An Update on Research to Guide United States Policy on Aircraft Noise Impact

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INTRODUCTION

Aircraft noise is a major environmental concern and can constrain aviation growth. Over several decades, United States policy has promoted actions to reduce the impact of aircraft noise on people around airports. The number of Americans living in areas of significant aircraft noise exposure has been reduced from 7 million in the mid-1970's to less than 300,000. Looking forward, the goal is to continue to reduce people exposed to significant noise despite aviation growth, and provide additional measures to protect public health and welfare and national resources (e.g., national parks). Measures to reduce noise impact—including aircraft source noise reduction, noise abatement flight procedures, airport configuration changes, land use controls, funding for noise mitigation—are guided by the level of the cumulative noise impact using the Day-Night average sound Level (DNL) and whether land uses are deemed incompatible with that level. Determinations rely on studies that were last reexamined in the U.S. in the early 1990's. There have been changes in aircraft technology, operations, public expectations, and scientific knowledge. New software tools under development will have the capability to quantify interdependencies among aviation-related noise, emissions and fuel burn both at the source level and through changes in health and welfare endpoints.

This paper provides a synthesized review of major considerations related to aircraft noise impact and research being conducted to guide U.S. policy.

AVIATION NOISE IMPACTS ROADMAP

In 2009, the Federal Aviation Administration (FAA) Office of Environment and Energy began the process of developing a comprehensive research roadmap to address noise impact research needs (Girvin, 2009). In 2009-2010, the FAA conducted three workshops focused on noise impacts on health, annoyance, and sleep disturbance. During the workshops, the knowledge gaps were discussed and research projects were proposed to address the gaps. Following recommendations from experts in the field, the FAA funded several studies on the relationship of noise to annoyance and sleep disturbance, which are described in this paper. Workshop attendees expressed an interest in conducting regular meetings to coordinate and communicate research activities and findings, advance collective scientific knowledge, and develop optimal mitigation solutions.

The first Meeting on the Aviation Noise Impacts Roadmap was held in April 2011 in Washington DC. The FAA, National Aeronautics and Space Administration (NASA), Department of Defense (DoD), Department of Housing and Urban Development,

National Park Service, Centers for Disease Control and Prevention, National Institutes of Health, National Oceanic and Atmospheric Administration and other federal agencies, international organizations, industry, academia, and the public met to discuss ongoing activities and future noise impacts research needs. Based on presented material, discussion and responses to knowledge gaps questionnaires, the Aviation Noise Impacts Roadmap will be developed and posted on the FAA website. The roadmap will outline key research elements, summarize current programs and projects, identify knowledge gaps, and future research activities.

CURRENT FAA SPONSORED NOISE RESEARCH

The noise research framework is grounded in understanding the problem and developing solutions (Girvin, 2008). There are four key focus areas: noise effects on health and welfare, aircraft noise modeling, costs of aircraft noise on society, and noise in national parks and wilderness.

Noise effects on health and welfare

The current criterion of DNL 65 dB as a threshold for significant noise impact was established in 1980. In 1992, the Federal Interagency Committee On Noise (FICON) reviewed and reaffirmed DNL as the best noise exposure metric and endorsed the dose-response relationship to determine community noise impacts, with broad acceptance of 65 dB as a reasonable criterion. These determinations rely on studies that were last reexamined in the U.S. in the early 1990's. Since that time, there have been changes in aircraft technology, operations, public expectations, and scientific knowledge. In addition, the majority (more than 95%) of all social surveys of reaction to noise after the 1970s were conducted overseas (Bassarab et al, 2009) and may not be reflective of the U.S. experience. In short, it is timely to revisit the foundations on which the criterion has been established.

The experts and other attendees at the 2009-2010 workshops identified five high priority research project topics on annoyance and eight on sleep disturbance. The topics on annoyance include: a review of available studies, the conduct of new surveys in U.S., the retrospective study of community reactions, the development of a standardized noise complaint handling system, and test methods for communicating with the public on aircraft noise. The identified research interests on sleep disturbance include: meta-studies of reports of sleep disturbance, the comparison of sleep disturbance studies of U.S. populations with other populations, the comparison of sleep disturbance models and prediction results for realistic scenarios of an entire night of operations, the review of studies of next-day effects, the review of studies to identify populations that experienced variable nighttime exposures and to separate effects by exposure, the use of available sleep disturbance models to compare awakenings with corresponding values of L_{night}, the examination of available non-sleep disturbance studies of health effects for applicability to disturbances produced by noise, and collaboration with the National Institutes of Health to determine whether previous or pending research has or could include noise and sleep (FAA Noise Impacts Research Workshops, 2009-2010).

