RESEARCH REVIEW OF SELECTED AVIATION NOISE ISSUES

BY

FEDERAL INTERAGENCY COMMITTEE ON AVIATION NOISE

April 2018

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FEDERAL INTERAGENCY COMMITTEE ON AVIATION NOISE

EXECUTIVE SUMMARY

The 1992 FICON Report, *Federal Agency Review of Selected Airport Noise Analysis Issues,* provided a comprehensive review of selected airport noise analysis issues, and included policy guidance that still remains in effect. Since 1992, research has been conducted to inform several of the issues discussed in the FICON Report. In addition, other issues have been raised and research conducted. Finally, several issues still remain unresolved, and have clear research needs.

This report serves the following purposes: (1) updating FICON findings to reflect research that has been conducted since the FICON Report was published; (2) summarizing additional findings concerning aviation noise issues that were not addressed by FICON; and (3) identifying those aviation noise research issues that warrant additional research and focus. The report focuses on those areas where there has been *change in understanding* or *new research that has led to different findings*. FICON findings on technical issues that have not been addressed in this report remain unchanged; thus, readers should view this document as a supplement to the FICON Report, not a replacement for it. Further, this FICAN review is limited to discussion of technical findings. FICAN has not attempted to undertake any policy analyses based on those findings; that is left to the discretion of FICAN member agencies.

Since publication of the FICON Report, a great deal of research has been conducted on the effects of noise, though not all of it has focused on transportation noise. While it is possible to generalize conclusions concerning the effects of surface transportation noise, the character of aviation noise can be quite different from highway noise (i.e., higher maximum levels, more time between events) and rail noise (different frequency content); thus, some caution should be taken in extrapolating conclusions from those results.

Regarding original FICON conclusions, FICAN has reviewed the findings of the 1992 FICON Report, and makes the following updated findings and recommendations:

- Sleep disturbance: FICAN recommends that environmental impact analyses that address sleep disturbance utilize ANSI S12.9-2008[1], *Quantities and Procedures for Description and Measurement of Environmental Sound — Part 6: Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes*. As this guidance was developed based on data collected in resident's homes, it may underestimate sleep disruption in unfamiliar and outdoor settings.
- Effects of aircraft noise on children's learning: FICAN recommends that analyses addressing noise effects on children's learning include predictions of school-day noise exposure, as measured by 8-hour Leq, until other research suggests a more appropriate metric. FICAN also recommends that acoustic measurements of classroom noise and new classroom acoustic design follow guidelines presented by ANSI S12.60-2002, *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools*.
- Aircraft noise annoyance: Research conducted since the FICON Report was released indicates that annoyance to aircraft noise is higher than that described by FICON. FICAN will review ISO Standard ISO 1996-1:2003[2] that was released on March 1, 2016 and results of federal research studies currently underway[3]. Review and revision of noise impact thresholds that may result from

[1] At the time of this report's publication, The Acoustical Society of America is reviewing the status of ANSI S12.9-2008. Section 2.2.3 below provides additional detail.

[2] ISO 1996-1:2003 *Acoustics — Description, measurement and assessment of environmental noise:*
— Part 1: Basic quantities and assessment procedures
— Part 2: Determination of sound pressure levels

[3] See ACRP Project 02-35: *Research Methods for Understanding Aircraft Noise Annoyances and Sleep Disturbance* available at http://nap.edu/22352 and the FAA's National Annoyance Survey undertaken between July 2015 and Fall 2017, an announcement for which can be found at 79 FR 33797, June 12, 2014.

updated annoyance relationships will be left to agency discretion. In addition, FICAN notes that recent research on aircraft noise annoyance has been and will continue to be conducted around civilian airports. Additional research is needed to identify possible differences in annoyance around military aviation facilities.

- Non-auditory health effects: Extensive research has demonstrated that chronic road traffic noise has non-auditory health effects. Due to the lack of studies on the effects of aviation noise on non-auditory health effects, research needs to be conducted to quantify relationships between aircraft noise level (dose) and the health outcome in question (effect).
- Noise model accuracy: FICAN does not believe that noise predictions should be limited to Day-Night Average Sound Level (DNL) 65 dB and higher. While FICAN acknowledges that the accuracy of the modeling tends to decrease as source to receptor propagation distance increases, modern aircraft noise models are able to predict noise exposure with acceptable precision whether above or below DNL 65 dB (under most conditions). Absolute accuracy has not been quantified, but depends on the accuracy of input, internal databases, and user proficiency, rather than on the model itself.

FICAN has identified a number of aviation noise issues that were not addressed in the 1992 FICON Report and merit its attention today:

- Low Frequency Noise: FICAN finds that additional research needs to be conducted before a low frequency noise (LFN) metric and an associated dose-response relationship can be recommended. For airports with low frequency noise concerns, supplemental noise analysis – possibly including vibration measurements – should be considered.
- Effects of noise on wildlife and visitors in parks and wilderness areas: There has been some research on visitor response to aviation noise in parks; standards for predicting response are in development. Research suggests that wildlife is affected by noise, but no dose-response relationships between aviation noise and its effect on wildlife have been established. Regarding cultural resources, there have been a handful of studies on noise, but no conclusive findings; additional research is needed in order to make specific recommendations.

FICAN believes there are a number of key research needs in the areas of: annoyance; non-auditory health effects; sleep disturbance; emerging aviation noise issues related to non-traditional vehicles, including unmanned aerial systems (UAS), helicopters, military fighter jet aircraft and the phenomenon of crackle, commercial space, and civil supersonic aircraft; noise in national parks, wilderness, and other rural areas; and supplemental metrics.

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1 INTRODUCTION

This report provides an update of the status of airport noise issues of concern to federal agencies. It was undertaken as an update to the 1992 *Federal Agency Review of Selected Airport Noise Analysis Issues*[4] ("the 1992 FICON Report").

The FICON Report presented a series of conclusions on technical issues in the following categories:

- General Findings
- Public Health and Welfare Findings
- Environmental Degradation/Impact Findings
- Land Use Planning Findings
- Education of the Public Findings

The FICON Report also recommended that "a standing federal interagency committee should be established to assist agencies in providing adequate forums for discussion of public and private sector proposals, identifying needed research, and in encouraging the conduct of research and development in these areas". The Federal Aviation Administration (FAA) committed to the establishment of an interagency committee in its November 1993 *Report to Congress on Effects of Airport Noise*, and subsequently convened the Federal Interagency Committee on Aviation Noise (FICAN) in November 1993.

FICAN has prepared this report with the following goals in mind: (1) to update FICON findings to reflect research that has been conducted since the FICON Report was published; (2) to summarize additional findings concerning aviation noise issues that were not addressed by FICON; and (3) to identify those aviation noise research issues that still warrant additional research and focus. The report focuses on *those areas where there has been change in understanding or subsequent research that has led to different findings*. FICON findings on technical issues that are not discussed in this report remain unchanged. Further*, this FICAN review is limited to discussion of technical findings as opposed to policy analyses*. While it is appropriate for FICAN to determine that the scientific findings of a particular dose-response relationships between aircraft noise and effects are scientifically valid, it is not appropriate for FICAN to identify a specific noise level as a threshold of impact. Those policy analyses and decisions are left to the discretion of FICAN member agencies.

