyle Report 09-18, November 2009. (Also DOT/FAA/AEE/2009-01 and DOT-VNTSC-FAA-10-02.)

Finally, Plotkin provided some food for thought:

• Equal energy principle dominates, partly for reasons not necessarily related to science	• *Basics that were simplified need to be revisited. Other metrics (like current "supplementary") may better reflect impact.*
• Schultz curve has been reworked many times	• *Would another similar data point really make a difference?*
• Relationship between DNL and annoyance has high degree of uncertainty.	• *Would different metric(s) reduce uncertainty? Is %HA versus DNL the only way?*
• Most of the social surveys are over 20 years old (>60%).	• *What are the influences of changes in public attitudes and aircraft characteristics?*
• All recent social surveys have been done overseas (Europe and Japan).	• *Do Americans have a different attitude about their environment?*

Synthesis of Discussions on Research Topics

The discussions at the workshop covered many of the topics and thoughts raised previously in the Ottawa Forum, but provided additional details and brought new participants into the process. From these two meetings, sufficient ideas and perspectives have been aired to permit development of a draft research roadmap.

Discussions started with the important distinction between personal annoyance with aircraft noise and public or community action against aircraft noise. Annoyance can be determined only by social surveys of individuals exposed to known levels of noise. Traditionally, the results are reported as percent of the population who say they are highly annoyed. Public or community action is what is manifest as complaints to an airport, organized expression of dissatisfaction or, occasionally, legal action. The following issues address one or the other of these two phenomena.

KEY ISSUES RAISED DURING THE DISCUSSION THAT NEED TO BE CONSIDERED IN DEFINING THE RESEARCH ON AIRCRAFT NOISE AND ANNOYANCE

1. What factors affect annoyance?

The current single relationship between %HA and annoyance may be inadequate because of a number of factors which need to be investigated systematically with research:

- Has annoyance increased with time? Some recent research studies suggest that for a given level of exposure in terms of DNL or Lden, annoyance has increased.
- Is annoyance different for different aircraft? All things being equal, would people in communities around general aviation airports with all or predominantly propeller aircraft report similar degrees of annoyance to people living around commercial jet airports or military bases?
- Is annoyance different in locations dominated by low frequency noise or in different areas around an airport? Many airports have observed that the noise environment along a runway, exposed to start of take-off noise is very different from that under the flight corridors. Residents have complained

when standard computations show the levels to be normally compatible. This issue is intended to address whether reported annoyance is different in these areas and whether they should be analyzed differently from other areas.

- Is annoyance affected by airport/community interactions? Workshop attendees suggest that an important component of individual annoyance is the relationship the individual/community has toward the airport.
- Is annoyance due to a step change, the same as annoyance for more gradual changes?

Note: There are a number of other known issues not discussed at the workshop, but need to be part of the research roadmap because they are not considered in current practice. These issues include differences in exposure-response relationships between transportation modes and determining whether a model based on noise metrics other than DNL or a model based on DNL's separate components might be better than the current DNL model.

2. Can community reactions in the form of public action be predicted?
Projects such as new or lengthened runways, redesigned airspace, or new aircraft types sometimes result in significant community reactions including organized complaints to the airport and to local or federal officials. Understanding the factors that may be related to these reactions could help in predicting beforehand such outcomes and managing for them.

3. Can noise complaint data be used as an aid to airport management?
Complaints about noise tend to identify unusual or unexpected events or circumstances. Patterns of complaints (aside from those by the few individuals who complain very frequently) may reveal changes at an airport previously judged to be inconsequential. Many airports collect complaint data and may respond with an acknowledgement or with follow-up investigation. But rarely do airports have the time or resources to construct and analyze patterns of complaints. Limited research into alternative uses of these data could assist airports in tracking trends and identifying changes that may not be incidental or occasional.

There was some disagreement among workshop participants regarding what could be learned from currently available data versus the need for new data, especially in the U.S. The FAA has invited subject matter experts to write brief papers discussing the current state of knowledge and prospects for further research using currently available data as well as acquiring new U.S. community noise survey data. These information briefs will be provided at the noise research roadmap workshop to be held in San Diego, CA, in conjunction with the annual UC Davis Symposium on Aviation Noise and Air Quality, on March 4, 2010.

A.1: INITIAL PROJECTS - WHAT RESEARCH RELATIVE TO THE KEY ISSUES HAS ALREADY BEEN DONE?

From the discussions, it is clear that a great deal of research has been done on the relationship of community annoyance to aircraft noise, but there remains potential for investigating the issues above using already available data. The primary research of

interest is based on surveys of populations affected by aircraft noise, either living around airports or living under fight corridors–or a combination of the two. This research has resulted in reports and often, in databases of the survey responses, associated sound levels, and other variables of interest.

An initial project could focus on identifying previous work that addresses the key issues identified above, assembling and making accessible as much of this previous work as possible. This project would help us determine whether existing data could be reanalyzed to answer some of our research questions. Other initial projects include identification of past airport or airspace developments that resulted in significant changes in community noise levels, and selection of acceptable methods for computing the effects of aircraft noise on people.

A.2: FOLLOW-ON ANALYSIS OF COLLECTED INFORMATION

Once the preliminary projects A.1 have identified useful studies, data, projects and noise effects calculation methods, the follow-on projects would use that information in an effort to develop improved models of the relationship between noise exposure and annoyance, to determine whether public action against noise can be predicted, and to provide airports and agencies with methods for making constructive use of complaints. All projects will identify gaps in information or knowledge that can help in the design of future studies

A.3: NEW AIRPORT COMMUNITY NOISE STUDIES

While studying how existing data can improve our understanding, it is anticipated that these efforts would need to be supplemented with new community studies in order to more definitively improve upon the model (or develop multiple models) that better capture the relationship between noise exposure and annoyance.

Discussion Topics not included in above Projects

During the workshop there were mentions or discussion of several topics that are not addressed explicitly in any of the above projects.

- Meta-lab or lab studies – to compare reactions to low frequency noise with the Tokita and Nakamura[6] human reaction relationship. Possible use of the NASA low-frequency listening room was suggested.
- Use of virtual technologies – Are there any known applications of virtual technologies to help understand annoyance – visual or audio virtual realities?
- Getting information directly from the public – Is there some way to acquire annoyance or other judgments directly from the public through use of the internet, social networking applications, or other? (See http://soundaroundyou.com/ for a method being used in Europe to build a database of opinion about soundscapes using mobile phones or PDAs.)
- Implementation needs – If FAA does move toward changing land use compatibility guidelines or indicators of noise impact, such changes would likely need extensive intra-government / intra-agency coordination and cooperation.

[6] Tokita, Y, Nakamura, S. Frequency Weighting Characteristics for Evaluation of Low Frequency Sound, 1981 International Conference on Noise Control Engineering Nederlands Akoetisch Genootschap, Delft, The Netherlands, 39-742, 1981.

- Simple description of 65 DNL – Many attendees thought that having from FAA a clear, concise statement of why 65 DNL is the compatibility policy would be very helpful in working with the public. The description might also include what effects occur at 65 DNL.

SLEEP DISTURBANCE DISCUSSION

Present FAA policy addresses land use compatibility and impact solely in terms of type of land use and the value of aircraft-produced DNL. While DNL takes into account the increased sensitivity to noise during nighttime hours by including a 10dB penalty on nighttime flights, researchers have found that other noise metrics relate better to the effects of nighttime aircraft noise on sleep. Accordingly, one part of FAA's focus for research is the relationship between nighttime aircraft noise and its effects on sleep.

This discussion began with presentations on sleep disturbance related research.[7] The first by David F. Dinges, Ph.D., Professor and Chief Division of Sleep & Chronobiology, University of Pennsylvania School of Medicine. His presentation summarized research about sleep and sleep disturbance unrelated to noise produced disturbance. Following his presentation, Mathias Basner,[8] M.D., M.S., M.Sc., Assistant Professor of Sleep and Chronobiology in Psychiatry, University of Pennsylvania School of Medicine gave a presentation that addressed research on sleep disturbance that results from noise.

David Dinges' Presentation: "Sleep and Waking Functions: What aspects of sleep are important for healthy functioning?"

The presentation gave an overview of what is known about sleep from a biological perspective. In general, healthy humans all sleep in the same way, passing from awakening through progressively deeper sleep to "slow wave" sleep. Sleep is regularly punctuated by rapid eye movement (REM) sleep which, from a brain activity perspective appears almost the same as awake or the least deep level of sleep. Muscles are paralyzed during this phase, including the inner ear which may be of interest from a noise disturbance perspective.

