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14. ABSTRACT
In support of the Federal Aviation Administration (FAA) Office of the Associate Administrator Commercial Space Transportation, the John A. Volpe National Transportation Systems Center has retained the services of Harris Miller Miller & Hanson Inc. and the Aerospace Corporation to conduct a study of noise and sonic boom models which may be applicable to the computation of environmental impacts for the commercial space industry.

This Final Report catalogs existing noise and sonic boom models from recent government and commercial launch environmental documents and a search of relevant literature. The models are evaluated against calculation methods presented in recent literature and the requirements of the National Environmental Policy Act as provided in FAA Order 1050.1E, FAA Order 5050.4B, and the Environmental Desk Reference for Airport Actions to determine the necessity of a new model. The process of developing a model is described through a summary of the recent draft Environmental Protection Agency document, Draft Guidance on the Development, Evaluation and Application of Environmental Models, and the direct experience of persons who have worked on past model development efforts for FAA's Integrated Noise Model (INM) and the Federal Highway Administration's Traffic Noise Model. The feasibility of integrating a new model into the INM is examined by comparing the input, computation methods, and output for the INM and launch noise and sonic boom models.

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DOT-VNTSC-RITA-FAA-09-02

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1 PURPOSE AND INTRODUCTION

In support of the Federal Aviation Administration (FAA) Office of the Associate Administrator Commercial Space Transportation (AST), the John A. Volpe National Transportation Systems Center (Volpe Center) has retained the services of Harris Miller Miller & Hanson Inc. (HMMH) and the Aerospace Corporation to conduct a study of noise and sonic boom models which may be applicable to the computation of environmental impacts for the commercial space industry.

This Final Report catalogs and evaluates existing noise and sonic boom models, investigates the necessity of a new model, describes the process of creating a new model if required, and determines if the recommended existing or new model could be integrated into the FAA's Integrated Noise Model (INM). It integrates the following draft technical reports and includes additional material and edits based on AST, Volpe Center, Aerospace, and HMMH comments on the draft reports:

- List of Models (Chapter 2)
- Task 4, Requirement for a New Model, Process to Develop a New Model (Chapters 3 and 4)
- Task 5, Integration of Launch Modeling into the INM (Chapter 5).

Appendix A presents background information on acoustics and noise terminology. Appendix B provides a detailed timeline of events in the development of the INM.

2 EXISTING MODELS

This chapter presents existing noise and sonic boom models which may be applicable to the commercial space industry. Models which may be used to compute launch noise are presented first with sonic boom models following.

2.1 Noise Models

The sub-sections below describe noise models used in published commercial and government space launch environmental reports and available aircraft noise models.

2.1.1 Models Used in Published Environmental Documents

HMMH examined published environmental documents to determine the models that may already be in use to compute noise from commercial and government space launches.

The preparers of the commercial space environmental documents used a variety of methods to estimate noise impacts. With the exception of horizontal launches where the INM was utilized, computations seem to have been restricted to simple spreadsheet methods. Often the preparer did not have any noise data for the vehicles in question. The most common tactic was to compare the study launch vehicle to a vehicle of known noise level which the investigator expected to produce equal or greater noise as compared to the study vehicle. The investigator typically compared thrust levels to arrive at the conclusion that the study vehicle would produce less noise. Some documents presented no computational results whatsoever when the vehicle was expected to be much quieter than existing operations or so infrequent as to cause no increase in long-term average noise levels.

Table 1 summarizes the noise methodologies for six published commercial space environmental documents. Please see the footnotes for references to all of the documents which are listed below as well as all others discussed throughout this report.

Table 1 Noise Impact Assessment Methodologies for Published Commercial Space Environmental Documents

Document	Launch Type(s)	Noise Methodology
Environmental Assessment of the Kodiak Launch Complex Kodiak Island, Alaska[1]	Vertical orbital launches	Spreadsheet computations using a noise curve from the mean of test stand measurements, upper bound theoretical calculations, and a United States Air Force EA for a rocket with the same engine
Final Environmental Assessment for the Blue Origin West Texas Commercial Launch Site[2]	Vertical suborbital launches	Spreadsheet calculations based on a higher thrust vehicle from the Kodiak EA
Draft Environmental Impact Statement for the Spaceport America Commercial Launch Site, Sierra County, New Mexico[3]	Horizontal and vertical suborbital launches	Spreadsheet calculations based on an "upper bound" vehicle from the Kodiak EA for vertical launch; Spreadsheet extrapolation of test –stand data from Oklahoma EA for on-ground rocket tests; INM for horizontal launch
Final Environmental Assessment for the Oklahoma Spaceport[4]	Horizontal suborbital launches	No analysis of jet noise due to small number of operations and existing high levels of jet noise; Reference to simple un-weighted rocket noise model with A-weighted levels 20 to 25 dB lower; Comparison to existing levels to dismiss impact
Final Environmental Assessment for the East Kern Airport District Launch Site Operator License for the Mojave Airport[5]	Horizontal suborbital launches	Comparisons to previously-studied jet aircraft with greater afterburners using similar thrust levels at the airport. No actual computation of noise levels or Day Night Average Sound Level (DNL). Reference to previous study of rocket test stand firings.
X Prize Cup Final Environmental Assessment[6]	Vertical suborbital launches	Simply states that there would be no impacts and that the 60 dB DNL contour would be on airport property.

[1] Federal Aviation Administration Office of Commercial Space Transportation, Environmental Assessment of the Kodiak Launch Complex Kodiak Island, Alaska, May 1996.

[2] Federal Aviation Administration Office of Commercial Space Transportation, Final Environmental Assessment for the Blue Origin West Texas Commercial Launch Site, August 2006.

[3] Federal Aviation Administration Office of Commercial Space Transportation, Draft Environmental Impact Statement for the Spaceport America Commercial Launch Site, Sierra County, New Mexico, June 2008.

[4] Federal Aviation Administration Office of Commercial Space Transportation, Final Environmental Assessment for the Oklahoma Spaceport, May 2006.

[5] Federal Aviation Administration Office of Commercial Space Transportation, Final Environmental Assessment for the East Kern Airport District Launch Site Operator License for the Mojave Airport, February 2004.

[6] Federal Aviation Administration Office of Commercial Space Transportation, X Prize Cup Final Environmental Assessment, September 2006.

The only model specifically referenced in the studies listed above was the INM which was utilized for horizontal launches. Vertical launch computations, when present, appeared to have been accomplished using spreadsheet models.

Table 2 presents the noise analysis methods for six published government launch environmental documents. As was the case for the commercial launch documents, the preparers used a variety of methods. Few did detailed computations and relied mostly on simple extrapolations from previous studies. The EA for atmospheric interceptor technology (ait) program is an exception, with detailed analysis using the proprietary model, RNOISE. A literature search has thus far yielded no publicly available stand-alone computer model specifically designed for launch noise.