Section 2 provides FICAN's current finding on the following topics: awakenings from aircraft noise; effects of noise on children's learning; annoyance; and accuracy of noise model predictions.

Subsequent to the publication of the FICON Report, additional aviation noise issues have arisen and been brought to FICAN's attention. These issues are discussed in Section 3, and include: low frequency noise, and noise in national parks and wilderness areas.

In Section 4, FICAN summarizes research recommendations in a number of areas:

- Non-auditory health effects;
- Sleep disturbance;
- Emerging aviation noise issues related to non-traditional vehicles, including unmanned aerial systems (UAS), helicopters, military fighter jet aircraft and the phenomenon of crackle, commercial space, and civil supersonic aircraft;
- Noise in national parks, wilderness, and other rural areas; and
- Supplemental metrics.

[4] Federal Interagency Committee on Noise, *Federal Interagency Review of Selected Airport Noise Analysis Issues*, August 1992; at: http://www.fican.org/pdf/nai-8-92.pdf.

2 UPDATE OF FICON FINDINGS

Aviation noise research conducted since the issuance of the 1992 FICON Report has resulted in findings that confirm or modify those made in the 1992 FICON Report. These research areas include:

- Annoyance
- Awakenings from aircraft noise
- Effects of noise on children's learning
- Accuracy of noise model predictions

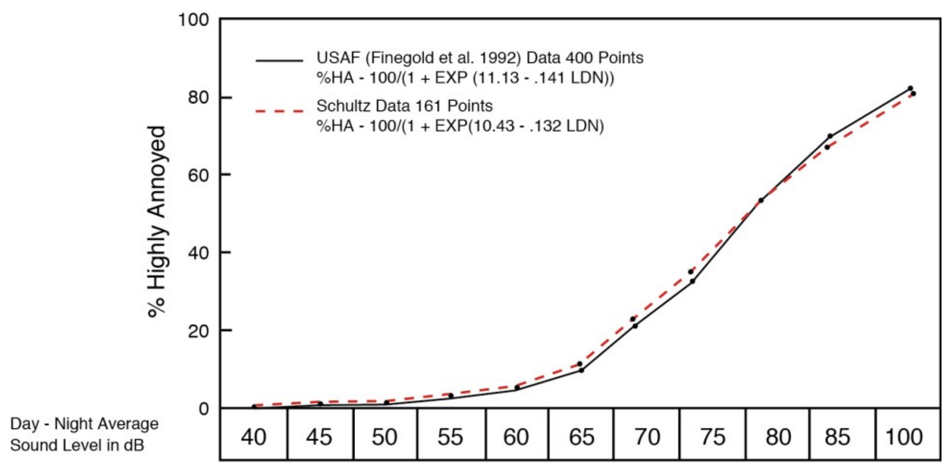
This section presents, for each of these topics, a summary of selected FICON 1992 findings, research conducted since the 1992 FICON Report, and FICAN's current finding on the topic or recommendations for additional research.

2.1 Annoyance

Annoyance is a summary measure of the general adverse reactions persons may experience when living in noisy environments. Annoyance includes reactions to noise events that may cause such effects as: speech interference (conversation, interference with telephone, radio and television); sleep disturbance; and other activity interference.

2.1.1 FICON Finding on DNL as Adequate Measure of Noise Impact Based on Annoyance

FICON recommended Day-Night Average Sound Level (DNL) as the preferred noise metric for assessing aircraft noise. FICON stated that "the methodology employing DNL as the noise exposure metric and appropriate dose-response relationships (primarily the Schultz curve for Percent Highly Annoyed[5]) to determine noise impacts on populations is considered the proper one for civil and military aviation scenarios in the general vicinity of airports." The "revised Schultz curve", referred to as USAF, as then presented by FICON, is shown below.



Calculated % HA Points	40	45	50	55	60	65	70	75	80	85	100
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

Figure 1. Revised Schultz Curve, FICON (Source: FICON, 1992)

[5] Schultz T.J., 1978. "Synthesis of Social Surveys on Noise Annoyance." *Journal of the Acoustical Society of America* 64(2): 377-405. http://doi.org/10.1121/1.382013

2.1.2 Aircraft Annoyance Research since FICON

The updated Schultz dose-response curve presented in the 1992 FICON Report contained data from all modes of transportation. Since the FICON Report was published, additional annoyance surveys and meta-analyses have been conducted and catalogued[6]. In general, the findings suggest the following: (1) people are more annoyed by aircraft noise than by surface transportation noise; and (2) Annoyance due to aircraft noise is greater than that described by the dose-response curve recommended by FICON.

There are some indications from European studies that annoyance caused by aircraft noise has increased since the FICON report. In the U.S., the FAA is conducting concurrent community annoyance surveys of residents living near 20 airports with scheduled air carrier service to update the scientific evidence on the relationship between aircraft noise exposure and its effects on communities around airports.

From the earliest surveys to the most current, research suggests that noise exposure explains only part of the variance in annoyance. Demographic factors have been shown to have little influence. Attitudinal factors and general sensitivity to noise are more important, but they still leave unexplained large differences among communities[7].

The International Standards Organization (ISO) released a new annex to ISO Standard 1996- Part 1[8], 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. It includes an updated community annoyance prediction curve based on analyses that include more current data.

2.1.3 FICAN Recommendation

FICAN member agencies are considering the implications of the ISO standard in conjunction with federal research studies regarding annoyance.

FICAN will review applicable research studies as they become available. Recommendations and decisions on whether or not to review and revise noise impact thresholds currently in effect due to updated annoyance relationships will be left to agency discretion.

In addition, FICAN notes that recent research on aircraft noise annoyance has been focused around civilian airports. Additional research is needed to identify possible differences in annoyance around military aviation facilities.

2.2 Awakenings from Aircraft Noise

The effect of aviation noise on sleep is a long-recognized concern of those interested in addressing the impacts of noise on people. Early studies of sleep disturbance were conducted mainly in laboratories, using various indicators of response (electroencephalographic recordings, verbal response [morning after questionnaires], button push, etc.). Field studies also were conducted, in which subjects were exposed to noise in their own homes.

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[6] Bassarab R., Sharp B., and Robinette B., "An Updated Catalog of Social Surveys of Residents' Reaction to Environmental Noise (1943-2008)", Wyle Report 09-18, November 2009. (Also DOT/FAA/AEE/2009-01 and DOT-VNTSC-FAA-10-02).

[7] Fidell S., Mestre V., Schomer P., Horonjeff R., and Reid T., "A systematic rationale for defining the significance of aircraft noise impacts" *Journal of the Acoustical Society of America* 136 (3), September 2014. http://dx.doi.org/10.1121/1.4892933

[8] International Standards Organization, ISO 1996-1:2003, *Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures*.