As the night progresses, the sleep pattern of arousing then lapsing back into deeper sleep recurs, but being less deep until full awakening at the end of the sleep period. Arousal (for example, from noise) should be more likely as the night progresses. [Research on noise induced awakenings has confirmed this characteristic.]

The recovery provided by sleep can be characterized in terms of continuity, intensity and duration. Curtailment or disruption of any one of these on a regular basis builds pressure and need to sleep, which the body will try to make up–leading to lapses of attention or serious sleepiness that can disrupt/interrupt tasks. Sleep disorders, such as sleep apnea can cause significant sleep disturbances 40–50 times per hour. It may be a stretch to think that disturbance of sleep from noise is, in comparison, likely to result in meaningful

[7] All presentations made may be found at: http://www.fican.org/pages/faa_presentations.html
[8] Formerly Head of Flight Physiology at the German Aerospace Center DLR

loss of sleep. Notably, people have an inability to correctly judge their ability to perform or the quality of the sleep they are experiencing. This inability extends to being unable to accurately identify the noise that awoke them.

For policy purposes, objective markers that quantify behavioral or health changes are preferred as opposed to scales that determine the quality of the sleep.

People are highly variable in their responses to sleep deprivation, with differences increasing as sleep loss increases. In the U.S., there is widespread use of drugs that affect sleep, suggesting that most sample populations for sleep studies will be affected by this drug use.

Mathias Basner's Presentation: An Introduction to Research on Traffic Noise Effects on Sleep

Epidemiological studies show nighttime aircraft noise may be important for public health. While asleep, the brain has the ability to evaluate sounds and decide whether reaction is important. We can have many (perhaps 20 to 30 or more) very short awakenings during the night and a few long enough to remember. Hence, noise-induced arousals or awakenings can occur along with these "spontaneous" awakenings and can be difficult to distinguish from each other. In terms of sleep disturbance from noise, it is the single noise events that are likely to produce awakenings. Many factors can affect whether or not an awakening results from a noise event.

Absent noise, there can be 20–25 brief awakenings that are unlikely to be remembered, as many as 100 EEG-arousals per night and 1–5 awakenings of about 1 minute or longer– the type that might be remembered. These represent a hierarchy of possibilities, each level of disturbance measured by different methods, the least sensitive being the "button push" when awakened, the most being polysomnography (EEG, eye movement, muscle activity). Each method has pros and cons. Morning-after questionnaires are sometimes employed, and these may be useful for determining the subject's evaluation of their sleep, but can bear only a limited relationship to the actual sleep experienced.

In their homes, while people appear to habituate to some degree to their specific situation, it appears reactions to noise events will continue for years without acclimation.

Noise metrics for entire night (Lnight) may not correlate well with sleep disturbance potential. Also, people's sensitivity to arousal varies significantly.

Finally, people who participate in sleep studies are self-selected, and we likely miss many people who may differ considerably in their sleep disturbance response to noise events.

Synthesis of Discussions into Research Topics

In general, there was agreement that the study data relating noise events to sleep disturbance represent a very small sample of the populations exposed to nighttime noise. The samples are highly selective since the studies are demanding of the subjects' time and effort, and do not include children, the sick or those with sleep disorders.

There was no consensus on the value of examining/reviewing previous studies; however, there appeared to be sufficient support to do so, such that a review should be an initial step in the sleep research roadmap. These studies of noise (from any noise source) and sleep would be reviewed for their usefulness in addressing the research topics, either with data or results, or to determine the type and size of future studies required. The following topics represent a synthesis of the group discussions and roadmap concepts developed by the expert panel before the workshop and follow-on expert panel review.

As was the case with annoyance, the FAA has invited subject matter experts to write brief papers discussing the current state of knowledge and prospects for further research using currently available data as well as acquiring new data in the US. These information briefs will also be provided at the March 4, 2010, research roadmap workshop in San Diego, CA.

KEY ISSUES TO BE CONSIDERED IN DEFINING RESEARCH ON AIRCRAFT NOISE AND SLEEP DISTURBANCE

The synthesis of discussions at the workshops and expert panel review and comments identified six issues that, if understood, could assist FAA in evaluating policy relative to nighttime aircraft noise.

1. What factors might cause populations to respond differently to nighttime noise?
Much of the recent research on noise and sleep has been conducted in Europe. This issue addresses whether those studies and results could apply to U.S. populations.

2. What noise metric correlates with sleep disturbance?
Are there sufficiently reliable models that relate a noise metric to sleep disturbance? There are reliable computer models that predict aircraft noise. This question seeks to determine whether there are reliable methods for using those predictions in estimating sleep disturbance from night time aircraft operations.

3. Does time of night make a difference?
Some research has shown that study subjects awaken more easily from noise as morning approaches. Having the ability to estimate this difference would permit a distinction between the sleep disturbance effects of late-night arrivals and of early morning departures.

4. What is the relationship of noise induced sleep disturbance to next-day effects?
Do studies reliably identify the performance/sleepiness effects of sleep disturbance caused by nighttime noise? Such a relationship would suggest consequences beyond disturbing sleep.

5. How does a given population react to different levels of nighttime operations?
One means for reducing the effects of aircraft noise on sleep would be to provide additional sound insulation. FAA has provided significant funding to support sound insulation of homes around airports throughout the U.S. This sound insulation decidedly reduces speech interference and general noise intrusion indoors. But how has such

reduction of interior noise levels affected sleep disturbance? Are there any previous studies of populations living in areas around airports that from one night to the next experience very different levels of aircraft noise, such as those that would occur for changing nighttime runway use? If so, analysis might be able to quantify the benefit of added sound insulation in terms of reduced sleep disturbance.

6. How does Lnight correlate with number of noise-induced sleep disturbance?
World Heath Organization-Europe has recommended use of Lnight for setting standards in Europe for nighttime noise. Research, however, has focused on the relationship between single noise events and the probability of awakening. Can these different approaches be reconciled?

7. What other studies of sleep disturbance can inform research of aircraft noise and sleep disturbance?
Considerable work has been done on understanding the causes and effects of sleep disturbance. Can any of this work help advance the limited knowledge on the effects of noise-produced sleep disturbance?

Other issues not discussed but that need to be part of the research roadmap because they are gaps in our understanding of aircraft noise-induced sleep disturbance include how to determine if an awakening was spontaneous versus one that was caused by aircraft noise.

S.1: INITIAL PROJECTS - WHAT RESEARCH RELATIVE TO THESE KEY ISSUES HAS ALREADY BEEN DONE?

Project S.1.1 - Meta study of reports on sleep disturbance
As with the annoyance/community reaction issues, this initial project is needed to determine what previous studies, data, and results might be useful to address the key issues. A first step would be to clearly identify the important variables associated with each of the issues. The studies would be reviewed to identify those that are included. Needed information that is not available represents a gap in knowledge that may be used either to formulate follow-on studies or that suggests further attention to the issue.

S.2: FOLLOW-ON ANALYSES OF COLLECTED INFORMATION
Potential projects listed below were discussed.

Project S.2.1 – Compare sleep disturbance across populations
A limited number of U.S. and European studies collected similar awakening data; a few studies in both areas used “behavioral awakenings” – i.e., the subject pressed a button when awakened. These can be compared to statistically compute differences in responses. Reasonable similarity could be used to justify application of other European or other country study results to the U.S. Cultural differences should be documented if possible. Additional differences include different house construction techniques and window-opening practices. Weakness of the correlations would suggest need for additional U.S. studies - probably modeled on an accepted EU approach.

Project S.2.2 – Evaluate available noise dose-sleep response relationships for practical application
There exist some models for estimating awakenings from single-noise events and for a full night of operations. Do models contain time of night of the event as a variable, and if not, is it possible to derive the dependence from existing data? These models should be evaluated/tested for producing results that are reasonable and that could serve policy development. Identify strengths and weaknesses of the models.

Project S.2.3 – Examine relation of noise-produced sleep disturbance indicators with next day effects.
There are some studies that relate sleep disturbance to next-day measures of performance, sleepiness, or other effects. Are these sufficient to relate noise-produced sleep disturbance to performance or are additional studies required?

Project S.2.4 – Examine sleep disturbance for a population exposed to different numbers and levels of night time noise events
Most sleep studies accumulate all awakening and noise event data across all nights by subject. Can reanalysis evaluate nights separately by subject so that the disturbance can be correlated with nights having significantly different levels of noise? For example, changed runway use night-to-night would result in some areas receiving very different noise exposures, night-to-night.