With these recommendations in mind, the FAA has launched several research projects through the FAA sponsored and managed by the National Academies Airport Cooperative Research Program (ACRP), the FAA Center of Excellence Partnership for Air Transportation Noise & Emission Reduction (PARTNER) sponsored by the FAA, NASA Transport Canada, DoD and Environmental Protection Agency, and the John A. Volpe National Transportation Systems Center. Below is brief description of several projects.

Schultz Curve Update: The dose-response curve initially developed by Schultz in 1978 (Schultz, 1978) and endorsed by FICON in 1992 (FICON, 1992) is currently used by the FAA. The International Standards Organization (ISO) Working Group 45 is developing a new annex to ISO Standard 1996- Part 1, which specifies methods to assess environmental noise and gives guidance on predicting the potential annoyance response of a community to long-term exposure from various types of environmental noises. The Working Group is considering adopting an updated community annoyance prediction curve based on two data analyses that include more data and more current data. One analysis was conducted by American acoustician Sanford Fidell (Fidell et al, 2011), and another by Dutch noise experts Henk Miedema and Henk Vos of TNO (Miedema and Vos, 1998, and Miedema and Vos, 1999). The latter approach serves as a basis for the European Commission Position Paper on dose-response relationships between transportation noise and annoyance (EU/ WG2, 2002), which presents curves for noise annoyance from aircraft, road traffic and railway noise. Two dose-response curves derived by teams are essentially identical below DNL 65 dB. Both teams' recent analyses were partially sponsored by the FAA (Fidell et al, 2011, Janssen and Vos, 2011 and Janssen et al, 2011).

Alternate and Supplemental Metrics: Last year the FAA contracted with two expert teams to determine whether the rationale for the primary reliance on DNL to define noise impact remains valid or requires updating to better reflect current understandings of community annoyance caused by aircraft noise exposure. Reports concluded that DNL values for noise exposure of aircraft operations correlate well with other conventional noise metrics. The teams pointed out that there is no improvement in the accuracy of prediction that may be expected from the substitution of other cumulative noise metrics for DNL. Several improvements can be considered, such as modifying the level, time of day, and weighting factors; accounting for the influence of non-acoustic factors; and also using supplemental metrics that are better understood by the public. It was also concluded that in order to modify or replace DNL, a significant new study is required. Fifteen high interest existing aircraft noise surveys were identified as candidates for further analysis, and recommendations for new surveys were formulated.

Survey Design Project: The objective of this ACRP project, "*Understanding Public Perception of Aircraft Noise and Noise-induced Sleep Disturbance*," is to develop and validate research protocol for a large-scale study of aircraft noise exposure- annoyance response relationships across the U.S. and to prepare a scope of work for initiating a large–scale study to assess the relationship between aircraft noise and sleep disturbance for U.S. airports. The purpose of the annoyance study would be to determine the extent to which the aircraft noise exposure-response relationship should

be updated based on current U.S. data, in view of changes including increases in traffic volume, decreases in aircraft source noise, and public environmental expectations.

Annoyance and Sleep Disturbance: Studies on annoyance and sleep disturbance are being carried out under the PARTNER program. Part of the research is focused on assessing how different attributes of aircraft noise (loudness, spectral balance, roughness, tonality, and fluctuation strength) can affect annoyance. Another aspect of the research is focused on understanding the impact of low frequency noise on annoyance. A different project is investigating the impact of aircraft noise on sleep and will attempt to develop models to predict sleep disruption for a given aircraft noise profile.

Children's Learning: The FAA supports the mitigation of noise impacts on schools by providing technical guidance and funding for sound insulation. Current criteria for noise impacts on schools and for sound insulation are the same as for residential housing. Should they be the same? An ACRP project *"Assessing Aircraft Noise Conditions Affecting Student Learning"* is aiming to identify and evaluate conditions under which aircraft noise affects student learning and to identify and evaluate alternative noise metrics that best define those conditions.

Noise Issues beyond DNL 65 dB: Land areas immediately beyond the DNL 65 dB around airports are experiencing population growth. A Volpe Center project, "*Address Noise Issues beyond 65 DNL Contour Requirements,*" is evaluating measures to address noise outside of DNL 65 dB contours, including the cost/benefit tradeoff of each measure. The concept is to recommend measures that could establish "buffer zones" (Albee, 2003) around airports where noise levels are not deemed to be significant, but may still cause community concerns and engender opposition to airport growth.