2.2.1 FICON Finding on Awakenings from Aircraft Noise

In 1992, FICON recommended an interim dose-response curve to predict the percent of the exposed population expected to be awakened (% awakening) as a function of the exposure to single event noise levels expressed in terms of sound exposure level (SEL). This interim curve was based on the data presented in the 1989 study by Pearsons[9] and summarized in a 1992 article[10] by Finegold. The 1992 FICON Report recommended continued research into community reactions to aircraft noise, including sleep disturbance. The 1992 FICON Report also acknowledged that "single event metrics are of limited use in predicting and interpreting cumulative noise exposure impacts.[11]"

2.2.2 Research on Noise Induced Awakening since FICON

Since the adoption of FICON's interim curve in 1992, substantial field research, mostly outside U.S., in the area of sleep disturbance has been completed, using a variety of test methods, and in a number of locations. In 2012, in collaboration with colleagues from the German Aerospace Center (DLR)[12], American scientists developed a methodology to monitor physiological changes in field conditions. A combination of ECG electrodes and actigraphs is non-invasive and an inexpensive technique that can be easily applied to identify awakenings. U.S. pilot field studies using this methodology have been conducted[13,14] to examine whether the indoor noise level of single aircraft events was related to awakenings determined with the ECG and actigraphy.

The findings were similar to those found in two studies conducted by the German Aerospace Center. The first occurred in the vicinity of Cologne-Bonn airport and is known as STRAIN (STudy on human Response on AIrcraft Noise) study[15]; the second occurred in the vicinity of Frankfurt airport and is referred to as NORAH (NOise-Related Annoyance, cognition and Health) study[16]. Follow on studies with larger sample sizes and a wider range of noise levels are needed to obtain more precise exposure-response functions for health impact assessments of awakenings caused by aircraft noise.

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[9] Pearsons K., Barber D., and Tabachnik B., 1989. "Analysis of the Predictability of Noise-Induced Sleep Disturbance." NSBIT Report No. HAD-TR-89-029. Brooks AFB, Texas: U.S. Air Force, Human Systems Division, Noise and Sonic Boom Impact Technology, Advanced Development Program Office (HQ HSD/YAH).

[10] Cited as "Finegold, L.S., Harris C.S., VonGierke, H.E., 1992. 'Applied Acoustical Report: Criteria for Assessment of Noise Impacts on People.' submitted to *Journal of Acoustical Society of America*. June 1992" in the 1992 FICON report but not published. See also Finegold, Harris, and von Gierke. 1994. *Community Annoyance and Sleep Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise on People.* Noise Control Eng. J. 42 (1), Jan–Feb https://doi.org/10.3397/1.2827857

[11] FICAN Report Page ES-2.

[12] The abbreviation comes from the name of Germany's aeronautical and space research center: Deutsche Zentrum für Luft- und Raumfahrt (DLR)

[13] Basner M., 2012. "Design for a U.S. Field Study in the Effects of Aircraft Noise on Sleep", Report No. PARTNER-COE-2012-003.

[14] Basner M. and McGuire S. *Pilot Sleep Study near Philadelphia International Airport*, ASCENT Project 17 Report, August 2016

[15] Bartel S., 2014. "Aircraft noise-induced annoyance in the vicinity of Cologne/Bonn Airport-The examination of short-term and long-term annoyance as well as their major determinants," PhD Dissertation Thesis, Technische Universität Darmstadt.

[16] http://www.laermstudie.de/en/

2.2.3 FICAN Recommendation

In 2008, FICAN recommended ANSI S12.9/6 (2008)[17] for use in estimating impact of aircraft noise on awakenings[18]. The ANSI S12.9/6 (2008) methodology predicts sleep disturbance in terms of probability of awakening associated with noise levels expressed in terms of indoor A-weighted sound exposure level. The Standard was developed from field studies of behavioral awakening primarily in homes near airports subject to routine jet aircraft operations, and reflects data from about 10,000 subject-nights of observations in a variety of communities in the United States and Europe. The Standard provides an equation for quantifying the probability of awakening as a function of both the time (in minutes) since retiring and the indoor A-weighted sound exposure level in a sleeper's quarters. The Standard also provides a method for calculating the probability of awakening at least once from the distributions of single noise events.

The ANSI Standard addresses concerns raised by FICON, such that: (1) the methodology is based on behavioral awakening data collected from people in their own homes, and (2) it provides a method for computing cumulative impacts of an entire night's noise events.

FICAN recommends that environmental impact analyses that address sleep disturbance utilize ANSI S12.9-2008[19], Quantities and Procedures for Description and Measurement of Environmental Sound — Part 6: Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes.

It should be noted that this guidance was developed based on data collected in residential settings. Thus, it may underestimate sleep disturbance in unfamiliar and outdoor settings.

2.3 Effects of Noise on Children's Learning

Research on the effects of aircraft noise on children's learning suggests that aircraft noise can interfere with learning in the following areas: reading, motivation, language and speech acquisition, and memory. The strongest findings to date have been in the area of reading, where studies have shown that children can be negatively affected by aircraft noise.

2.3.1 FICON Finding on Noise in Schools

FICON recommended that noise in schools be addressed through the use of two metrics: (1) the Long-Term Equivalent Sound Level [L_{eq}(x)] (where X represents the time period of concern) or (2) Time Above (TA) for analysis of school communications requirements, also during specific hours.

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[17] ANSI S12.9/6, 2008, *Quantities and Procedures for Description and Measurement of Environmental Sound — Part 6: Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes*.

[18] Federal Interagency Committee on Aviation Noise (FICAN), *FICAN Recommendation for use of ANSI Standard to Predict Awakenings from Aircraft Noise*, December, 2008 at: https://fican1.files.wordpress.com/2015/10/findings_awakenings_2008.pdf.

[19] As of the publication of this report, the American Acoustical Society has submitted for balloting to withdraw ANSI S12.9-20008; stating that "*Additional information published since the development of ANSI/ASA S12.9-2008/Part 6 ("the Standard") calls into question the generalizability of its predictions, as well as its suitability for NEPA-related purposes. Experience in application of the Standard has also revealed limitations to its ability to distinguish among the environmental impacts of preferred and alternative proposed actions. By itself, however, the newly available information offers no unambiguous basis for revising the 2008 Standard".* While research continues to mature, FICAN endorses the use of the process described in the standard, which represents the best available information for quantifying impacts due to awakenings.

2.3.2 Research on Noise and Learning since FICON

Considerable research on the effects of noise on learning has been conducted since 1992. It generally shows that higher levels of aircraft noise can be associated with poorer reading and memory recognition[20]. The European Union-funded RANCH Project[21] (road traffic and aircraft noise exposure and children's cognition and health: exposure-effect relationships and combined effects) investigated the relationship between exposure to aircraft and road traffic noise and cognitive and health outcomes in a number of European Union countries. The study found exposure-response associations between aircraft noise and impaired reading comprehension and impaired recognition memory, after taking demographics and other noise sources into account.[22]

In the U.S., FICAN undertook a pilot study[23] to evaluate the effectiveness of school sound insulation programs in 2004. The study was designed to answer the following: Is abrupt aircraft noise reduction within classrooms related to mandatory, standardized test-score improvement? The study found (1) a substantial association between noise reduction and decreased failure (worst-score) rates for high-school students, and (2) significant association between noise reduction and increased average test scores for student/test subgroups. In general, the study found little dependence upon student group or test type.