Project S.2.5 – Explore relation between $L_{night,outside}$ and sleep disturbance
The World Health Organization has proposed night noise guidelines for Europe using $L_{night,outside}$ as the metric of noise. Some studies have found that, though sleep disturbance increases with increasing $L_{night,outside}$, better agreement between nighttime noise and disturbance is achieved by including number of operations. This project is to examine different methods for using available models of awakening (e.g., Project S.2.2) to examine the relationship between $L_{night,outside}$ and predicted awakenings.

Project S.2.6 – Use findings of non-noise sleep disturbance studies to associate sleep disturbance in terms of physiological metrics with follow-on health effects
- Identify expert sleep researcher(s)
- Consult with expert(s) on likelihood of using available sleep research results to inform investigations of noise-produced sleep disturbance.

Project S.2.7 – Coordinate with the National Institutes of Health (NIH) to determine whether any health studies have included noise, and whether any upcoming studies might be modified to include noise and sleep.
These NIH studies should be valuable in connecting sleep disturbance of any origin with health effects.

S.3: NEW NOISE/SLEEP STUDIES
Studies of the effects of noise on sleep are limited and technologies have been developed for better data collection. It is widely recognized that these studies have been conducted on very limited populations, especially in the U.S. Consequently, new studies will be designed and pursued, using findings of the above projects as guides to critical gaps in

knowledge. Research should consider use of the more simplified ECG method for detecting sleep disturbance.

Figure 1 summarizes the projects and maps the two that relate directly to a model of the path that links acoustic factors to effects on humans.

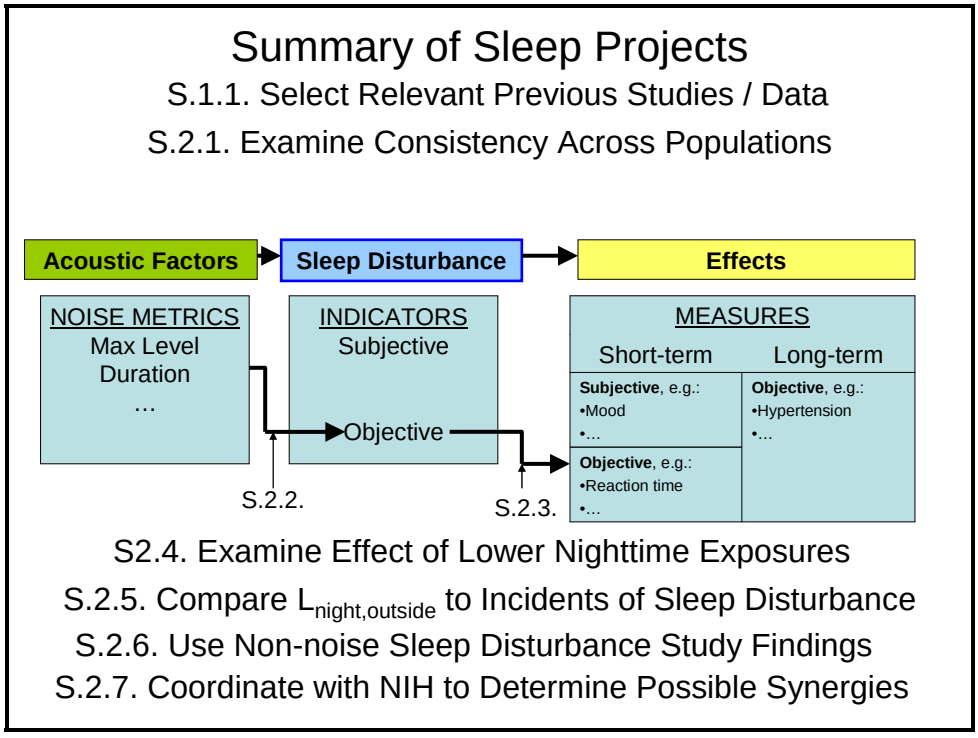


Figure 1 Summary of Proposed Sleep Projects

The group discussions tended to support the need for these projects, but also identified considerations that may limit what can be learned from researching these topics. Discussions also identified additional variables that should be considered in any research efforts.

Discussions Supporting or Limiting the Research Topics

Because FAA seeks to examine the effects of nighttime aircraft noise on U.S. populations, and because most noise/sleep research has been conducted in other countries, Project S.2.1 is important. The discussions at the workshop raised the likelihood that use of non-U.S. data without some scientific justification could easily lead to challenges, possibly legal ones.

If the association of noise with sleep disturbance is clear, Project S.2.2 will help set a course for FAA action. If there is a noise metric that reliably correlates with an objective indicator of sleep disturbance, then FAA can consider using it to adjust its noise analysis and mitigation methods and policies.

In general, there was considerable skepticism that adverse health effects, especially long-term health effects, produced by noise-induced sleep disturbance could be identified with anything less than a long-term, very expensive study. Health effects, such as high blood pressure, can have many contributing factors, and it is unlikely that a contribution from sleep disturbance due to aircraft noise can be singled out. Hence, using current data, Project S.2.3 looks only for a relationship between objective indicators of sleep disturbance and short-term performance effects.

Though not discussed during the workshop, some available data and a simple analysis of numbers tend to support the limited or complex role likely to be played by noise events on health effects. Several relationships for sleep disturbance from noise have been derived in previous studies and are presented in a slide from M. Basner's presentation, Figure 2. Figure 3 presents distributions of indoor sound levels from sleep studies at four specific air facilities.[9] Except for Castle (an air force base with fighter aircraft), indoor levels rarely exceed 70 to 75 dB. From Figure 2, at most these levels produce a 10% probability of an EEG awakening. Assuming 50 aircraft noise events a night as perhaps a high but reasonable number, there is a likelihood of 5 noise-induced EEG awakenings. Compared with a typical value of as many as 20-30 EEG awakenings in a night, the increment of 5 may not be insignificant.

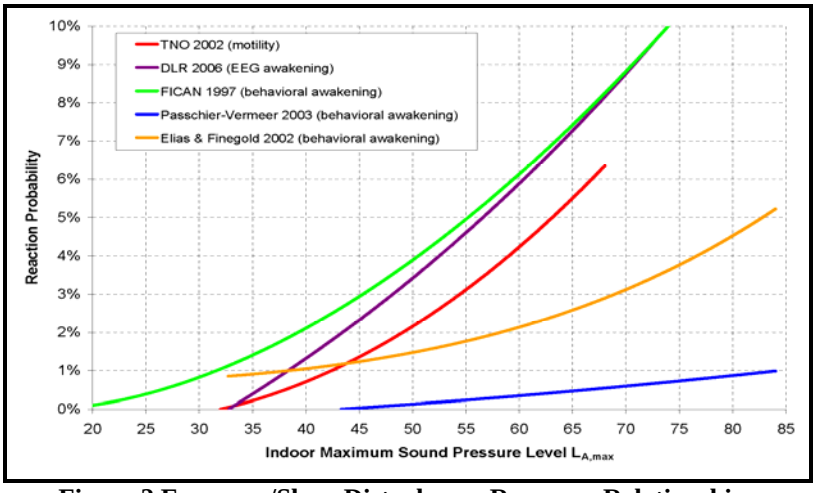


Figure 2 Exposure/Sleep Disturbance Response Relationships

[9] Data are from:
Fidell, S et al, "Noise-induced sleep disturbance in residences near two civil airports," NASA Contractor Report 198252, Contract NAS1-200101 (December 1995).
Fidell, S., et al. (2000). "Effects on sleep disturbance of changes in aircraft noise near three airports," J. Acoust. Soc. Am. 107, 2535–2547.