Table 2 Noise Impact Assessment Methodologies for Published Government Space Launch Environmental Documents

Document	Launch Type(s)	Noise Methodology
Final Site-Wide Environmental Assessment for Wallops Flight Facility[7]	Vertical suborbital launches	Noise levels quoted from the Kodiak EA and extrapolated to nearest community locations
Environmental Assessment for ICESAT: NASA Goddard Space Flight Center[8]	Vertical orbital launches	Noise level for Delta II launch quoted from previous NASA document at a single distance closer than closest public area
Environmental Assessment for Range Operations Expansion at the National Aeronautics and Space Administration Goddard Space Flight Center[9]	Vertical orbital and sub-orbital launches	Estimate of noise levels at a single distance for a single rocket type – method unclear
Environmental Assessment for NASA Launch Abort System (LAS) Test Activities at the U.S. Army White Sands Missile Range, NM FINAL[10]	Vertical launches - aborted	No analysis results presented, asserts that launch noise will be brief and recommends monitoring during first launch
Environmental Assessment (EA) for the United States Air Force (USAF) atmospheric interceptor technology (ait) Program[11]	Vertical sub-orbital launches	RNOISE for computation of launch noise contours
Final Environmental Assessment for U.S. Air Force Quick Reaction Launch Vehicle Program[12]	Vertical suborbital launches	Measurements of same vehicles on-site utilized to determine impact

[7] URS Group Inc. and EG&G Technical Services, Final Site-Wide Environmental Assessment for Wallops Flight Facility, January 2005.

[8] National Aeronautics and Space Administration, Environmental Assessment for ICESAT: NASA Goddard Space Flight Center, March 2002.

[9] National Aeronautics and Space Administration, Environmental Assessment for Range Operations Expansion at the National Aeronautics and Space Administration, Goddard Space Flight Center, October 1997.

[10] National Aeronautics and Space Administration, Environmental Assessment for NASA Launch Abort System (LAS) Test Activities at the U.S. Army White Sands Missile Range, NM, FINAL, August 2007.

[11] Department of the Air Force, Environmental Assessment (EA) for the United States Air Force (USAF) atmospheric interceptor technology (ait) Program, November 1997.

[12] Department of the Air Force, Final Environmental Assessment for U.S. Air Force Quick Reaction Launch Vehicle Program, January 2001.

2.1.2 Aircraft Noise Models

There are many models for the computation of aircraft noise impacts. Because the use of an aircraft noise model would negate the need for the costly development of a new model for launch noise, it is worth examining these models. Table 3 lists publicly available and documented noise models utilized for aircraft noise which may prove useful for the computation of launch noise. Evaluation of their input, output, and computation methodologies will determine their applicability to the commercial space industry.

Table 3 List of Aircraft Noise Models for Evaluation

Model	Author/Owner	Current Application/Studies
Integrated Noise Model	FAA	FAA standard aircraft noise model
Noise Integrated Routing System (NIRS)	Metron, FAA	FAA standard aircraft noise model for regional analysis
Noisemap[13]	US Department of Defense	Military aircraft noise studies
NMSim	Wyle Laboratories, National Park Service	National Park Service Aircraft Noise Model Validation Study
SoundPLAN	Braunstein + Berndt GmbH	Industry noise, city noise mapping, Logan Taxiway Noise Studies[14] [15]

With the exception of SoundPLAN, each of the models above was developed by or for the US government in order to study aircraft noise. SoundPLAN is a commercial product utilized for a variety of industrial and government applications. It allows user-defined source level and directivity data and provides selectable computation modes which match many international acoustical standards.

2.2 Sonic Boom Models

HMMH also examined published environmental documents to determine the models that may already be in use to compute sonic boom impacts from commercial space launches. Most studies took a similar approach for sonic boom analysis as noise analysis with a mix of study-specific computations and comparisons to previously published values. The studies with computation results cited the methods of Plotkin or Carlson (see Table 4 for specific references). The studies which utilized comparisons cited known sonic boom overpressure values, where the study vehicle was assumed to have an equal or lower impact. Table 4 summarizes the noise methodologies for six published commercial space environmental documents.

[13] Noisemap is a suite of aircraft noise models which can be accessed through the BaseOps graphical user interface. One or more models within this suite may be applicable.

[14] Menge, C., B. Nicholas, R. Miller, Noise Analysis of Taxi Queuing Alternatives for Taxiway November at Logan International Airport, HMMH Report No. 300280.003, May 2006.

[15] Menge, C., B. Nicholas, R. Miller, Noise Analysis of Taxi and Queuing Alternatives for the Centerfield Taxiway at Logan International Airport, HMMH Report No. 300280.006, May 2006.

Table 4 Sonic Boom Impact Assessment Methodologies for Published Commercial Space Environmental Documents

Document	Launch Type(s)	Sonic Boom Methodology
Final Environmental Assessment for the Blue Origin West Texas Commercial Launch Site	Vertical suborbital launches	Computation results are present; refers to Plotkin, 1989[16]
Draft Environmental Impact Statement for the Spaceport America Commercial Launch Site, Sierra County, New Mexico	Horizontal and vertical suborbital launches	Refers to Plotkin, 1989; no actual calculations; space shuttle as upper bound; anecdotal evidence from an amateur class launch at the proposed facility
Environmental Assessment of the Kodiak Launch Complex Kodiak Island, Alaska	Vertical orbital launches	Computation results are present; no methodology is presented; the source document was a private letter
Final Environmental Assessment for the Oklahoma Spaceport	Horizontal suborbital launches	Computation results are present; methodology reference: Carlson, 1978[17]
Final Environmental Assessment for the East Kern Airport District Launch Site Operator License for the Mojave Airport	Horizontal suborbital launches	No computations; utilized published values for a similarly sized vehicle at Edwards AFB
X Prize Cup Final Environmental Assessment	Vertical suborbital launches	Not documented

HMMH also examined published government launch environmental documents to determine the sonic boom models that may already be in use. Table 5 summarizes the noise methodologies for six published government launch environmental documents. With the exception of the Environmental Assessment (EA) for the United States Air Force (USAF) atmospheric interceptor technology (ait) Program, preparers did not explicitly compute potential sonic boom impacts. They either did not address the issue at all or dismissed any possibility for impact if the rocket trajectory was over water.

[16] Plotkin, K.J. 1989. "Review of Sonic Boom Theory," Wyle Laboratories, published at AIAA 12th Aeroacoustics Conference April 10-12, 1989, San Antonio, TX. Available from AIAA as paper AIAA-89-1105.

[17] Carlson, Harry W., 1978. Simplified Sonic-Boom Prediction. NASA TP-1122.