In 2013, ACRP Project 02-26[24], *Assessing Aircraft Noise Conditions Affecting Student Learning*, examined the relationship between changes in scholastic achievement to changes in aircraft noise exposures taking into account the presence of sound insulation and potentially confounding factors, such as, school characteristics and the socio-economic profile of the student population. The study found statistically significant associations between airport noise and student test scores, after taking demographic and school factors into account. Similarly, significant associations were also observed for ambient noise and total noise on student test scores, demonstrating that noise from other sources as well as aircraft might play.

In 2017 ACRP 02-47[25], *Assessing Aircraft Noise Conditions Affecting Student Achievement – Case Studies,* case studies at eleven schools near LAX were conducted to develop and implement a rigorous methodology to identify and measure which factors at the individual classroom, student, and teacher level influence the impact of aircraft noise on student achievement. The study was also designed to identify appropriate metrics that define the level and characteristics of aircraft noise that impact student achievement. The results of the classroom observations show that the predominant source of distraction for students was other students, accounting for 50.9% of the total number of distraction events. The second largest source of distractions was "other" at 29.2%. Aircraft operations occurred near the eleven schools throughout the study period, however there were no observed aircraft noise related distractions on any day of the study period. Even though no in-class distractions were directly attributed to individual

[20] Clark C. *Aircraft noise effects on health: report prepared for the UK Airport Commission* (Report number 150427). London: Queen Mary University of London, 2015.

[21] van Kempen E, van Kamp I, Nilsson, M, Lammers J., Emmen H., Clark C., and Stansfeld S., "The role of annoyance in the relation between transportation noise and children's health and cognition," *J. Acoust. Soc. Am*. Volume 128, Issue 5, pp. 2817-2828, 2010; http://dx.doi.org/10.1121/1.3483737

[22] Clark C, Martin R, van Kempen E, Alfred T., Head J., Davies H, Haines M., Lopez Barrio I, Matheson M., and Stansfeld A., "Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension - The RANCH project." *Am J Epidemiol* 2006; 163(1): 27-37; https://doi.org/10.1093/aje/kwj001

[23] Eagan M, Anderson G, Nicholas B., Horonjeff R., Tivnan T., "Relation Between Aircraft Noise Reduction in Schools and Standardized Test Scores", FICAN, February 2004 at http://www.fican.org/pdf/FICAN_Schools_Study_Handout.pdf.

[24] ACRP Project 02-26, Assessing Aircraft Noise Conditions Affecting Student Learning at: http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2797.

[25] ACRP 02-47, Assessing Aircraft Noise Conditions Affecting Student Achievement--Case Studies http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3693.

aircraft noise events, associations between the overall level of aircraft noise exposure in DNL do appear to correlate with teacher-reported interference of school activities in some situations. Teachers from schools experiencing DNL above 55dB were more likely to report interference with communication, students' attention, students' concentration, students' performance, and the quality of students' work.

2.3.3 FICAN Finding

ANSI has published a standard (ANSI S12.60-2002, *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools*) providing acoustical performance criteria, suggested architectural design requirements and guidelines for *newly constructed* school classrooms and other learning spaces[26]. For sound insulation guidance for retrofitting *existing* classrooms, the FAA Airport Improvement Program (AIP) Handbook[27] is the most appropriate source. The guidelines are keyed to the acoustical qualities needed to achieve a high degree of speech intelligibility in learning spaces. The Standard also includes detailed procedures for measuring conformance to the Standard. The Standard recommends that core learning spaces having enclosed volumes not greater than 20,000 ft^3 not be exposed to greater than 40 dB of A-weighted unsteady background noise from transportation noise sources for more than 10% of the noisiest hour; for core learning spaces having enclosed volumes greater than 20,000 ft^3, this level of exposure should not exceed 45 dB for more than 10% of the noisiest hour.

While there is evidence to suggest that aircraft noise has adverse learning effects, FICAN concludes there is not sufficient information to quantify the effect in terms of a recommended noise metric or dose-response relationship. FICAN recommends that analyses addressing noise effects on children's learning include predictions of school-day noise exposure (8-hourLeq) until research suggests a more appropriate metric. FICAN also recommends that classroom acoustic design for new construction follow guidelines presented by ANSI S12.60-2002, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools.

2.4 Accuracy of Noise Predictions below DNL 65

Noise modeling technology has evolved considerably since the FICON Report was published; models now produce more reliable results at levels below DNL 65 dB. Since the publication of the 1992 FICON Report, noise models have been enhanced, new metrics have been added, and a number of noise model validation efforts have occurred. These include a 2003 report on modeling the audibility of tour aircraft in the Grand Canyon[28], a 2005 FICAN study of two models used for modeling aircraft noise in national parks[29], an FAA-sponsored study that compared FAA's Integrated Noise Model (INM) results to measured data[30] and an Aviation Environmental Design Tool (AEDT) Uncertainty Quantification Report[31].

2.4.1 FICON Finding on the Accuracy of Noise Model Predictions

FICON concluded that noise model predictions could generally be considered accurate at levels above DNL 65 dB. Specifically, the FICON Report stated, "For a variety of reasons, noise predictions and

[26] ANSI S12.60-2002, *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools*, June 2002, American National Standards Institute, Inc.

[27] http://www.faa.gov/airports/aip/aip_handbook/

[28] HMMH Report No. 295860.29, *Aircraft Noise Model Validation Study*. January 2003.

[29] FICAN Report *Assessment of Tools for Modeling Aircraft Noise in the National Parks*. March 18, 2005.

[30] Plotkin K., Page J., Gurovich Y., and Hobbs C., *Detailed Weather and Terrain Analysis for Aircraft Noise Modeling*, Wyle Report 13-01, April 2013. (Also DOT/FAA/AEE/2009-01 and DOT-VNTSC-FAA-10-02).

[31] AEDT 2a Uncertainty Quantification Report, August 2013. <https://aedt.faa.gov/Documents/AEDT 2a Uncertainty Quantification Report.pdf>

interpretations are frequently less reliable below DNL 65 dB. DNL prediction models tend to degrade in accuracy at large distances from the airport. Therefore, predictions of noise exposure and impact below DNL 65 dB should take the possibility of such inaccuracy into account."

2.4.2 Current State of Noise Model Accuracy

Accuracy of noise models is directly related to the accuracy of noise model input, internal databases, and user expertise, and not to the level of noise being computed, as reported by FICON.