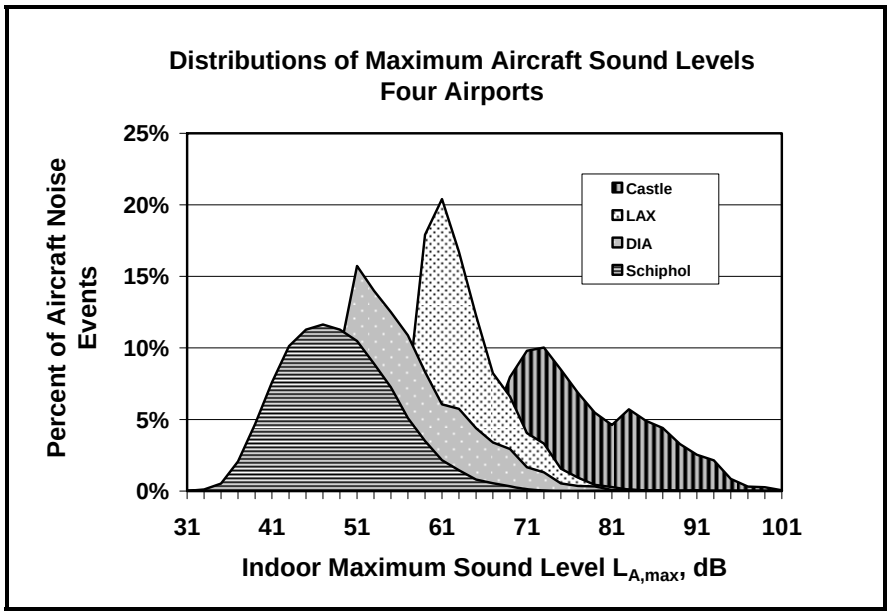


Figure 3 Typical Distributions of Indoor Sound Levels

One possible means for judging the effect of limiting nighttime aircraft noise is proposed in Project S.2.4. This is proposed as an examination of sleep data from airports where the variability of subject nighttime exposures was high. Runway use changes night-by-night could result in very different exposures for some neighborhoods, providing subjects who experience both large and small numbers of nighttime aircraft noise events. Limited data may mean the project can be used as a basis for designing a study at a U.S. airport that will provide the desired data.

Project S.2.6 is simply an acknowledgement that a great deal of work has been done in the study of sleep disturbance and its effects on performance and health. Some of this work may be useful for putting noise-induced sleep disturbance in the larger context of what is known about sleep disturbance effects.

In consideration of metrics, Lnight needs to be addressed because the World Health Organization has recommended it for use in its Night Noise Guidelines for Europe. This metric, however, takes a step beyond Project S.2.2 which addresses only the relationship between a single noise event and sleep disturbance. Use of Lnight brings into consideration the entire night of noise events and their effect on a full night of sleep. However, if a reliable relationship derives from the Project S.2.2, then a fairly simple computation in Project S.2.5, probably using noise data measured at several different airports, should show how Lnight in realistic situations correlates with probabilities of awakening.

Using data from studies referenced in footnote 9, Figure 4 and Figure 5 present a limited example of one type of analysis that could be conducted in Project S.2.5. The indoor aircraft noise events for each of nine nights for one study subject were used to compute $L_{night,indoors}$ for each night and the associated chance of at least one behavioral awakening using ANSI S12.9, Part 6, "Methods for Estimation of Awakenings Associated with

Outdoor Noise Events Heard in Homes." (The ANSI relationship is very close to the Elias & Finegold curve of Figure 2.)

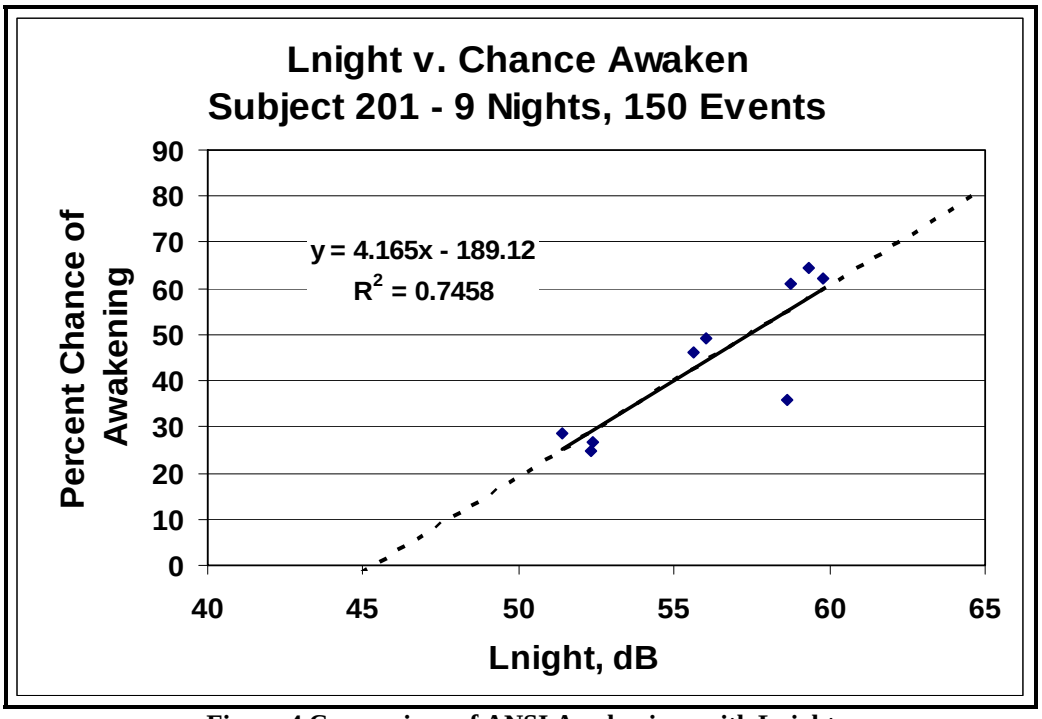


Figure 4 Comparison of ANSI Awakenings with Lnight

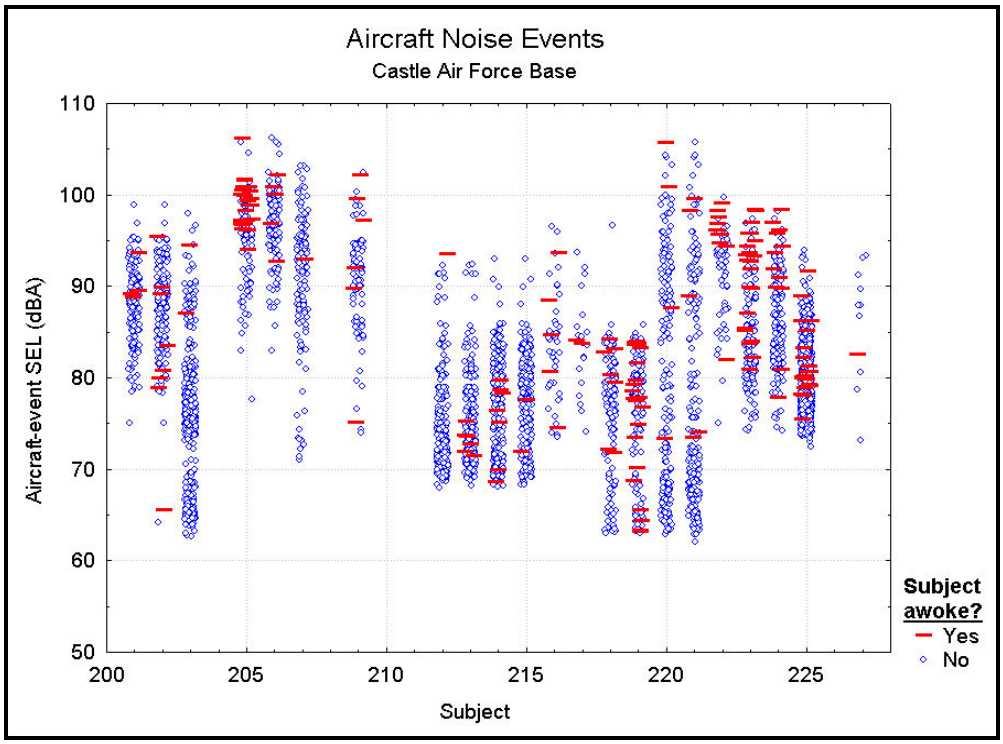


Figure 5 Distributions of Indoor Aircraft Noise Events, All Castle Subjects

Finally, because NIH conducts so many health studies, examination of whether any have included noise and whether there are any planned studies that could include noise is the purpose of Project S.2.7.

Discussions of Variables and Analysis Details to Consider

Many details were offered that might be a part of the research. Background noise affects how likely an intruding noise event will be heard or whether it will disturb sleep. Noise-induced vibrations may accompany aircraft noise events and contribute to sleep disturbance. Not only sleep disturbances, but shortening of sleep duration could be a result of noise events. Blood pressure "dipping" during sleep is an important part of sleep and whether or not noise events prevent or affect this phenomenon is important when estimating health effects.