Table 5 Sonic Boom Impact Assessment Methodologies for Published Government Space Launch Environmental Documents

Document	Launch Type(s)	Sonic Boom Methodology
Final Site-Wide Environmental Assessment for Wallops Flight Facility	Vertical suborbital launches	Sonic boom impacts would occur over water and are not analyzed
Environmental Assessment for ICESAT: NASA Goddard Space Flight Center	Vertical orbital launches	Sonic boom impacts would occur over water and are not analyzed
Environmental Assessment for Range Operations Expansion at the National Aeronautics and Space Administration Goddard Space Flight Center Wallops Flight Facility	Vertical orbital and sub-orbital launches	Not addressed
Environmental Assessment for NASA Launch Abort System (LAS) Test Activities at the U.S. Army White Sands Missile Range, NM FINAL	Vertical launches - aborted	No boom expected
Environmental Assessment (EA) for the United States Air Force (USAF) atmospheric interceptor technology (ait) Program	Vertical sub-orbital launches	PCBOOM for computation of launch and reentry sonic boom
Final Environmental Assessment for U.S. Air Force Quick Reaction Launch Vehicle Program	Vertical suborbital launches	Not addressed

PCBOOM is the sole model specifically listed in the documents cited above. Additionally, presentations by Plotkin[18] and the Air Force's noise model page[19] cite the program PCBoom. PCBoom produces overpressure contours for a user-defined flight trajectory. Vehicle shapes within the model include many fighter aircraft, the Space Shuttle, and a Titan rocket. A 1996 report[20] for the United States Air Force Research Laboratory provides background information on sonic booms, user instructions for formatting and entering input data and instructions for producing output. The report also has a section specifically devoted to considerations for the modeling of launch booms

[18] K. Plotkin and J. Page, AIAA-2007-3677, *Extension of PCBoom to Over- The- Top Booms, Ellipsoidal Earth, and Full 3- D Ray Tracing*, American Institute of Aeronautics and Astronautics, 13th AIAA/CEAS Aeroacoustics Conference, May 2007.

[19] http://www.afcee.af.mil/resources/aicuz/noisemodels/index.asp, accessed August 2008.

[20] K. Plotkin, PCBoom3 Sonic Boom Prediction Model Version 1.0c, AFRL-HE-WP-TR_2001-0155, Wyle Laboratories , May 1996.

including the sonic boom caused by the exhaust plume. Table 6 lists the only model identified which may be applicable to the commercial space industry.

Table 6 List of Sonic Boom Models for Evaluation

Model	Author/Owner	Current Application/Studies
PCBoom	Wyle Laboratories, US Department of Defense	Military aircraft studies and launch studies

Brief mention should be made of other sonic boom models in the literature which will not be evaluated in this report. The FOBOOM model is the computation engine within PCBoom and will not be discussed separately. Work done for the United States Air Force[21] discusses the CABoom, BooMap, and CORBoom aircraft sonic boom models. CABoom is a Wyle implementation of Carlson's simplified sonic boom computation method which only works for simple circumstances: straight line steady flight in a standard atmosphere. BooMap is a version of the BOOM-MAP[22] program. It does not produce detailed sonic boom footprints, but instead looks at impacts statistically over an elliptical operating area based on the distribution of aircraft sorties. It is bundled with the MOAOPS program which analyzes mission data tapes to produce input for the BooMap model. Similarly, CORBoom is not intended for detailed modeling of individual events. It analyzes cumulative impacts for straight-line flight corridors using simplified input assumptions and computations.

[21] Plotkin, K., F. Gradi, Computer Models for Sonic Boom Analysis: PCBoom4, CABoom, BooMap, CORBoom Wyle Report WR 02-11, June 2002.

[22] Wilby, E., R. Horonjeff, D. Bishop, User's Guide to MOAOPS and BOOM-MAP Computer Programs for Sonic Boom Research, HSD-TR-87-004, BBN Laboratories Inc., May 1987.

3 EVALUATION OF EXISTING MODELS

This chapter presents our findings regarding the applicability of existing noise and sonic boom models to the determination of environmental impacts from commercial space launch activities. The first three sections will discuss launch modeling input and methods, present the required output of the models, and summarize the required input, computation parameters, and output. The final section evaluates each model presented in Chapter 2 based on the information presented in the first three sections.

3.1 Launch Noise Models and Modeling

The first section below discusses characteristics of launch noise modeling and highlights differences from standard aircraft noise modeling techniques. The second section presents information on various launch noise modeling methods found in recent literature.

3.1.1 Characteristics of Launch Noise Models

A search of literature related to rocket noise modeling suggests that rocket noise modeling differs fundamentally from typical aircraft noise modeling for several reasons. First, the noise source itself is different due the extreme temperatures and velocities of the exhaust flow and the lack of bypass in the engine. Second, the source levels, spectrum, and directivity are typically computed as direct functions of the physical parameters of the rocket such as nozzle diameter, thrust, jet exit velocity, vehicle velocity, and the speed of sound within and outside of the jet. As characteristics of the rocket change throughout its trajectory, the acoustical output parameters change. Additional complexities include consideration of atmospheric effects due to large distances and high altitudes and effects due to the high speed of the sound source. Also at very high noise levels, the typical assumption of linear sound propagation no longer applies[23][24]. These non-linear effects change not only the level of the sound at the receiver, but also the frequency content of the signal.

3.1.2 Documented Launch Noise Modeling Methods

A literature search and discussions with noise preparers on several environmental documents has, as of yet, led to no publicly available computer model for vertical launch noise. Computations on environmental documents have been carried out using spreadsheet computations and proprietary models. A literature search has produced no standards related to the computation of rocket noise.

Although there is no well-documented and validated, publicly available launch noise model there are relevant methodologies documented in the literature. NASA documents include an extensive 1968 report edited by Sutherland[25] which covers many aspects of rocket noise generation and propagation

[23] McInerny, S.A., High-intensity rocket noise: Nonlinear propagation, atmospheric absorption, and characterization, J. Acoust. Soc. Am. 117 (s), Feb. 2005.

[24] McInerny, S.A., Spectral and Time Domain Characteristics of the Non-linear Acoustics Generated by Launch Vehicles, 15th AIAA Aeroacoustics Conference, AIAA-93-4384, October 1993.

[25] Sutherland, L.C. (ed.), Sonic and vibration environments for ground facilities - A design manual, Wyle Laboratories Report WR 68-2, 1968.

with a focus on the effects on ground facilities. Eldred's 1971 summary of the state of launch modeling[26] is still often cited as a primary source for rocket source levels, spectra, and directivity functions.