Agencies are continuously investing in improvements to noise prediction models. These improvements include better source data, improved performance modeling and improved propagation modeling, such that the models have significantly improved over time, especially their capability to accurately model aircraft noise at greater distances from the airports and at lower noise levels. [32,33,34,35]

2.4.3 FICAN Finding on Noise Model Accuracy

Modern aircraft noise models are able to predict noise exposure with acceptable accuracy whether above or below 65 dB DNL (under most conditions); absolute accuracy has not been quantified, but depends on the accuracy of input, internal databases, and user proficiency, rather than on the model itself.

3 AVIATION NOISE ISSUES NOT ADDRESSED BY FICON

The FICON Report was focused primarily on aircraft noise issues in the vicinity of airports. It did not specifically address noise in rural areas or in parks and wilderness areas. Similarly, FICON's discussion of noise effects focused primarily on annoyance and related effects. Additional research since 1992 has resulted in a significant body of research in the following areas:

- Low Frequency Noise
- Noise in National Parks and Wilderness Areas

3.1 Low Frequency Aircraft Noise

Low frequency noise (LFN) associated with fixed wing aircraft (i.e., frequency content associated with start of takeoff roll and deployment of thrust reversers upon landing) has been identified as a cause of significant levels of rattle-related annoyance in some locations near air carrier airports. LFN was not specifically addressed by FICON, but has been an issue that has been raised in the airport context, associated mainly with annoyance.

[32] Danish Ministry of the Environment, Environmental Protection Agency, Nord2000: Nordic noise prediction method, http://eng.mst.dk/topics/noise/traffic-noise/nord2000---nordic-noise-prediction-method/, accessed 5/15/15.

[33] DELTA Report AV 1117/06 *Nord2000. Validation of the Propagation Model*. March 31, 2006.

[34] US DOT/FAA/AEE/2012-03 and 2012-04. *Assessment of the Hybrid Propagation Model, Volume 1: Analysis of Noise Propagation Effects and Volume 2: Comparison with the Integrated Noise Model*. August 2012.

[35] US DOT/FAA/AEE/2012-05 *The Analysis Of Modeling Aircraft Noise With The Nord2000 Noise Model*. August 2012.

3.1.1 Low Frequency Noise Research

In 2002, FICAN reviewed the recommendation of an expert panel convened to evaluate low frequency noise around Minneapolis–St. Paul International Airport (MSP)[36]. The MSP Expert Panel recommended the adoption of a Low Frequency Sound Level Metric (LFSL), and further recommended that LFSL doses below 70 dB be considered compatible with residential use without requiring any remedial actions and that LFSL doses above 87 dB be deemed as incompatible with residential use and not amenable to successful remedial actions. Where the LFSL dose is between 70 dB and 87 dB, remedial treatment was identified as having a likelihood of success.

FICAN did not support the proposed LFSL metric[37] for a number of reasons, and concluded that additional research was necessary to address the complex interaction between (1) building construction, (2) the contribution of loudness to annoyance, and (3) the contribution of rattle to annoyance.

Subsequent to the FICAN finding made in 2002, FAA's Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) Center for Excellence conducted a study of LFN[38], designed to address FICAN's concerns. While the PARTNER study included findings on LFN and rattle generation during takeoff and landing, made recommendations concerning LFN analysis methods, provided criteria on potential for annoyance, and made recommendations for rattle avoidance, additional research is still needed. Specifically, the PARTNER study did not address community annoyance and response to LFN; this additional information would allow policy makers to develop appropriate interventions and mitigation treatments.

3.1.2 FICAN Finding on Low Frequency Noise

FICAN finds that additional research needs to be conducted before a LFN metric and an associated dose-response relationship can be recommended. For airports with low frequency noise concerns, supplemental noise analysis – possibly including vibration measurements – should be considered.

3.2 Noise in National Parks, National Wildlife Refuges, and Historic Sites

Agency environmental guidance documents give special consideration to the evaluation of the significance of aircraft noise impacts on noise-sensitive areas within national parks, national wildlife refuges, and historic sites including traditional cultural properties, based on the understanding that the DNL 65 dB threshold of significance for noise does not adequately address the effects of noise on visitors to areas within a national park or national wildlife refuge.

3.2.1 Research on Visitor Experience

Dose-response studies of aircraft noise in national parks have provided quantitative correlations between visitor survey responses and noise exposure. Though urban and park studies differ in the duration of noise exposure and the metric used, it is clear that park visitors are more sensitive to noise than urban residents. For annoyance and interference with the experience of natural quiet, studies at frontcountry locations have shown that LAeq computed for the duration of the visit is the best summary of noise

[36] MSP LFN Expert Panel, *Findings of the Low-Frequency Noise Expert Panel of the Richfield-MAC Mitigation Agreement of 17 December 1998*, Volumes I, 11, and III, 30 September 2000.

[37] FICAN, *FICAN on the Findings of the Minneapolis-St. Paul International Airport (MSP) Low-Frequency Noise (LFN) Expert Panel*, April 2002, at: http://www.fican.org/pdf/lfn_expertpanel.pdf.

[38] Hodgdon K, Atchley A., and Bernhard R.J., Partnership for AiR Transportation Noise and Emissions Reduction An FAA/NASA/Transport Canada-sponsored Center of Excellence, *Low Frequency Noise Study*, Report No. PARTNER-COE-2007-00 April 2007, at: http://web.mit.edu/aeroastro/partner/reports/proj1/lfnreport-2007-001.pdf.

exposure for predicting visitor survey responses. [39,40] For backcountry visitors, the best models of survey responses include a measure of percent time audible. These studies and additional social science research on the relationships between noise levels and visitor experience have revealed a variety of factors that influence visitor perceptions of noise: expectations of natural quiet, noise source characteristics, visitor group composition, and other factors.[41,42,43,44,45]

3.2.2 Research on Wildlife

Much research has been conducted looking at the effect of noise sources, beyond aviation, and their effects on wildlife. Decisive evidence of the effects of noise on wildlife has emerged from field studies that have been controlled for potential confounding effects and experimental studies that have broadcast road and energy development noise while minimizing other disturbing stimuli.[46,47,48,49,50] Additional studies have quantified changes in vigilance and discussed potential implications for predation and

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[39] Miller N. P., 1999. The effects of aircraft overflights on visitors to US National Parks. *Noise Control Engineering Journal*, 47(3), 112-117. https://doi.org/10.3397/1.599294

[40] Anderson G. S., Rapoza A. S., Fleming G. G., and Miller N. P., 2011. Aircraft noise dose-response relations for national parks. *Noise Control Engineering Journal*, 59(5), 519-540. https://doi.org/10.3397/1.3622636

[41] Yang W., & Kang J., 2005. Acoustic comfort evaluation in urban open public spaces. *Applied Acoustics*, 66(2), 211-229. http://dx.doi.org/10.1016/j.apacoust.2004.07.011

[42] Pilcher E. J., Newman P., and Manning R. E., 2008. Understanding and managing experiential aspects of soundscapes at Muir Woods National Monument. *Environmental Management*, 43(3), 425-435. http://dx.doi.org/10.1007/s00267-008-9224-1