Choice of populations for future studies is of concern. Populations used in previous studies exclude at-risk segments (aged, infants, the sick or handicapped). Future studies might examine large populations and find control groups for comparisons, but such studies are likely to be costly and perhaps beyond FAA's authority.

When assessing the effects on sleep, the number of people affected should probably be included in any measure of sleep disturbance.

Relating nightly awakenings or any model of awakenings to annual nighttime noise exposures should eventually be addressed.

Metrics other than SEL and LAmax, such as event duration, rise time, spectra, are not explicitly included in any of the projects, nor is the issue of variability of outdoor-to-indoor sound reductions provided by various house types across the U.S. and across other countries where studies have been conducted. Another variable that has not been addressed is the prevalence of nighttime opening of windows.

Annoyance and awakening are likely to be related. The relationship of the airport and the surrounding communities may be an important factor in determining how people react to nighttime aircraft noise events.

Most sleep studies have treated each noise event/awakening as independent of any previous noise event/awakening. Such an assumption of independence may or may not be significant in evaluating the sleep disturbance effect of noise.

Attachment 1
Attendees

Attended in Person, Thursday and/or Friday

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Attachment 1
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(Only Thursday participant names were available)

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Attachment 2
Planning Panel Members

Panelists for Sleep Disturbance:

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Patricia Davies	Purdue University
Jim Fields	Independent Consultant
Barbara Griefahn	Leibniz Research Center, TU Dortmund
Sarah McGuire	Purdue University
Nick Miller	HMMH

Panelists for Annoyance:

Kenneth Hume	Manchester Metropolitan University
Sandy Lancaster	Dallas-Ft Worth International Airport
Mayor Arlene Mulder	O'Hare Noise Compatibility Commission
Paul Schomer	Schomer and Associates, Inc
Catherine Stewart	U.S. Department of Army
Kevin Shepherd	NASA

Attachment 3
Draft Roadmap for FAA Aircraft Noise Impacts Research
Distributed before December 10-11, 2009, Workshop, Washington, D.C.

INTRODUCTION

This report presents first for sleep disturbance and then for annoyance, a draft research roadmap. The roadmap was derived first from the discussions at the Ottawa forum, and then revised through discussions and comments of the expert panels.[10] The roadmap is developed by identifying *Actionable Hypotheses* – hypotheses that can be tested – that are judged to capture the main issues raised by the Forum and follow-on discussions. *Associated Research Tasks* are simple examples of how the hypotheses might be tested. The research tasks are abbreviated in that they address only the basic form and the data acquisition of the research, not the complete analysis, synthesis and reporting that would be necessary. It is hoped that the hypotheses will provide the basis for development of complete scopes of work should the specific research hypotheses be pursued.

In all cases, this initial roadmap focuses on existing studies and data. The goal is to understand what existing data and results are most useful to advancing FAA's development of defensible science based information for use in formulating policy with respect to aircraft noise impacts. Additionally, it is expected that this examination / analysis of existing research will identify gaps in information / understanding that will require additional efforts to address.

For easy reference, the Actionable Hypotheses suggested in this roadmap are listed in the following table.

[10] The Ottawa discussions are documented in the "Summary Report on International Aircraft Noise Forum," October 8, 2009, available at http://www.fican.org/pdf/faa/IntlForumSummaryReport-11-19-09.pdf

Attachment 3
Draft Roadmap for FAA Aircraft Noise Impacts Research
Distributed before December 10-11, 2009, Workshop, Washington, D.C.

Actionable Hypotheses	
Sleep Related	
S1	Assemble results of all studies of noise induced sleep disturbance
S2	Compare sleep disturbance across populations
S3	Correlate noise metrics with objective indicators of sleep disturbance
S4	Examine relation of subjective and objective indicators of sleep disturbance
S5	Examine relation of objective sleep disturbance indicators with short-term performance and health effect
S6	Examine differences between aircraft noise exposed and non-aircraft noise exposed populations
S7	Use findings of non-noise sleep disturbance studies to associate sleep disturbance in terms of physiological metrics with follow-on health effects
S8	Explore relation between $L_{night,outside}$ and other metrics of nighttime aircraft noise
Annoyance Related	
A1	Assembling all available survey information that address annoyance reactions to aircraft noise
A2	Generalizability of %HA vs DNL curve
A3	Non-acoustic factors
A4	Acoustic metrics other than DNL and characterizing annoyance
A5	Short-term and long-term annoyance
A6	Complaint data are readily available and unexamined
A7	Improve communication about aircraft noise

Attachment 3
Draft Roadmap for FAA Aircraft Noise Impacts Research
Distributed before December 10-11, 2009, Workshop, Washington, D.C.

DRAFT RESEARCH ROADMAP COMPONENTS – SLEEP DISTURBANCE

WHY CONSIDER SLEEP AND HOW TO BEGIN

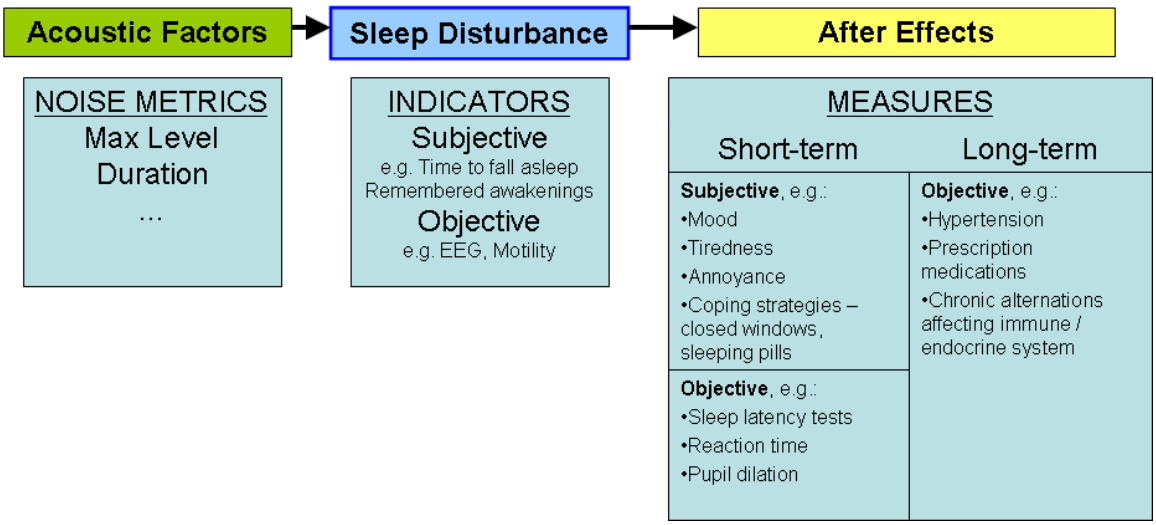
Present FAA policy addresses land use compatibility and impact solely in terms of type of land use and the value of aircraft-produced DNL. While DNL takes into account the increased sensitivity to noise during nighttime hours by including a 10dB penalty on nighttime flights, researchers have found that other noise metrics relate better to the effects of nighttime aircraft noise on sleep. Accordingly, one part of FAA's focus for research is the relationship between nighttime aircraft noise and its effects on sleep.

The following sleep disturbance roadmap is designed to begin the process of answering 5 fundamental questions:

1) What sleep related effects should /can FAA policy seek to limit insofar as public health and welfare is diminished or impaired by nighttime aircraft noise–
   a) Short-term – e.g., Subjective evaluations of the quality of a previous night's sleep, e.g., objective measures of next day reaction times
   b) Long-term - e.g. use of medications, hypertension?
2) To what extent should these effects be limited?
3) How can these effects be limited?
4) What data / research are available to provide answers?
5) What additional studies are needed?

TERMINOLOGY FOR THE SLEEP DISCUSSION

Both acoustic and non-acoustic factors may produce sleep disturbance, which in turn can lead to effects on performance and health. This roadmap aims to develop a model that relates how noise exposure affects sleep and the after-effects of sleep disturbance. Three different terms are used here to discuss acoustic factors, sleep disturbance and the associated effects and the figure below summarizes these terms. Acoustic factors are represented by "**noise metrics**," sleep disturbance is given by "**indicators"** either "subjective," reports of the sleep disturbed subject, or "objective" (observed, measureable) indicators. The resulting effects are identified by "**measures**" of Short-term or Long-term effects which can be either subjective or objective.