Sutherland's 1990 AIAA presentation[27] revisits the topic and presents simplified engineering models for sound power, spectrum, directivity, and propagation losses to the ground. McInerny's 1990 AIAA presentation[28] and 1996 paper in the Journal of Aircraft[29] provide findings on overall levels, spectral characteristics, and directivity. For notes on a particular application of theory to a proprietary noise model see Plotkin, Sutherland, and Moudou's 1997 AIAA presentation[30].

3.2 Catalog Model Output Requirements

All commercial launch facilities must operate in accordance with Federal Aviation Administration (FAA) regulations. The FAA is under the U.S. Department of Transportation (DOT) with regulatory responsibility for civil aviation.

FAA Order 1050.1E, Environmental Impacts: Policies and Procedures[31], describes agency-wide policies and procedures for compliance with the National Environmental Policy Act and implementing procedures outlined in the Council on Environmental Quality's (CEQ) Regulations for Implementing the National Environmental Policy Act (40 CFR 1500-1508). FAA Order 5050.4B, National Environmental Policy Act (NEPA) Implementing Instructions for Airport Actions[32], supplements FAA Order 1050.1E by providing NEPA instructions prepared especially for proposed Federal actions to support airport development projects under the Office of Airports (ARP) scope. The Environmental Desk Reference for Airport Actions[33] summarizes applicable special purpose laws[34]. Its function is to help FAA integrate the compliance of NEPA and applicable special purpose laws to the fullest extent possible.

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[26] Eldred, K., Acoustic Loads Generated by the Propulsion System, NASA SP-8072, Jun. 1971.

[27] Sutherland, L.C., Progress and Problems in Rocket Noise Prediction for Ground Facilities, 15th AIAA Aeroacoustics Conference, AIAA-93-4383, October 1993.

[28] McInerny, S., Rocket Noise - a Review , AIAA 13th Aeroacoustics Conference, AIAA-90-3981, October 1990.

[29] McInerny, S. A. Launch Vehicle Acoustics Part1: Overall Levels and Spectral characteristics, Journal of Aircraft 1996 0021-8669 vol.33 no.3 (511-517).

[30] Plotkin, K.J., L.C. Sutherland, M. Moudou, Predictions of Rocket Noise During Boost Phase, slide show for the American Institute of Aeronautics and Astronautics, 1997.

[31] FAA Order 1050.1E CHG 1, Environmental Impacts: Policies and Procedures, 20 March 2006.

[32] FAA Order 5050.4B, National Environmental Policy Act (NEPA) Implementing Instructions For Airport Actions, Federal Aviation Administration, Effective Date: 28 April, 2006.

[33] Environmental Desk Reference for Airport Actions, Federal Aviation Administration Office of Airports, October 2007.

[34] Order 5050.4B characterizes Federal environmental requirements outside NEPA as "special purpose laws."

3.2.1 Threshold of Significance

FAA Order 1050.1E CHG 1 specifies a number of requirements for noise analysis, including which noise models are acceptable under various circumstances, what constitutes significant impact, and when supplemental noise analyses are acceptable. It identifies the threshold of "significant impact" based on the yearly day-night average sound level (DNL)[35]. If a location of incompatible land use is exposed to a project-related increase in noise level of DNL 1.5 dB or more and that location lies within the 65 dB DNL noise contour for the "with action" condition, then the location is considered to be significantly impacted by noise and must be identified as such in environmental evaluations[36]. The criteria for land use compatibility at noise sensitive locations in Order 1010.1 E CHG1 are defined in 14 CFR Part 150[37].

In 1992, the Federal Interagency Committee on Noise (FICON)[38] recommended that, in addition to significant impacts, less-than-significant noise level changes be identified for noise-sensitive locations exposed to project-related increases. FICON recommended that if any noise sensitive areas at or above DNL 65 (with action) will experience an increase of DNL 1.5 dB or more, then further analysis should be conducted of areas reporting any changes in DNL of 3 dB or more between 60 and 65 dB DNL. Order 1050.1 now requires examination of noise levels between 60 and 65 dB DNL if screening shows significant impacts. Increases of 3 dB DNL or greater due to the proposed action between 60 and 65 dB DNL is not termed significant impact, but the potential for mitigation should be considered. Air traffic airspace actions where the study area is larger than the immediate vicinity of the airport, incorporates more than one airport, or includes actions above 3,000 feet above ground level require specialized analysis which includes screening for changes in DNL of 3 dB or more between 60 and 65 dB DNL and changes in DNL of 5 dB or more between 45 and 60 dB DNL at US Census population centroids[39].

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[35] The FAA recognizes the community noise equivalent level (CNEL) is an alternative metric for California, FAA Order 1050.1E CHG 1: section 14.1a.

[36] FAA Order 1050.1 E CHG 1 Appendix A Section 4.2c Table 1 list various land uses and their compatibility with yearly DNL. All listed land uses are compatible at less than 65 dB DNL.

[37] 14 C.F.R. Part 150 – Airport Noise Compatibility Planning

[38] Federal Agency Review of Selected Airport Noise Analysis Issues, Federal Interagency Committee on Noise, Washington, D.C., August 1992.

[39] A centroid is the geometric center of a Census block.

Significant noise impact:

- DNL increase of 1.5 dB or more in areas of 65 dB DNL and higher

Less than significant impact:

- DNL increase of 3 dB or more in areas between 60 and 65 dB DNL
- DNL increase of 5 dB or more in areas between 45 and 60 dB DNL

3.2.2 Supplemental Noise Analysis

A particular action may warrant additional analysis using noise metrics other than DNL. Order 1050.1E CHG1[40] recognizes the standard DNL analysis may not adequately address the effect of noise at certain section 4(f) properties[41] located in quiet settings. The responsible FAA official must consult all appropriate Federal, State, and local officials having jurisdiction over the affected section 4(f) resources to determine whether project related noise impacts would substantially impair the resource before making a determination[42]. The Environmental Desk Reference gives the example of new nighttime operations which may cause sleep disturbance and substantially impair the use of a park's campground[43]. The choice of sound exposure level (SEL) for the supplemental analysis in this scenario would be bolstered by the inclusion of the formula for percentage awakenings as a function of SEL in the Environmental Desk Reference[44]. In general, the metric would need to demonstrate the constructive use[45] of the resource.

DNL analysis with Part 150 land use categories is not sufficient to address noise effects on wildlife[46]. Officials, whenever possible, should use available, published information that addresses the effects of noise on the species of concern[47]. Such studies have utilized many metrics including maximum

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[40] FAA Order 1050.1 E CHG 1 Appendix A Section 6.2h and 6.2i.

[41] Section 4(f) of the Department of Transportation Act, recodified as section 303(c) of 49 U.S.C., provides certain protections to publicly owned historic areas, parks, recreation areas, or wildlife and waterfowl refuges of national, state, or local significance.

[42] FAA Order 1050.1 E CHG 1 Appendix A Section 6.2e.