[43] Aasvang G. M. and Engdahl B., 2004. Subjective responses to aircraft noise in an outdoor recreational setting: a combined field and laboratory study. *Journal of Sound and Vibration*, 276(3-5), 981-996. http://dx.doi.org/10.1016/j.jsv.2003.08.042

[44] Krog N. H., and Engdahl B., 2004. Annoyance with aircraft noise in local recreational areas, contingent on changes in exposure and other context variables. *Journal of the Acoustical Society of America*, 116(1), 323-333. https://doi.org/10.1121/1.1756162

[45] Rapoza A., Sudderth E., and Lewis K., 2015. Aircraft dose-response relations for day-use visitors to backcountry areas in National Parks. *The Journal of the Acoustical Society of America*, 138, (2090), 2405-2406. http://dx.doi.org/10.1121/1.4929934

[46] Habib L, Bayne E. M. and Boutin S, 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla. *Journal of Applied Ecology*. 44:176-184. http://dx.doi.org/10.1111/j.1365-2664.2006.01234.x

[47] Blickley J. L., Blackwood D., and Patricelli G. L., 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. *Conservation Biology*, 26(3), 461-471. 10.1111/j.1523-1739.2012.01840.x

[48] McClure C. J., Ware H. E., Carlisle J., Kaltenecker G., and Barber, J. R., 2013. An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. Proceedings of the Royal Society B: *Biological Sciences*, 280(1773), 20132290. http://dx.doi.org/10.1098/rspb.2013.2290

[49] Crino O. L., Johnson E. E., Blickley J. L., Patricelli G. L., and Breuner, C. W., 2013. Effects of experimentally elevated traffic noise on nestling white-crowned sparrow stress physiology, immune function and life history. *The Journal of Experimental Biology*, 216(11), 2055-2062. http://dx.doi.org/10.1242/jeb.081109

[50] Francis C. D., Paritsis J., Ortega C. P., and Cruz A., 2011. Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. *Landscape ecology*, 26(9), 1269-1280.

ecological processes.[51,52,53] Collectively, this literature demonstrates that chronic noise adversely affects wildlife at lower levels than are typically present in urban settings. Notably, most of these studies involved chronic exposures to noise that are less variable in level and have fewer noise-free intervals than many aircraft noise scenarios.

3.2.3 FICAN Finding on Noise in National Parks and Wilderness Areas

There has been substantial research to produce quantitative dose-response relationships on visitor response to air tour noise, and these relationships are being used in ongoing park management efforts.[54,55] Since 2000, there has been significant research suggesting that wildlife are affected by noise, but there are few studies pertaining to the effects of aviation noise and no dose-response relationship has been established. Regarding cultural resources, there have been a handful of studies, but no conclusive findings; additional research is needed in order to make specific recommendations.

4 AVIATION NOISE RESEARCH NEEDS

Although considerable research has been described in this document, FICAN has identified several high priority aviation noise research areas:

- Annoyance
- Non-auditory health effects
- Sleep disturbance
- Potential differences in annoyance from helicopter noise compared with fixed-wing aircraft noise
- Noise in national parks, wilderness, and other rural areas
- Emerging aviation noise issues related to non-traditional vehicles, including unmanned aerial systems (UAS), military fighter jet aircraft and the phenomenon of crackle, commercial space, and civil supersonic aircraft Additionally, FICAN believes it useful to clarify and restate its findings with respect to supplemental metrics. Each of these is described below.

4.1 Annoyance

A number of key research issues regarding annoyance are of interest, including:

- Do older airport noise annoyance data from the U.S., more recent data from other countries, or the currently underway, FAA-sponsored annoyance research provide better guidance for assessing current U.S. noise impacts?
- Annoyance has been widely used as a summary measure of noise impact. With greater understanding of components such as sleep interference and non-auditory health effects, is there an opportunity to examine interrelationships between components and gain a better understanding of overall impact?

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[51] Quinn J. L., Whittingham M. J., Butler S. J. and Cresswell W., 2006. Noise, predation risk compensation and vigilance in the chaffinch *Fringilla coelebs*, *Journal of Avian Biology* 37:601-608. http://dx.doi.org/10.1111/j.2006.0908-8857.03781.x

[52] Wale M. A., Simpson S. D., and Radford A. N., 2013. Noise negatively affects foraging and antipredator behaviour in shore crabs. *Animal Behaviour*, 86(1), 111-118. http://dx.doi.org/10.1016/j.anbehav.2013.05.001

[53] Francis C. D., Kleist N. J., Ortega C. P., and Cruz, A., 2012. Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. *Proceedings of the Royal Society B: Biological Sciences*, 279(1739), 2727-2735. http://dx.doi.org/10.1098/rspb.2012.0230

[54] Anderson G. S., Rapoza A. S., Fleming G. G., and Miller, N. P., 2011, *op. cit.*

[55] Rapoza A., Sudderth E., and Lewis K., 2015, *op. cit.*

- Little is known about residents' annoyance to infrequent, intense aircraft noise events. Examples include certain military operations, sonic booms, unscheduled commercial operations, and, in the future, unmanned aerial systems (UAS) and commercial launch vehicles. Does the "equal energy hypothesis", as found in DNL, still apply? A related issue that requires further investigation is the rate at which annoyance declines as the time since the last noise event increases. What research should be conducted on the growth and decay of annoyance under intermittent exposure conditions?
- How do abrupt changes in noise exposure correlate with changes in annoyance? Such changes can result from construction of new runways and redesign of airspace, or establishment of new Special Use Airspace/Airspace for Special Use for military testing and training.
- What effect do the unique acoustical characteristics (frequency content, duration, level, etc.), of aircraft such as launch vehicles, UAS, and helicopters have on annoyance?
- Much has been learned regarding observed differences in annoyance between individuals experiencing the same aircraft noise environment. What are the causes of observed differences in annoyance between communities experiencing similar noise environments?

4.2 Non-Auditory Health Effects

The World Health Organization[56] defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Non-auditory health effects can be defined as those physiological effects on health and well-being which are caused by aircraft noise, but excluding effects on hearing. These include: stress response, cardiovascular effects, mental health effects, and mortality. (Annoyance can be considered a non-auditory health effect and has been discussed above).

Plausible biological mechanisms have been identified that support the theory that long term exposure to environmental noise may affect the human cardiovascular system and thus contribute to disease. Few studies have examined aircraft noise, but extensive research has demonstrated that chronic road traffic noise has non-auditory (cardiovascular) health effects[57]. An open question is how to apply these findings to aircraft noise, given the different characteristics of aviation noise from roadway traffic (i.e., intermittency, maximum levels, etc.).

Associations between aircraft noise exposure and adverse effects such as hospital admissions and birth outcomes have been observed in a small number of studies. These studies frequently have difficulties regarding accurate estimates of noise exposure and control of confounding factors. There is a need for more and better-designed studies.