Aircraft Noise Modeling

The FAA's Integrated Noise Model (INM) is a computer model that evaluates aircraft noise impacts in the vicinity of airports. Originally released in 1978, it is the most widely distributed aircraft noise prediction tool in the world—with over 800 users in more than 40 countries (Fleming, 2005). INM has been continually updated since its inception.

Under the auspices of the Next Generation Air Transportation System (NextGen), the U.S. has adopted a five-pillar strategy to effectively address aviation environmental impacts. One of the pillars, to advance scientific understanding and improve integrated noise, emissions and fuel efficiency analyses capability, is being addressed through the FAA's Aviation Environmental Tools Suite initiatives.

Aviation Environmental Design Tool (AEDT): AEDT is a part of the Tools Suite. This PARTNER project is focusing on development a comprehensive suite of software tools to facilitate more comprehensive consideration of aviation's environmental effects. It is a software system that dynamically models aircraft performance in space and time to produce fuel burn, emissions and noise. Full flight gate-to-gate analyses are possible for study sizes ranging from a single flight at an airport to scenarios at the regional, national, and global levels. AEDT is currently used by the U.S. government to consider interdependencies among aircraft-related fuel burn, noise and emissions. AEDT is

being developed for public release, and will become the next generation aviation environmental tool. In 2012, AEDT version 2a will be released, replacing the current public-use Noise Integrated Routing System (NIRS) for regional noise analysis. That will be followed by AEDT version 2b that will have the airport analysis capabilities that will replace the INM and the Emissions and Dispersion Modeling System (EDMS).

Current FAA noise modeling research is addressing de-rated thrust take-off, behind start of takeoff roll noise directivity adjustment, helicopter spectral data below 50Hz, expansion of the aircraft database, and improvements in audibility.

Source Emission and Propagation: This PARTNER project is focusing on advanced noise propagation algorithms. It models a thrust reverser low frequency noise for aircraft landing operations, effects of complex terrain and meteorology, and high altitude enroute noise.

Airport Taxiway Noise: Predicting noise from taxiway operations is minimally addressed in current noise models. The objective of the *ACRP project "Aircraft Taxi Noise Database for Airport Modeling"* is to develop a Noise-Power-Distance (NPD) and spectral class database for nominal taxi, break-away and idle thrust levels to improve taxi noise calculations. The research is mature and is planned to be implemented within the AEDT 2b release.

As aircraft technology continues to advance, modeling tools must continue to evolve to be able to assess new technology. Research exploring the effects of open rotor and supersonic aircraft has begun.

Multimodal Noise Modeling: Another future direction of modeling is modeling across various transportation modes (multimodal). At the end of 2010, the ACRP project *"A Comprehensive Development Plan for a Multimodal Noise and Emission Model"* (MDP) was completed (Connor, 2011). MDP focused on feasibility and the creation of the process of tool development for a multimodal tool to perform an environmental analysis consisting of noise, air quality, climate and economics for all modes of transport.

Costs of Aircraft Noise on Society

At the seventh meeting of the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP), held February 5-16, 2007 (ICAO, 2007), "the meeting acknowledged the growing complexity associated with assessing noise and emissions effects of aviation, especially when considering impacts and their influence on benefits-costs." The meeting also noted that "to fully assess interdependencies and analyses of the human health and welfare impacts…, it would need to employ tools that were capable of looking not only at one aviation environmental parameter in isolation, but also at the effect that changing one aviation-related environmental parameter has on other aviation environmental parameters." It "would (also) need to frame the impacts of these parameters on common terms, so that it can understand the implications of the interdependencies and make policy decisions taking those implications into account."

The components of the FAA's Aviation Environmental Tools Suite directly relevant to impacts analyses include the following.

Aviation environmental Portfolio Management Tool for Impacts (APMT-Impacts): estimates the environmental impacts of aircraft operations through changes in health and welfare endpoints for climate, air quality and noise;

Aviation environmental Portfolio Management Tool for Economics (APMT-Economics): models airline and aviation market responses to environmental policy options; and

Cost Benefit with the Aviation environmental Portfolio Management Tool (APMT-Cost Benefit): combines Tools Suite output to perform cost benefit analyses.