[43] FAA Environmental Desk Reference Chapter 7 Section 2.

[44] FAA Environmental Desk Reference Chapter 17 Section 8 c.(1)(a). Note also that the Federal Interagency Committee on Aviation Noise (FICAN) has released a recommendation for the use of a new calculation procedure for estimating behavioral awakenings from aircraft noise. The calculation procedure is contained in the American National Standards Institute (ANSI) Standard S12.9-2008, Part 6: "Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes." ANSI S12.9-2008 provides a method for predicting sleep disturbance in terms of percent awakenings or numbers of people awakened from a full night of aircraft noise events. This method could be useful for assessing nighttime launch effects.

[45] A constructive use occurs when the action would substantially impair the activities, features, or attributes of the resource which contribute to the resources significance or enjoyment.

[46] FAA Order 1050.1 E CHG 1 Appendix A Section 4.3.

[47] FAA Environmental Desk Reference Chapter 17 Section 1 f.(3)(b).

A-weighted sound pressure level (L_{MAX}), equivalent sound pressure level (L_{EQ}), and sonic boom over-pressure values[48][49].

Supplemental metrics are also useful in addressing community concerns about a particular noise-sensitive location or situation or to assist in the public's understanding of the noise impact. FAA's selection of a supplemental analysis will depend on the circumstances of each particular case[50]. The Environmental Desk References expands upon the list of supplemental metrics provided in Order 1050.1E CHG1.

Table 7 summarizes these metrics. In addition, 1050.1E CH1 Appendix A section 14.5f lists one-third octave band sound pressure level, which can be useful in assessing soundproofing and building vibration[51], and audibility which is a time based metric developed to evaluate the substantial restoration of natural quiet in Grand Canyon National Park as mandated by Public Law 100-91. Note that any noise metric in Table 7, and many more, can be computed from a lists one-third octave band sound pressure level time history.

[48] Manci, K.M., D.N. Gladwin, R. Villella, and M.G. Cavendish. *Effects of Aircraft Noise and Sonic Booms on Domestic Animals and Wildlife: A Literature Synthesis,* Report NERC- 88/29, U.S. Fish and Wildlife Service, National Ecology Research Center, Fort Collins, Co, June 1988.

[49] The work of H.K. Cheng of the University of Southern California on the penetration of sonic booms into the wavy surface of the ocean is notable here. See Appendices C.2 and C.3 of Department of the Air Force, Environmental Assessment U.S. Air Force atmospheric interceptor technology Program, Nov 1997 and Cheng, H. K., J. Lee, Sonic-boom noise penetration under a wavy ocean: theory, Journal of Fluid Mechanics (2004), 514:281-312. This work is applicable to studies which examine noise effects on marine mammals.

[50] FAA Order 1050.1 E CHG 1 Appendix A Section 14.5b.

[51] Hubbard, Harvey H., Noise Induced House Vibrations and Human Perception, Noise Control Engineering Journal, September-October 1982.

Table 7 Suggested Metrics to Determine or Describe Noise Impacts[52]

Possible Human Response	Corresponding Average, Cumulative Noise Metric	Corresponding Single Event Metric	Time Aircraft Heard Above a Particular Noise Level	The Number of Events that Will Occur Above Particular Noise Metric
Community annoyance - How people psychologically respond to a given noise	**DNL** - Average Day-Night Sound Level. *L_{EQ} – Equivalent Sound Level.	*L_{MAX} – Maximum Sound Level. ***SEL** – Sound Exposure Level.	***Time Above** – Typically, 60 or 65 dB. Above these levels, noise would interfere with normal conversational levels.	*N_X – Numbers of events specified at each sound level.
Sleep disturbance - Sound levels causing sleep arousal	***Nighttime** L_{EQ} – (10:00 p.m. – 7:00 a.m.= typical sleeping hours).	***SEL** – Federal Interagency Committee on Aviation Noise (FICAN) recommends use of ANSI S12.9-2008, Part 6		
Speech interference - Intruding noise levels that mask normal conversational speech levels and reduces listener understanding	* L_{EQ} **daytime**– (7:00 a.m. – 10:00 p.m.= typical activity hours).	*L_{MAX} or **SEL**		
School learning - Noise level that could adversely affect classroom activities. This level is used to determine the level of noise level reduction needed to reduce or eliminate that interference	***School hour** L_{EQ} (vary) *L_{EQ} – 45 dB interior sound level goal.	***SEL** used to determine the interior noise level reduction (NLR). The minimum standard is 5 dB SEL. SEL is favored for analytical purposes over Preferred Speech Interference Level#.		
Park visitor annoyance - Noise level that would interfere with visitor enjoyment and appreciation of natural quiet. May vary by season or time of day	*L_{EQ} based on hours of park operation or visitor hours. (varies)	L_{MAX}	**TAA** – Time Above Ambient sound levels%.	

* = Supplemental metrics used to further explain and disclose noise impacts. See section 8.d. of the Environmental Desk Reference chapter 17 for more information. There are no required supplemental metrics. Selecting supplemental metrics is done case-by-case.
# PSIL is the arithmetic average of the sound pressure levels for the 500, 1,000, and 2,000- hertz octave bands.
% Often, local ambient (background) measurements are helpful.

[52] FAA Environmental Desk Reference Chapter 17 Table 17.1., except for sleep disturbance which is updated to be consistent with the December 2008 recommendation by FICAN.

3.3 Recommended Launch Noise Model Requirements

Table 8, Table 9, and Table 10 summarize the recommended requirements for a launch noise model to comply with appropriate regulations and documented modeling methods described in Sections 3.1 and 3.2.

Table 8 Launch Noise Model Input Parameters

Parameter Type	Parameter	Notes
Trajectory	Position	
	Thrust	
	Speed	
	Time	
Operations	Number of daytime, evening, and night operations	
Vehicle	Exhaust velocity	
	Speed of sound in nozzle throat	
	Nozzle diameter	
	Acoustic efficiency	
	Source levels	The ability to utilize empirical source values may be a valuable alternative
Environment	Site elevation	
	Temperature profile	
	Humidity profile	
	Wind profile	
	Ground types at receiver points	
	Coordinates of receiver points	Or extents and density of a regular grid

Table 9 Launch Noise Model Computation Requirements

Requirement
Compute noise from full trajectory including both launch and re-entry where applicable
Compute noise source properties (overall power, spectrum, and directivity) from rocket physical parameters or allow direct input of approved empirical values
Compute effect of the atmosphere on sound propagation including temperature, pressure, humidity, and wind effects
Account for forward motion on the source radiation properties
Account for non-linear propagation effects on noise levels and spectra at receivers
Include the effect of ground type throughout the computation area

Table 10 Launch Noise Model Output Parameters

Parameter	Notes
DNL	The Day Night Average Sound Level is the fundamental metric of noise impact for NEPA analysis.
CNEL	The Community Noise Equivalent Level is the fundamental metric of noise impact for NEPA analysis in California.
SEL*	The Sound Exposure Level is a supplemental metric for the computation of possible sleep interference effects. It is also the building block for DNL, CNEL, and a variety of exposure-based supplemental metrics.
Lmax*	The Maximum A-Weighted Sound Pressure Level is a supplemental metric for speech interference effects, among others.
1/3 Octave Band Time History	The computation of a full time history in 1/3 octave frequency bands allows the computation of a wide range of noise metrics. These include C-weighted metrics which are used for examinations of sources with large amounts low-frequency noise. High level rocket noise may also lead to building vibration which can cause annoyance and structural damage[53].