Before adopting policies and methodologies for predicting health outcomes, research needs to be conducted to quantify relationships between aircraft noise level (dose) and the health outcome in question (effect). FICAN believes it is premature to adopt quantification methods for computing burden of disease from environmental noise (including the computation of healthy life years lost) until this fundamental research has been developed and validated.

[56] Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.

[57] Basner M., Babisch W., Davis A., Brink M., Clark C., Janssen S., and Stansfeld S., "Auditory and non-auditory effects of noise on health *The Lancet*, Volume 383, No. 9925, p1325–1332, 12 April 2014, Published Online: 30 October 2013. http://dx.doi.org/10.1016/S0140-6736(13)61613-X

4.3 Sleep Disturbance

FICAN believes that research focused on collecting physiological measurement is likely to provide more insight than studies relying upon participants logging noise-induced awakenings. Research questions include:

- What is the contribution of aircraft noise to sleep disturbance? Can aircraft noise impacts be isolated from other sleep disruptions?
- To what degree are sleep disturbance responses conditioned on social, cultural, and other community contexts?

Much research has been conducted on the relationship between chronic sleep disruption and negative health effects. What is the potential contribution of aircraft noise-induced sleep disturbance to broader health outcomes?

4.4 Helicopters

Helicopter noise annoyance has become a bigger challenge in recent years, as helicopter operations have proliferated. Helicopter noise differs from fixed-wing aircraft noise in many ways; the frequency content, sound level onset and decay rates, and duration constitute a unique noise signature that differs significantly from that of fixed-wing aircraft. These distinctions may result in differences in human reaction to helicopter noise versus fixed-wing aircraft noise. There may also be other psychological factors affecting human response to helicopter noise, including detectability and perceived safety and privacy concerns. Further, helicopter operations and their routes are often more variable than those for fixed-wing aircraft and frequently occur at lower altitudes. As a result, there is currently a lack of understanding regarding the relationship between helicopter noise and community response. Questions being considered as part of ongoing research include:

- What are the acoustical and non-acoustical factors that influence community annoyance to helicopter noise?
- How do the acoustical and non-acoustical factors that influence community annoyance compare to those contributing to fixed-wing aircraft community annoyance? An initial attempt to determine whether helicopter noise is more annoying then fixed-wing noise has been conducted through ACRP 02-48 "Assessing Community Annoyance of helicopter Noise."[58]
- Research methods relating noise exposure to surveyed community annoyance have been developed for road, rail, and fixed-wing aircraft. Are these methods appropriate for helicopters, given the differences in the nature of helicopter noise and their unique operational characteristics?
- Can current noise prediction models be adapted to address unique aspects of helicopter noise?
- Are there opportunities to develop operational noise abatement procedures for helicopters?

4.5 Noise in National Parks and Wilderness Areas

4.5.1 Research on Visitors

Research needs regarding visitor experience range from replicating recent/previous studies, to realizing appropriate sample sizes, to opening new research topics.

Some additional questions that need to be answered are:

- What additional information is needed from day trip and overnight visitors to generate the necessary dose-response results?

[58] ACRP 02-48, Assessing Community Annoyance of Helicopter Noise http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3694

- Should research focus on the physiological responses to noise and connections between physiological responses and survey responses? This could provide opportunities for a broader investigation of aircraft noise impacts as well as onsite evidence of the restorative benefits of quiet environments and the sounds of nature.

4.5.2 Research on Historic and Cultural Sites

Additional studies in historical or cultural parks may be needed to determine effects of aircraft noise. Two key questions to be explored regarding historic and cultural sites are:

- Does aircraft noise interfere with the historical or cultural significance of some national parks?
- Do visitors feel their opportunities to experience the historical and cultural resources in parks are impacted?

4.5.3 Research on Wildlife

Recent studies that decisively documented noise impacts on wildlife addressed road and energy development noise. These noise sources differ from aircraft noise in two ways. Road and energy development noise are less intermittent than most aircraft noise scenarios. Also, road and energy development noise are associated with nearby human presence, so animals may not be reacting to the sensory degradation caused by noise itself, but to the threat the noise signifies. Accordingly, research that distinguishes between these mechanisms of wildlife noise responses is important for evaluating aircraft noise impacts, because it is unlikely that most aircraft represent a perceived threat to wildlife. The episodic character of most aircraft noise also raises the largely unresolved issue of the length of time to respond to the onset of noise, and the time required for wildlife to return to their prior state.

Planning efforts often assess impacts to species whose responses to noise have not been studied, and scientific inference usually incorporates a web of supportive reasoning derived from studies that share some similarities with the scenario of interest. These requirements recommend research syntheses to identify which biological factors provide the best guide for selecting other species whose research results will be most relevant. Relevant biological similarities may include studies of other species engaged in similar behaviors, studies of species that play similar ecological roles, studies of species with close evolutionary relationships, studies of species with similar auditory function, and studies of species subject to similar suites of non-acoustic stressors.

4.6 Emerging Issues and New Technologies

Since the 1992 FICON Report was released, market changes and advances in technology have resulted in the emergence and increased prominence of non-traditional vehicles, specifically unmanned aerial systems (UAS), advanced military fighter aircraft, commercial space vehicles, and civil applications of supersonic aircraft. The differences in operational flight characteristics between these non-traditional aerial vehicles and the aircraft upon which current methods, analyses, and findings have been based makes it likely that current metrics and processes will fail to adequately predict adverse effects such as community annoyance.

4.6.1 Unmanned Aerial Systems (UAS)

The rapid and continuing growth of Unmanned Aerial Systems in the National Airspace System has led to the development of a wide range of new vehicles, both fixed- and rotary-wing types. Some, such as multi-rotor vertical lift designs have no precedent as full-scale manned aircraft. From an acoustical perspective, the ones of most interest are those that are different from conventional aircraft either in terms of their noise characteristics or the missions they fly. Some of the current and proposed missions require operations to occur in close proximity to people. Noise may be a contributing factor to response (e.g., annoyance) to these vehicles. The development of methodologies to characterize and assess noise from UAS is an emerging field of study.

4.6.2 Military Fighter Jet Aircraft and the Phenomenon of Crackle

New high performance tactical aircraft have different noise characteristics than traditional subsonic, fixed-wing jet aircraft. Crackle, a supersonic jet phenomenon, has been described as “sudden spasmodic bursts of a rasping fricative sound . . . It is a startling staccato of cracks and bangs and its onomatope, ‘crackle’, conveys a subjectively accurate impression.”[59] Potential lines of inquiry include the degree to which crackle from these aircraft affects annoyance and whether current metrics adequately predict annoyance.

4.6.3 Commercial Space Vehicles

Several new vehicles are being developed to launch commercial payloads and tourists, and for government purposes, primarily those of NASA and the DOD. In addition to the traditional NASA and DOD sites, a few new launch facilities have been developed and more are under consideration, some of which are dual-use with aircraft operations. Noise generated by these launch vehicles includes that from the rocket exhaust as well as sonic booms on ascent and descent. The latter includes returning vehicles and re-usable rocket stages. Little is known about the environmental impact from such launch events, which are likely to generate high sound levels or sonic booms on an intermittent basis. Developing methodologies to accurately characterize and assess rocket noise emissions and sonic booms from commercial space vehicles are an emerging field of study.