The APMT-Impacts tool is sub-divided into three modules: Noise, Air Quality and Climate. The methodologies for each module begin with noise and emissions data from AEDT, followed by the calculation of physical and monetary impacts. Impacts and associated uncertainties are simulated based on a probabilistic approach using Monte Carlo methods. The policy analysis function considers the calculation of the environmental and economic impacts of a policy option relative to a baseline case, where the baseline represents the extrapolation of the status quo. Table 1 below (He, 2010) lists the effects modeled under each impact area and corresponding metrics. Additional information is available on-line at http://www.apmt.aero.

Table 1: Overview of Environmental impacts modeled in APMT

Impact Type	Effects Modeled	Primary Physical Metrics	Primary Monetary Metrics
Noise	• Property value depreciation (owner occupied and rental properties)	• Population exposed to noise • Noise exposure area	• Capitalized impacts • Annual impacts • Net present value
Climate	• CO2 • Non-CO2, NOx-O3, cirrus, sulfates, soot, H2O, contrails, NOx-CH4, NOx-O3 long	• Globally-averaged surface temperature change	• Annual impacts • Net present value
Air Quality	• Primary particulate matter (PM) • Secondary PM by NOx and SOx	• Incidences of mortality and morbidity	• Annual impacts • Net present value

As shown in the Table 1, noise costs are estimated using a hedonic property value or hedonic price methods. The property value depreciation metric is the only currently available metric for this type of analysis. Additional data is needed to be able to monetize potential health and welfare impacts of aircraft noise in APMT.

Noise in National Parks and Wilderness

The FAA's guidance for assessing aircraft noise for purposes of compliance with the National Environmental Policy Act (*FAA Order 1050.1E, "Policies and Procedures for Considering Environmental Impacts"*) states that special consideration needs to be given to the evaluation of noise impacts on noise sensitive areas within national parks and similar areas where other noise is very low and a quiet setting is a generally recognized purpose and attribute. The DNL 65 dB threshold for significant impact does not adequately address the effects of noise on such areas. Since the early 1990s, the FAA and the National Park Service have collaborated periodically to investigate the relationship between aircraft noise exposure and park visitors' response, but have not yet achieved a generally-accepted systematic approach to metrics or impact criteria.

Currently, the FAA is working in coordination with the National Park Service on AEDT/INM enhancements to improve the prediction of noise for flights over national parks. In addition to modeling enhancements, studies are being carried out on predicting ground based audibility and collecting and analyzing ambient noise data.

Noise Modeling of Overelapping Flights: A team at the Volpe Center is working on the development of an algorithm to reduce the over-prediction of the time aircraft noise is audible by accounting for the effect of simultaneously occurring aircraft events.

Park Visitor Dose –Response: There is work underway on *Park Visitor Dose-Response* assessment in cooperation with experts on park management, recreational sociology, psychology, and acoustics. This work seeks to establish noise exposure-response relationship for visitors to naturally quiet areas and to develop thresholds for significant noise impact (Anderson et al, 2011).

In addition to visitor dose-response assessment, wildlife dose-response relationships are also of interest Animal response to aircraft noise can range from acute behavior responses to long-term responses. Researchers emphasize the challenges of translating information on wildlife responses to categories of impacts due to the many possible animal responses that may result from a given acoustic exposure. The isolation of aircraft dose from other components of the acoustic environment and correlation with wildlife responses will be difficult and may require manipulation of dose. Researchers have established recommendations for future data collections efforts.

CONCLUSIONS

The FAA continues to pursue collaborative research activities with other federal agencies, academia, consultants and other parties interested in aviation noise. The studies described in this paper are part of a multi-year planned noise research effort that will be executed as funding becomes available.

The FAA will review research results on a periodic basis. When knowledge is sufficiently mature, research results will inform and guide policy. The FAA is not a solo performer of research. Neither is the FAA a solo decision-maker for potential policy revisions. This will necessarily be a collaborative effort with other agencies engaged in and affected by aircraft noise determinations. There will also be a publicly transparent process for considering new policy directions.

The FAA's future vision is to continue to reduce the impacts of aircraft noise through a balanced approach of aircraft source noise reduction, NextGen operational capabilities, and airport and land use compatibility planning and mitigation. Noise impact and mitigation criteria and land use compatibility guidelines must be based on the best available science. The adverse effects of noise should be addressed where and when it matters, and should be balanced with other environmental considerations. Policy built on a solid scientific foundation should also increase the public trust and understanding in how aircraft noise impacts are described, computed, addressed, and mitigated.

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