Notes:
* Supplemental metric as define in 1050.1E CHG1.
The output values must be calculated as contours of equal value and values at user-specified grid points (time history excepted).

3.4 Evaluate Applicability of Existing Noise and Sonic Boom Models to Commercial Space Industry

3.4.1 Noise Models – Aircraft Noise Models

Though aircraft noise models are available and generally well-documented, for the reasons stated in Section 3.1.1, aircraft noise models are not appropriate for the modeling of launch noise with the exception of carrier vehicles. An exact or similar carrier vehicle may already be represented within a particular aircraft noise model. The following sections will discuss relevant aspects of the noise models presented in the Section 2.1.2.

3.4.1.1 The Integrated Noise Model (INM)

The Integrated Noise Model (INM) is FAA's official airport noise model. It is developed and maintained by the FAA's Office of Environment and Energy (AEE-100), the Volpe National Transportation System Center (Volpe), and ATAC Corporation. Three Society of Automotive Engineers (SAE) reports are the basis of the current INM 7.0a noise model:

- SAE-AIR-1845, Procedure for the Calculation of Airplane Noise in the Vicinity of Airports, prepared by SAE Committee A-21, March 1986.
- SAE-AIR-5662, Method for Predicting Lateral Attenuation of Airplane Noise, April 2006.
- SAE-ARP-866A, Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity, August 1964, revised March 1975.

Additionally, INM 7.0 is designed to comply with standards set by the European Civil Aviation Conference (ECAC) Doc 29, titled "Report on Standard Method of Computing Noise Contours Around Civil Airports". As detailed in Section 4.2.2 and Appendix B, it is well supported through multiple large scale validation studies and frequent updates. With the exception of one-third octave band noise levels, the INM can compute all of the noise metrics discussed in Table 10 above.

[53] Hubbard, 1982.

The INM allows a fully user-defined trajectory and many aspects of the aircraft source can be customized. However, in addition to differences between aircraft and rocket noise modeling noted above the following aspects of the INM acoustic computation methodology may be inappropriate for rocket noise modeling:

- Set choice of spectral shapes based on aircraft within database
- Set directivity pattern for aircraft take-off roll only
- Lateral attenuation algorithms which incorporate aircraft shielding effects
- No accounting for non-linear propagation effects which occur at very high noise levels

A specific pitfall of the use of vehicles within the INM with similar thrust values to a launch vehicle in order to approximate impacts is seen in the computation of atmospheric absorption. The peak levels in a launch vehicle's source spectrum are generally at a much lower frequency than that of an aircraft. Since lower frequencies are attenuated much less than higher frequencies, the use of an aircraft proxy will overestimate the loss of energy to the atmosphere and thus underestimate the noise at a receiver.

As with most other aircraft models which follow, the INM is an integrated model. Integrated models are designed to look at the total noise exposure of events and not the details of individual events in time. The details of source directivity and propagation effects based on specific atmospherics are not possible. For all of the reasons stated above, the INM, as it is currently configured, should not be used to compute launch noise.

3.4.1.2 NMSim

NMSim is a simulation noise model produced by Wyle Laboratories. A limited version produced for the National Park Service is freely available[54]. The model allows flexible input of aircraft source data: one-third octave band levels and directivity. One-third octave band time history output is computed at each gridpoint[55]. This would allow computation of any noise metric. Though not sharing all of the weaknesses of other aircraft noise models, it lacks the ability to compute noise levels from physical rocket parameters, account for a fully defined atmosphere, or model non-linear propagation effects and thus is not an appropriate model for the computation of launch noise.

Given the strengths of NMSim, it is worth noting the current work by Wyle Laboratories under the auspices of the Strategic Environmental Research and Development Program on a new model for military aircraft[56]. This model, based on NMSim and Wyle's Rotocraft Noise Model, will be a simulation model which includes atmospheric gradient, non-linear propagation, and complex terrain effects.

3.4.1.3 Noisemap

NMap, the US Department of Defense's model of aircraft flight and run-up noise near air bases, is part of the Noisemap suite of aircraft noise models. NMap 7.0, produced by Wyle Laboratories, is

[54] http://www.wylelabs.com/products/acousticsoftwareproducts/nmsim.html (accessed September 2008)

[55] Ikelheimer, B., K. Plotkin, Noise Model Simulation (NMSim) User's Manual, Wyle Laboratories, June 2005.

[56] Plotkin, K., T. Schultz, Development of an Advanced Acoustic Model for Military Aircraft Noise, NOISE-CON 2007 Reno, NV, October 2007.

utilized through the BaseOps interface produced by Wasmer Consulting[57]. NMap 7.0 computes 5 metrics, DNL, CNEL, LEQ, Noise Exposure Forecast (NEF), and Weighted Effective Continuous Perceived Noise Level (WECPNL)[58]. The model allows some customization of aircraft and profiles[59]. Like the INM, it is an integrated model and does not account for the unique aspects of launch noise noted above. As such, it is not appropriate for modeling launch noise.

3.4.1.4 Noise Integrated Routing System (NIRS)

The Noise Integrated Routing System (NIRS) analyzes the changes in noise associated with air traffic changes over broad areas. It was first developed in 1998 and the current version, NIRS 6.1, is the FAA's standard regional noise model[60]. NIRS output include population-impact and change-of-exposure reports and graphics. NIRS does not compute noise contours and is limited to the use of DNL for its impact table and graph features[61]. The aircraft database and noise computation methodology are consistent with INM 6.1[62]. It offers no acoustical advantages over the INM and has much more limited output. Given the specific focus of the model, limitations of its output, and its reliance on the same computation methodology as the INM, NIRS is not appropriate for computations of launch noise for the commercial space industry.