ROADMAP TO EXAMINE EXISTING STUDY RESULTS AND DATA

The approach taken by this initial roadmap is to thoroughly collect, review and analyze available sleep disturbance studies, results and associated data to determine whether existing information is sufficient to answer these questions or to identify gaps that should be addressed by additional studies. The roadmap anticipates that most available information will come from studies of sleep disturbance that results from aircraft noise or possibly that is caused by other sources of noise. However, one actionable hypothesis (#S7) provides for examination of sleep disturbance studies that do not include noise as a source of disturbance.

Preparatory Actionable Hypotheses

Actionable Hypotheses # S1 and S2 prepare the basis for most of the following sleep related hypotheses and research tasks. Hypothesis #S1 collects all existing sleep studies and their associated results, methods, variables measured and data in a form accessible for addressing the remaining hypotheses. Hypothesis #S2 is intended to explore whether sleep study data and results are invariant from one population to another and, since there are relatively few studies of U.S. populations, can reasonably be applied to populations around U.S. airports.

Actionable Hypothesis#S1 – Assemble results of all studies of noise induce sleep disturbance

Many studies, both laboratory and field (in people's homes) have been conducted, but neither has a comprehensive meta-study been conducted nor has a complete accessible database of methods, results and data available been constructed. This hypothesis assumes that it is possible to assemble all, or most, study information in a manner that provides background for developing initial answers to the five fundamental questions listed above.

- *Data and results from available studies of noise induced sleep disturbance can be organized and summarized in a way that permits cross-comparisons of all noise metrics, indicators of sleep disturbance and measures of effects.*

Tasks S1.1 through S1.4 below collect and summarize existing studies, their results and the information available from them, and a means for efficiently accessing all information. It is recognized that many individuals and organizations have conducted these studies, and that their participation is critical to assembling a comprehensive, useful database. Accordingly, the process for assembling the studies must be one that is satisfactory to these individuals and organizations, and is the critical step in addressing this hypothesis and pursuing much of the roadmap as described here.

Associated Research Tasks:
S1.1 Identify all available existing studies
S1.2 Identify researchers and sponsoring organizations
S1.3 Assemble all publications and unpublished information about the studies.
S1.4 Identify studies where further analysis would be useful and work with these researchers and organizations to acquire the data from those studies.
S1.5 Develop methods for accessing studies, their results and associated data

Actionable Hypothesis#S2 – Compare sleep disturbance across populations

Because relatively few noise and sleep disturbance studies have been conducted around airports in the U.S., Hypothesis #S2 compares data across populations, including those in the U.S., to determine similarity of sleep disturbance responses.

- *Populations are similar in their awakening responses to aircraft noise*

Associated Research Tasks:
S2.1 Identify U.S. and other study results that may reasonably be compared.
S2.2 Conduct statistical comparisons of sleep disturbance to estimate probabilities of similar disturbance results.
S2.3 Develop hypotheses for applying results of all sleep disturbance results to U.S populations.

Substantive Actionable Hypotheses

The following hypotheses and associated tasks are designed to directly address the five fundamental questions. They address first the relationships of noise metrics, sleep disturbance indicators and effects measures (S3 – S5), then compare noise and non-noise exposed populations (S6). Finally, hypothesis S7 provides for incorporating sleep research unassociated with noise, and S8 examines the World Health Organization "Night Noise Guidelines for Europe" which include using the noise metric $L_{night,\ outside}$ for protection of the public.

At this stage of roadmap development, the tasks associated with each of hypotheses S3 – S6 and S8 cannot be completely specified, but in general are expected to take the following form:

Associated Research Tasks:
Sx.1 Identify studies that have data / results relating to the specific comparison to be made
Sx.2 Identify models or synthesize a model intended to predict one or more variables from associated independent variable(s).
Sx.3 Test model(s) with available data or compare models by using similar inputs
Sx.4 Identify tentative conclusions and research gaps / needs

Actionable Hypothesis#S3 – Correlate noise metrics with objective indicators of sleep disturbance

A considerable amount of research has been devoted to understanding the relationship of metrics of noise exposure and sleep disturbance. This hypothesis permits a review and summary of the available studies, results and sleep disturbance models, if any. If data are available, and some studies could justifiably be combined, it can provide an opportunity to derive relationships supported by the work of several researchers.

Noise metrics are similarly related to the various objective indicators of sleep disturbance

Actionable Hypothesis#S4 – Examine relation of subjective and objective indicators of sleep disturbance

This hypothesis addresses whether there appear to be any correlations between subjective indicators of a night's sleep and the objective indicators of sleep disturbance. Such correlation, or lack thereof, will assist in determining, for example, whether policy directed at the objective indicators (motility, EEG changes, etc.) is likely to affect subjective evaluations of sleep. High correlation could also mean that collection of sleep disturbance information may be as simple as asking people about their subjective evaluation of their sleep.

Subjective and objective indicators of sleep disturbance are correlated for nights of sleep disturbed by noise events.

Actionable Hypothesis#S5 – Examine relation of objective sleep disturbance indicators with short-term performance and health effects

Assumption: Long-term health effects of noise induced awakenings are too uncertain, too little studied, potentially too much a result of non-noise awakenings and other health issues to be productively examined at this time.

- *Noise induced awakenings as determined by objective indicators result in adverse short-term performance and health effects*

Actionable Hypothesis#S6 – Examine differences between aircraft noise exposed and non-aircraft noise exposed populations

Awakenings occur whether or not noise events are present. This hypothesis intends to explore the differences between this "normal" sleep disturbance, and noise induced sleep disturbance.

- *There are significant sleep disturbance differences between aircraft noise exposed and non-aircraft noise exposed populations.*

Actionable Hypothesis#S7 – Use findings of non-noise sleep disturbance studies to associate sleep disturbance in terms of physiological metrics with follow-on health effects

Ideally, tasks addressing this hypothesis would determine which of the indicators of sleep disturbance are best correlated with different types of short- and long-term health effects. Such correlations could be used to focus the analyses of those physiological metrics as measured in noise / sleep disturbance studies.

The effects of non-noise sleep disturbance studies can help identify which indicators of sleep disturbance are best correlated with the health and performance effects that may result

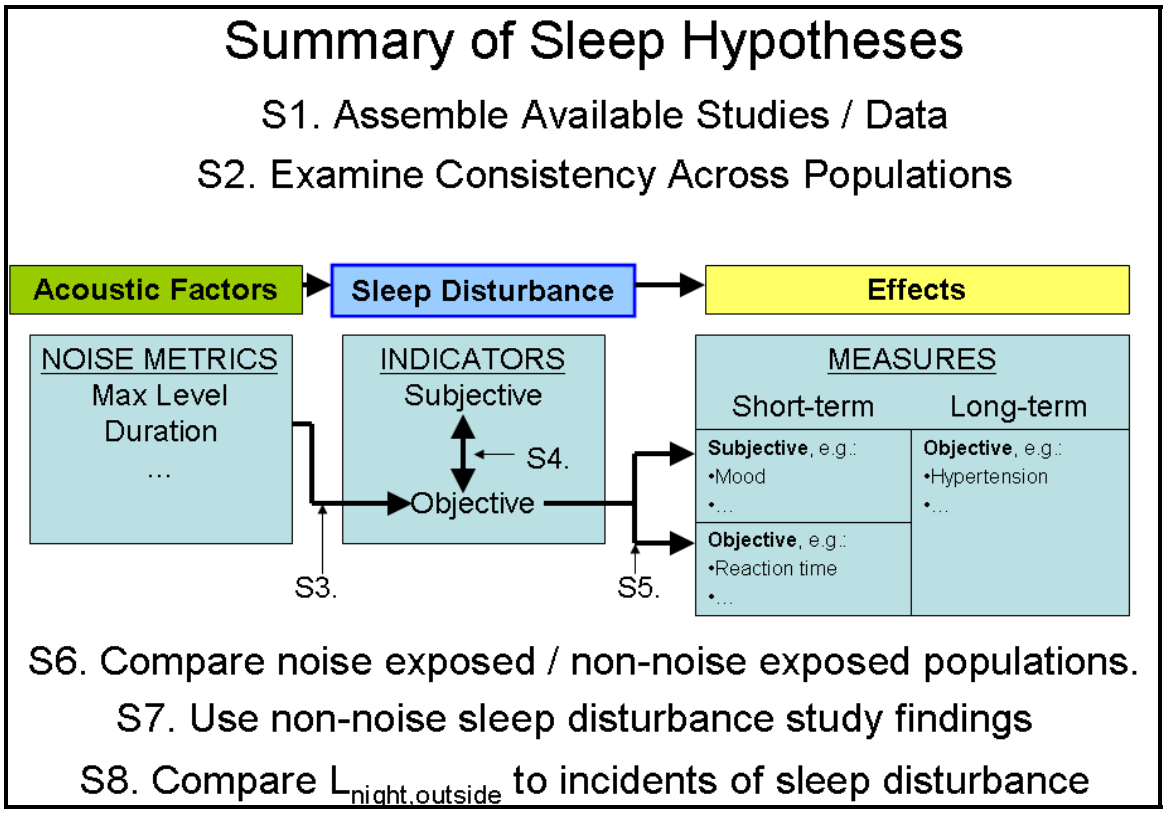
Associated Research Tasks:
S7.1 Identify expert sleep researcher(s)
S7.2 Consult with expert(s) on likelihood of using available sleep research results to inform investigations of noise-produced sleep disturbance.
S7.3 Develop with experts an approach for integrating results into analyses for Actionable Hypotheses #S3 - #S6.
S7.4 Produce white paper describing suggested approach for integration