4.6.4 Civil Supersonic Aircraft

A number of supersonic commercial aircraft have been proposed for development. These aircraft would range in size from small business jets to 40 passenger aircraft. Some intend to fly supersonically over water and others over both land and water. The latter requires that the aircraft be designed and operated in such a way that either, 1) the aircraft’s sonic boom does not reach the ground (known as Mach cut-off flight), or 2) the sonic boom is greatly attenuated relative to all previous supersonic aircraft, both military and civilian. Substantial progress in the past decade by industry, universities, and government agencies indicates that aircraft can be designed to produce sonic booms with far lower amplitudes than, for example, the Concorde. NASA has established the achievement of low boom flight and the creation of an en route standard as a strategic objective for the next decade. NASA has proposed a project that will culminate in the construction of a sub-scale aircraft to demonstrate low-boom technology and to determine public reaction to these low- amplitude sonic booms. The prospect of routine overland supersonic flight raises many of the same issues that pertain to conventional aircraft, including annoyance, sleep disturbance, effects on wildlife, etc.

4.7 Metrics to Supplement DNL (“Supplemental Metrics”)

The 1992 FICON Report recommended that Federal agencies continue to have “discretion in the use of supplemental noise analysis.”[60]

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[59] Gee K. L., Neilsen T. B., Wall A. T., Downing M. J., James M. M., McKinley R. L., “Propagation of crackle-containing jet noise from high-performance engines”, Noise Control Engineering Journal 64, 1-12, Jan/Feb 2016 https://doi.org/10.3397/1/376354, citing J.E. Ffowcs Williams “‘Crackle’: An annoying component of jet noise”, J. Fluid Mechanics, 71, 251–271 https://doi.org/10.1017/S0022112075002558

[60] The relevant text read as follows:

A supplemental metric is any metric, other than DNL, which is used for communicating changes to the noise setting or how individuals experience noise events. It is any metric that supplements the impact information disclosed by the DNL metric. A supplemental metric would be presented with the objective of enhancing the public's understanding and acceptance of impact analysis, usually by de-constructing the constituents of DNL for purposes of explaining particular impacts of interest (e.g., speech interference) in a manner that is readily accessible and comprehended by members of the public who are not trained in acoustics. That is, certain individual effects from aircraft noise, such as sleep disturbance, or non-auditory effects, such as on learning, may lend themselves to being more readily described by supplemental metrics. It must be stressed, however, that when FICAN uses this term (supplemental metric), it is to convey the idea of supplementing DNL in *communicating* effects as opposed to supplementing DNL in *assessing significance* in the context of impact analysis, particularly as defined under the National Environmental Policy Act of 1969 (NEPA) or regulations implementing NEPA. FICAN believes, consistent with guidance published by the President's Council on Environmental Quality (specifically at 40 CFR 1507.3) that ascertaining significance and establishment of thresholds or significance criteria are the province of individual departments and agencies of the US government, relying upon their expertise and understanding of their particular missions, roles, and responsibilities.

Since 1992 substantial effort has been undertaken by Federal agencies to define particular supplemental metrics and assess their efficacy and validity.[61,62]

Supplemental metrics provide valuable additional information to support understanding of complex, cumulative metrics and allow analysts to tease out and describe various, discrete components and effects embedded within the DNL metric. Supplemental metrics similarly assist in characterizing those discrete aspects of the noise environment that are more sensitive to, and capably described by, a supplemental metric compared to DNL.

Apart from the development and use of supplemental metrics since 1992 described above, it is foreseeable that advances in technology (e.g., increased computational and data storage capacity, improved sound level measurement instruments), further sociological research, and emerging technologies (new entrants to the National Airspace System (NAS) such as commercial space) might make the use of additional or

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Some Federal agencies supplement DNL analysis on a case-by-case basis to characterize specific noise effects. Supplemental analyses use various metrics, including the cumulative metric Leq (Equivalent Sound Level) for varying representative time periods; and the single event metrics. SEL (Sound Exposure Level), Lmax (A-weighted Maximum Sound Level), Third Octave Band Sound Pressure Levels (SPL), and TA (Time Above - expressed in minutes for which aircraft-related noise exceeds specified A-weighted sound levels).

Supplemental analyses are most often used to determine aircraft noise impacts at specific noise-sensitive locations, particularly in analyses of speech interference or sleep disturbance. Single event analysis is sometimes conducted to evaluate sleep disturbance and, less frequently, some speech interference, primarily at locations where the DNL is below 65 dB.

Generally, supplemental metrics are used to further analyze specific noise-sensitive situations. Because of the diversity of such situations, the variety of supplemental metrics available, and the limitations of individual supplemental metrics, the FICON concluded that the use of supplemental metrics to analyze noise should continue to be left to the discretion of individual agencies. (FICON 1992, §3.2)

[61] See, for example a Defense Noise Working Group (DNWG) publication, *Improving Aviation Noise Planning, Analysis and Public Communication with Supplemental Metrics – Guide to Using Supplemental Metrics* (December 2009) including work referenced therein by FAA/NASA Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation (PARTNER), and the Australian Department of Transportation and Regional Services on defining supplemental metrics, analyses, and communications methods has also occurred since the 1992 FICON report.

[62] Citation for the work undertaken in Australia referenced in the 2009 DNWG *Guide to Using Supplemental Metrics* and referred to in Footnote 51 is: Department of Transport and Regional Services (Australia). 2000.

different metrics for disclosing environmental impacts in a manner that is preferable to, and perhaps replaces the use of, DNL for this purpose. Researchers should consider collecting noise exposure data in a manner to enable evaluation of a broader range of potential noise metrics (i.e., other than A-weighted) through such techniques as making sound recordings/*.wav files).

It is anticipated that new supplemental metrics might be developed as part of the ongoing and future research efforts in the topics areas mentioned above (§4.1 through §4.6). Instead of continuing to expand the variety and quantity of supplemental metrics, FICAN believes that the future research should focus on developing guidance on using existing supplemental metrics – for example when and how the supplemental metrics should be used (or not used). There are still significant gaps in agreement among key stakeholders regarding, among other things, the readiness and effectiveness of many existing supplemental metrics. A comprehensive evaluation of the supplemental metrics is needed for each application category in terms of their effectiveness and readiness. Successes and lessons learned from using the metrics should be compiled as well. Then recommended practices should be developed on the proper use of the metrics that are considered mature enough for wide applications. However, until such time as such a comprehensive evaluation were to occur, and consensus among the several agencies were achieved, FICAN finds the original 1992 recommendation that individual Federal agencies retain discretion in whether and how supplemental metrics are employed remains sound. However, additional periodic review and research is required to ascertain their continuing validity.