3.4.1.5 SoundPLAN

SoundPLAN is a versatile noise model produced and sold by Braunstein + Berndt GmbH. Use of SoundPLAN modules requires an initial purchase plus annual maintenance fees. It allows user-definition of source levels and directivity. Computations are performed using user selectable acoustic propagation standards from various international organizations. Its primary application areas are industry noise, road and rail noise, city noise mapping, and aircraft noise. The aircraft noise module is designed to conform to the German AzB/ DIN 45643 standard with some aspects derived from ECAC Doc 29[63]. The aircraft module allows computation of L_{EQ} and DNL. As with other aircraft models, SoundPLAN will not allow modeling rocket noise from physical rocket parameters and its acoustic algorithms will not account for the unique aspects of rocket launch noise. For these reasons, SoundPLAN is unlikely to be useful for the modeling of launch noise for the commercial space industry.

3.4.1.6 Summary of Noise Model Evaluations

None of the models reviewed above currently meets the requirements for input, computation, methodology, and output cataloged in Section 3.3. Given this and the lack of available, documented,

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[57] Available for download at http://wasmerconsulting.com/nmplot.htm, accessed January 2009.

[58] Czech, J., K. Plotkin, NMap 7.0 User's Manual, Wyle Laboratories, November 1998.

[59] Wasmer, F., F. Maunsell, BaseOps 7.32 User's Guide, Wasmer Consulting.

[60] http://www.faa.gov/about/office_org/headquarters_offices/aep/models/nirs_nst/ (accessed September 2008)

[61] Federal Aviation Administration and Metron Aviation Inc., Noise Integrated Routing System User's Guide Version 6.1, January 2006.

[62] NIRS 6.1 Release Notes

[63] Braunstein + Berndt GmbH/ SoundPLAN LLC, SoundPLAN User's Guide, October 2005.

and validated launch noise models, a new model for the computation of launch noise impacts is recommended.

3.4.2 Sonic Boom Models

Both the literature search and conversations with noise preparers have shown the PCBOOM model by Ken Plotkin of Wyle Laboratories to be the only publicly available computer model for the computation of launch sonic boom impacts. The model was developed for the Air Force and was previously available through an Air Force website[64].

The model has the following features[65]:

- Arbitrary user-defined trajectories
- Pre-set or user-defined aircraft shape
- Computations using ray-tracing theory
- Non-standard atmosphere with winds
- Focusing effects
- Single event sonic boom overpressure contour output

Ken Plotkin is the author of numerous papers and presentations on sonic booms including a review of sonic boom theory[66], a presentation on modeling launch vehicles using PCBOOM[67], a paper on the state of the art in sonic boom modeling[68], and a general overview of sonic boom creation, modeling, and effects[69].

Though not a computer model, the simplified method of sonic boom computation proposed by Carlson[70] in 1978 is relevant as evidenced by conversations with environmental document preparers and inclusion in Plotkin's 2002 paper on the state of the art in sonic boom modeling. Its applicability may be limited by the restriction to level flight or moderate descent or climb profiles. Even if not used for boom modeling, his paper is useful in providing methods and charts relating to the source strength for various body configurations which may be used in other models.

A literature search has produced no standards documents related to the computation of sonic boom impacts.

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[64] http://www.afcee.af.mil/resources/aicuz/noisemodels/index.asp (accessed September 2008).

[65] Plotkin, K., M. Downing, J. Page, USAF Single-Event Sonic Book Prediction Model: PCBoom3, NASA Langley Research Center, High-Speed Research: 1994 Sonic Boom Workshop: Atmospheric Propagation and Acceptability Studies p 171-184, N95-14878 03-02, October 1994.

[66] Plotkin, K. J., Review of Sonic Boom Theory, American Institute of Aeronautics and Astronautics, Inc., AIAA-89-1105, 1989.

[67] Plotkin, Kenneth J., Predicting Launch Vehicle and Plume Sonic Boom Using PCBOOM3, Wyle Laboratories, October 30, 2000.

[68] Plotkin, K. J., State of the Art of Sonic Boom Modeling, Journal of the Acoustical Society of America, vol 111 (1), Pt.2, January 2002.

[69] Plotkin, Kenneth J., Sonic Boom: Origins, Modeling And Effects, Wyle Laboratories, June 8-9, 2004.

[70] Carlson, Harry W., Simplified Sonic-Boom Prediction, NASA TP-1122, 1978.

4 PROCESS TO DEVELOP NEW MODEL

This chapter presents guidance on model development and descriptions of the process for past model development efforts. The following sections describe aspects of the model development process using data from draft Environmental Protection Agency (EPA) guidance and the direct experience of persons who have worked on past model development efforts.

4.1 EPA Model Development Guidance

In August of 2008 the Council for Regulatory Environmental Modeling, U.S. Environmental Protection Agency released for public comment the document, Draft Guidance on the Development, Evaluation and Application of Environmental Models[71]. Its recommendations are organized in three topics:

- **Development** – includes identification of the issue, construction of a conceptual model, construction of the mathematical model, and parameterization of the model.
- **Evaluation** – involves examination of the underlying science, comparison to available data, and testing performance against objectives.
- **Application** – concerns transparency in documentation and project work.

The document recommends a transparent modeling process which includes objective peer review, data quality assessments, comparisons to measured values, and sensitivity and uncertainty analyses. Though the document provides guidance for EPA staff to internally create, manage, and use a wide range of environmental models, many of the concepts and practices will prove useful to any model development effort. The following sections summarize the relevant EPA guidance on each of these phases of model development.

4.1.1 Model Development

Success of a model development effort is dependant on a clear specification of the purpose and domain of the model. During the initial problem identification stage the following steps are useful:

- Definition of Model Purpose
    - Goal
    - Decisions to be supported
    - Predictions to be made
- Specification of Modeling Context
    - Scale (spatial and temporal)
    - Application domain
    - User community
    - Desired output
    - Evaluation criteria

[71] Document available at http://www.epa.gov/crem/model-evaluation.html (accessed September 2008).

This problem identification phase can be an iterative process which should incorporate serious discussion between developers and model users regarding factors such as budget, time, and data constraints.

The next steps are the development of the conceptual and computational models. A detailed conceptual model guides the development of the computational model and assures that the needs of the guiding agency and end users are implemented by the software developer.

- Conceptual Model Formulation
  - Assumptions (dynamic, static, stochastic, deterministic)
  - State variables represented
  - Level of process detail necessary
  - Scientific foundations
- Computational Model Development
  - Algorithms
  - Mathematical/computational methods
  - Inputs
  - Hardware platforms and software infrastructure
  - User interface
  - Calibration/parameter determination
  - Documentation

4.1.2 Model Evaluation

Whether a user develops a model or acquires one, evaluation of the model is necessary to determine if it is appropriate for a particular application. Evaluation and revision should continue throughout the life of the model to utilize improvements in research, hardware and software capabilities, and data availability. Investigations can probe the range of uncertainties due to the model framework and input data. Studies may reveal how well a model works when used beyond its original application domain.