Actionable Hypothesis#S8 – Explore relation between $L_{night,outside}$ and other metrics of nighttime aircraft noise

The World Health Organization has proposed night noise guidelines for Europe using $L_{night,outside}$ as the metric of noise. However, in the research proposed here, emphasis is placed first on the noise metrics of the single aircraft produced noise events because those are the metrics likely to be most closely correlated with noise-induced sleep disturbance and hence subjective reports of sleep quality and health effects. This hypothesis uses the Task S1 database to explore the empirical relationship between the number of noise induced awakenings and $L_{night,outside}$. If possible, relationships among a modeled chance of awakening or modeled number of awakenings during the night, the number of awakenings and $L_{night,outside}$ will also be explored.

- *The value of $L_{night,outside}$ is a reliable predictor of noise-induced awakenings and both correlate with a suitably derived model for computing probability of awakening.*

The following figure summarizes the 8 Sleep Hypotheses



Issues not addressed directly:

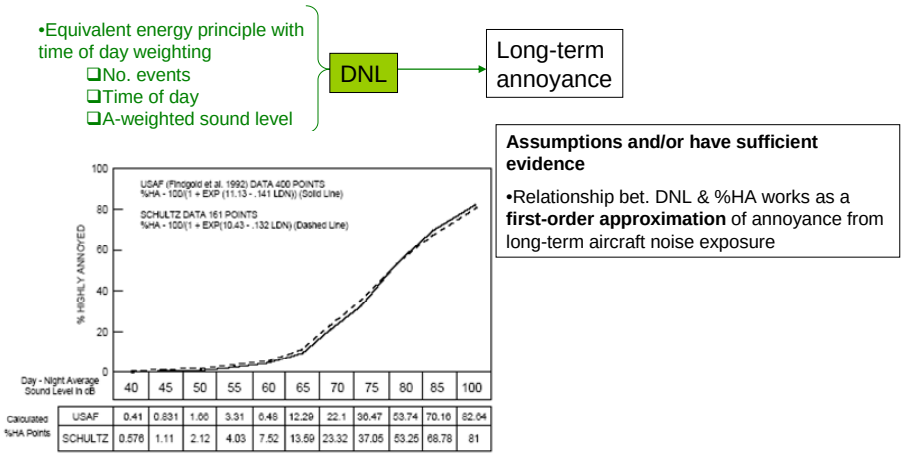
- Metrics that correlate with awakenings other than SEL, LAmax (duration, rise time, spectra, etc.) – may be able to address with Task S1 database
- Relating results to "annual average" aircraft operations
- Time awake relative to short / long-term health effects - may be able to address with Task S1 database
- Sensitive populations – Some relevant information may result from Actionable Hypotheses #S3, through #S7
- Night time weightings for exposure – May be possible to include in Actionable Hypothesis #S8
- Variability of outdoor-to-indoor sound reductions provided by various house types across the U.S. climate / regional zones.

Attachment 3
Draft Roadmap for FAA Aircraft Noise Impacts Research
Distributed before December 10-11, 2009, Workshop, Washington, D.C.

DRAFT RESEARCH ROADMAP COMPONENTS – ANNOYANCE

The annoyance roadmap aims to seek improvements to the current first-order approximation model used by FAA for a relationship between noise exposure and annoyance, shown below.

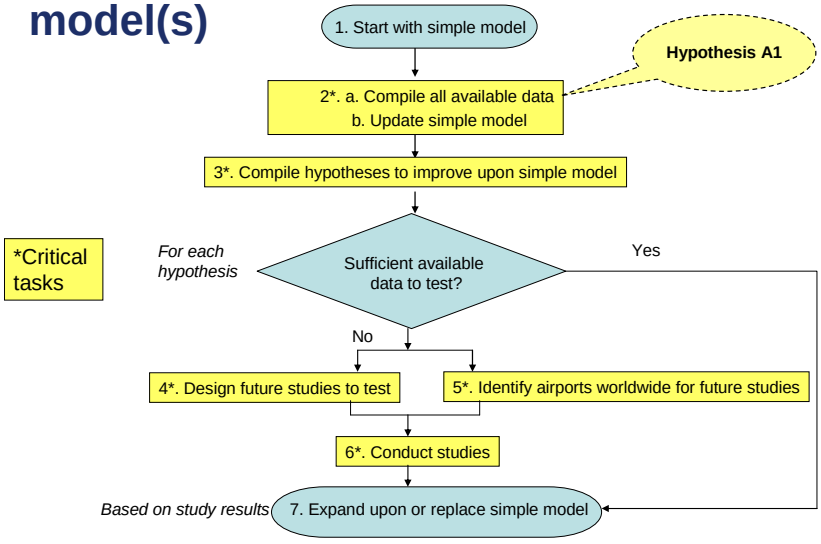
Simple model for annoyance



[FICON 1992, Federal Agency Review of Selected Airport Noise Analysis Issues]

The roadmap follows a path that starts with the simple model above and identifies hypotheses that would be tested either with existing data or field studies to improve upon the model and develop models of increasing complexity that better capture the relationship between noise exposure and annoyance.

Roadmap to improved annoyance model(s)



Preparatory Actionable Hypothesis#A1 – Assembling all available survey information that address annoyance reactions to aircraft noise

- *Data and results from available surveys of community annoyance and aircraft noise exposure can be organized and summarized in a way that permits exploration of a variety of hypotheses to improve upon the simple model of %People Highly Annoyed (%HA) to DNL.*

There is a large body of community noise survey data that continues to grow and we want to learn as much as much as possible from these data. FAA funded an update to the catalog of noise surveys from around the world, which now lists 628 such surveys between 1943 and 2008. This catalog update and engaging organizations that house large noise survey databases provide a starting point for assembling the body of work.

Associated Research Tasks:
A1.1 Identify all available existing studies (Community survey catalog update: need link to document)
A1.2 Identify acoustical variables available for each study (Community survey catalog notes whether the study included noise measurements.)
A1.3 Identify other data available in existing studies such as: aircraft operations – number and type – during survey, survey locations, house construction types / temperatures during survey, noise complaint data, public records – news items, reports, press releases, etc. – that document community / airport interactions prior to and during the surveys, form and content of survey questionnaire.
A1.4 Develop summary tables of study methods and variables

Actionable Hypotheses#A2 – Generalizability of %HA vs DNL curve

- *A single %HA vs DNL curve may not be generalizable because, despite all other things being equal, of the effects of*
  - *Time: Relationship between DNL & %HA has shifted upward over time.*
  - *Step changes: Relationship between DNL & %HA is shifted upward for communities that experience step change in noise exposure relative to those exposed to gradual change*
  - *Type and number of aircraft operations: Relationship between DNL & %HA is different for communities exposed to primarily commercial operations relative to communities exposed to primarily general aviation or military operations*

Some studies have suggested some of the above effects. A systematic investigation of these effects could lead to improvements in quantifying extent of annoyance for more specific situations.

Actionable Hypotheses #A3 – Non-acoustic factors

- *Non-acoustic factors contribute to community annoyance and their contribution is quantifiable. (Adjusting for non-acoustic factors (attitude toward airport, fear of crashes, opinion about airlines / pilots / flying public, etc.) improves correlation between %HA and DNL.)*

Some, but limited research has systematically studied quantitatively how non-acoustic factors affect community annoyance. Building upon this research may prove fruitful in several ways:

- if non-acoustic factors that contribute significantly to annoyance are within FAA's sphere of influence, FAA can work on reducing the effect of these non-acoustic factors
- better understanding of non-acoustic factors' contribution to annoyance could help improve the noise effects model (for those factors that can be determined/estimated *a priori*) or to explain model uncertainty and define uncertainty bands.

Actionable Hypotheses #A4 – Acoustic metrics other than DNL and characterizing annoyance

- *DNL may not sufficiently capture elements of noise exposure that cause long-term annoyance:*
  - *Numbers of operations influence extent of annoyance, independent of exposure (DNL)*
  - *Sound levels of loudest aircraft influence extent of annoyance, independent of numbers of quieter aircraft*
  - *Aircraft noise levels as heard indoors correlate better with the extent of annoyance than do outdoor aircraft noise levels*
  - *24-hour exposure metrics become less correlated with extent of annoyance if aircraft operations are concentrated either in the daytime or the nighttime*
  - *Duration of "quiet periods" correlates with extent of annoyance*
  - *Vibration and/or rattle from low frequencies influence extent of annoyance*

- *Self-reported annoyance may be complemented by other ways to measure annoyance*
  - *Acoustic metrics that correlate with other noise effects (such as speech interference, sleep disturbance, induced house vibrations) correlate better with extent of annoyance than does DNL*

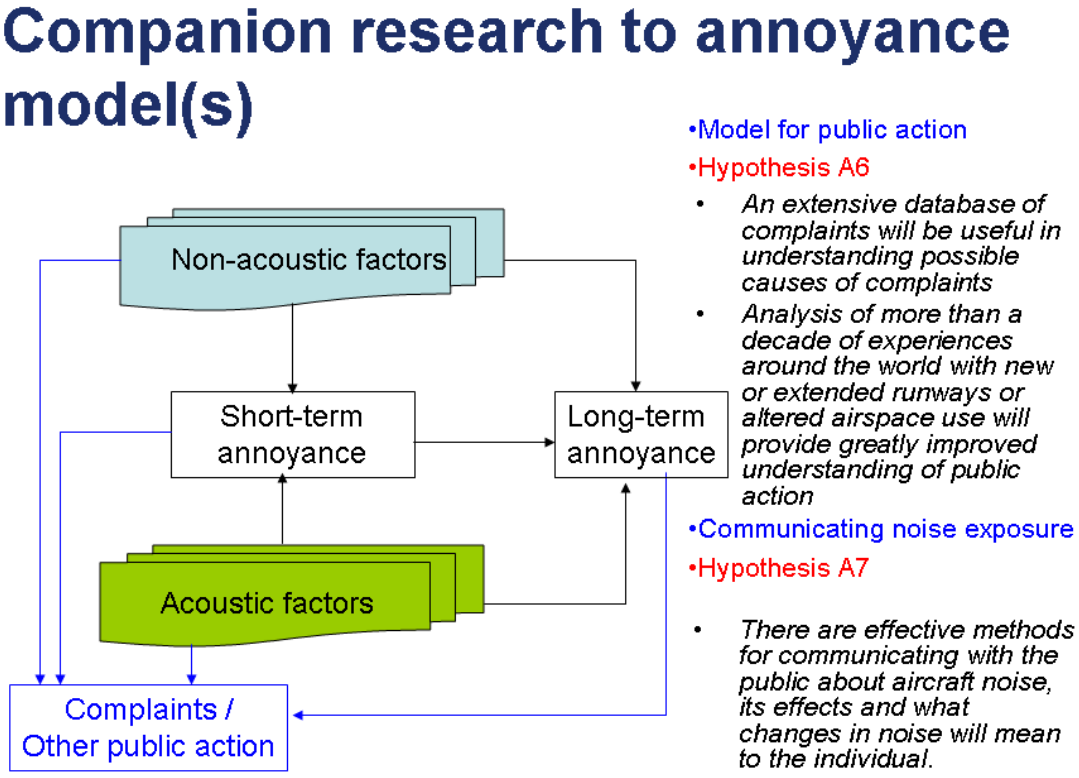
Systematically testing the validity of these hypotheses would contribute to improving the noise effects model. The tasks under hypothesis A1 will determine if sufficient acoustic and aircraft operations data are available from the databases to test these hypotheses. If not, new studies would be needed.

Actionable Hypotheses #A5 – Short-term and long-term annoyance

- *People respond to individual noise events.*
- *Long-term annoyance can be correlated with short-term annoyance from single events.*
- *Percent of population that is noise sensitive (self-reported or physiological) influences extent of annoyance*

This research would offer an alternate noise effects model that can then be compared to and evaluated against the current model.

Companion research to improving upon annoyance models is based on the assumption, illustrated below, that there are interrelationships between complaints/other public action and acoustic and non-acoustic factors (including communication) as well as short-term and long-term annoyance.



Actionable HypothesisA6 – Complaint data are readily available and unexamined

- *An extensive database of complaints will be useful in understanding possible causes of complaints*

More than 40 North American airports and many European airports collect complaint data and match them with operations likely to have produced the complaint. There has been no systematic assembly or analyses of these data. There is some research that suggests complaints result primarily from unusual events and may not be associated with

the extent of annoyance. Use of these data should provide an improved understanding of when and why complaints occur.

Associated Research Tasks:
A6.1 Identify airports that collect complaint data, determine time period and availability of data and tabulate
A6.2 Design database for storage of and access to data
A6.3 Construct database and document
A6.4 Design initial analyses of relationship of complaints to other variables
A6.5 Conduct agreed-upon analyses and document results
A6.6 Draft a universal complaint form; sample reference: "A Good Practice Guide to the Assessment and Management of Aircraft Noise Disturbance around Northern Ireland Airports," Manchester Metropolitan University, July 2003, and "An analysis of community complaints to noise," Luz, G.A., et al, J. Acoust. Soc. Am. 73 (4). April 1983.

Actionable Hypotheses#A7 – Improve communication about aircraft noise

- *There are effective methods for communicating with the public about aircraft noise, its effects and what changes in noise will mean to the individual.*

One of the recognized impediments to community understanding of aircraft noise analyses, effects and decisions related to airport / airspace changes, is the impenetrable derivation and meaning of DNL. Several countries have made some progress in improving communication, particularly Australia and a recent effort in the UK by Manchester Metropolitan University (OMEGA) with focus groups providing insight into what further research might be useful.

Associated Research Tasks:
A7.1. Review the OMEGA Community Noise Study, "Indices to enhance understanding & management of community responses to aircraft noise exposure," Hooper, Maughan, Flindell, Hume, January 2009
A7.2 Review reports produced by the Australian Department of Transport and Regional Services on providing aircraft noise information.
A7.3 Explore potential joint studies, e.g., FAA/Omega follow-on study conducted in both the UK and the US/

The last elements of the draft roadmap below are additional considerations and tasks:

- *Investigate applicability of EPA risk assessment methodology*
  - FAA may need to establish new land use compatibility guidelines based on the above proposed research
  - EPA has long-term experience in judging risk and costs for setting thresholds of exposure
  - FAA may be able to benefit from the EPA experience

Considerations for Future Studies – Collaborative Approach

- *Build upon state of the art research to design standardized study.*

This task would ideally be a cooperative international effort to develop a standardized series of questions for future use. This task should be accomplished in coordination with Actionable Hypotheses above so that important variables and questions not previously included may be considered.

- *Identify state-of-art technologies to acquire noise data and conduct surveys*

Noise level measurement techniques to complement surveys using the above series of questionnaires need further design, considering recent developments in instrumentation and associated software. For example, sound level monitors have the ability to make digital recordings of events, and promising pattern recognition software may be available to automate noise source identification. Use of internet / wireless communication may also improve acoustic measurement capabilities.

- *Plan similar studies for airports worldwide*

Aircraft noise is a world-wide problem for near-by communities and for airports / airspace systems needing to expand capacity. Gathering consistent data internationally will improve the understanding of the problem, and should increase the abilities of airports and communities to work together addressing this issue that affects quality of life and the ability of economies to provide needed air commerce capacity.

Issues not directly or only partially addressed:

- Effects on education / learning – (ACRP investigating)
- Effects of rural background sound levels on annoyance / reaction / effects
- Airport / community interaction successes
- Non-acoustic factors explain why aircraft annoyance is greater than road annoyance in %HA vs DNL data.