The following steps are crucial to the acceptance and ongoing improvement of a model:

- Model Testing and Revision
  - Theoretical corroboration
  - Model components verification
  - Corroboration (independent data)
  - Sensitivity analysis
  - Uncertainty analysis
  - Robustness determination
  - Comparison to evaluation criteria set during formulation

4.1.3 Model Application

Once a model is accepted, its use changes from running tests against known data to making predictions which may be used for decision-making. The key to successful application is transparency between all parties involved in the modeling process: developers, modelers, decision makers, and the public. Written documentation in public process projects should include:

- Plain language description of the problem, approach, and results
- Technical description of the modeling including its limits and uncertainties

Accurate documentation begins with full documentation of all methods and assumptions by the model developer, continues with documentation of input data and analysis methods by the modeler, and ends with a clear description of the application of the results by decision makers.

4.2 Model Development Examples

Aspects of the process presented in the EPA's environmental model guidance are demonstrated in the development of the two models discussed below. A notable difference between the EPA guidance and the examples below is that the EPA's models are intended for use by EPA staff. Much of the peer review of the models, definition of user needs, and validation studies are done by and for EPA scientists. In the examples below, these tasks are accomplished through technical committees, expert groups, government and private consultants, and user groups.

4.2.1 Traffic Noise Model[72]

The development of the Federal Highway Administration's (FHWA) Traffic Noise Model (TNM) was funded by FHWA, managed by the Volpe National Transportation Systems Center acoustics group, and conducted by Harris Miller Miller & Hanson Inc. (HMMH) during the 1990s.

The Federal Highway Administration frequently uses the Transportation Research Board's ADC40 (formerly A1F04) Committee on Transportation-related Noise and Vibration as a resource for furthering highway noise research. This committee has many members in state departments of transportation, consulting practice, academic institutions and industry, who are knowledgeable and active in the field of highway noise analysis and control. Periodically, the FHWA conducts "research needs" workshops and surveys to determine the status of noise-related research needs nationwide. In the late 1980s and early 1990s, these workshops and surveys highlighted a strong desire for a new and improved official FHWA highway noise prediction model to replace the aging STAMINA model. Recent research in sound propagation suggested that new algorithms could predict noise levels with significantly greater accuracy. Also, changes in technology and user expectations demanded a graphical user interface with CAD-like features.

Initially, FHWA selected an expert group from the TRB A1F04 committee to serve on a panel to lead the conceptual development of the new model. This expert group developed a request for proposal and oversaw the review of proposals and selection of a firm to perform the development work. HMMH was selected as the lead firm in the development of the program architecture and acoustical algorithms. HMMH was supported by Foliage Software, Inc. who developed the database and graphical user interface. The Volpe Center acoustics group conducted measurements to update the vehicle noise emissions used in the model.

Only a preliminary list of the desired features of the new model was developed for the request for proposal. Firm selection was based primarily on qualifications, not on a detailed research approach or program design. The initial outline of the program features and design was developed under Phase 1 of the contract.

The purpose of Phase 1 of the contract was to develop the detailed scope and cost of the model development effort. A clear budget for the overall program development effort was known, and the consultant team and expert panel worked together to establish the highest degree of desirable

[72] Prepared by Christopher Menge, HMMH, September 2008.

program functionality for the available funds. The consultant team developed a design outline for a program with core functionality, and developed the practicality, approach and additional costs associated with various desired additional functionality and features. Periodic meetings with the expert group were held to discuss and refine the core functionality, and to discuss the characteristics and development costs and then prioritize the myriad noncritical but desirable features. The wish list of desirable features reached into the hundreds of items.

After several meetings and refinements of the program plan, the plan details and development costs were finalized at the end of Phase 1. A written program development plan was issued to the expert panel (which included FHWA representatives) that described the expected final program functionality.

Phase 2 was the program development effort. Notable events during the development included an effort to decrease program run time, which was unacceptably long at first. Also, model validation efforts were carried on throughout the development process, evaluating individual algorithms first, then with combinations of algorithms. Subsequent to release of the TNM, the Volpe Center has been conducting comprehensive validation measurements. The FHWA released TNM 1.0 in 1998 and has subsequently released six updates to the model including the current version, TNM 2.5, released in 2004[73].

4.2.2 Integrated Noise Model[74]

Version 1.0 of the FAA's Integrated Noise Model (INM) was released in January of 1979 to provide an analysis tool to assist in assessing the impact of aircraft noise in the vicinity of airports. Over the past twenty years, nineteen more versions of the model have been released including INM 7.0a in September of 2008. A detailed list of events in the INM's development is presented in Appendix A.

The history of events shows ongoing interactions between the FAA, government researchers, model developers, standards committees, aircraft manufacturers, and industry users to develop and improve algorithms, increase usability, and validate modeling results.

Interaction with standards/technical committees and organizations has included:

- FAA adopts SAE AIR 1845 and ICAO report 208 procedures as standards for the noise model (1987).
- Transportation Research Board (TRB) held four workshops for the development of the Aviation Environmental Design Tool (AEDT), a new tool that will combine the noise model (INM) with the emissions model (EDMS) to allow users to evaluate noise and emissions plus the tradeoffs between the two (2004 - 2006).

[73] For more information on the TNM including background information and validation reports see http://www.fhwa.dot.gov/environment/noise/tnm/index.htm (accessed September 2008).

[74] Prepared by Robert Mentzer, HMMH, September 2007.

Ongoing model review and validation has led to improvements in the aircraft database and computations. These studies, which have been conducted by a variety of agencies and companies, have included the following:

- Tests conducted at Dulles Airport and compared to the modeled results in 1979 led to improvements in the database[75].
- Tests were conducted at Seattle-Tacoma Airport and compared to the modeled results in 1981 led to improvements in the database[76].
- A 1999 study comparing INM computed SEL values with SEL values collected by permanent noise monitoring equipment at Denver International Airport and Minneapolis Saint Paul International Airport.[77]
- A 2003 study[78] evaluated INM assumptions against Boeing source data with the goal of automating the manufacturers' methods of data development to enable the maintenance of the INM database over time and supply new data for Boeing aircraft.
- A 2005 Federal Interagency Committee on Aircraft Noise (FICAN) sponsored study[79] by Volpe and Wyle compared INM and NMSIM model results to actual data from Grand Canyon National Park. This study also lead to development in the model towards National Park data and metrics.
- A 2006 study[80] by NASA and Boeing with appendices by HMMH and Wyle examined noise modeling for high altitudes and flexible flight operations.

Over the years, the FAA has sought the input of high-level users of the INM to test and improve the model. This has included beta testing of pre-release versions in several instances. In 1994, in order to solicit further feedback, FAA formed a Design Review Group (DRG) for INM. This group was made up of 26 members from FAA, other government agencies, corporations and international organizations. Members of the DRG participated in various beta testing efforts.

With the kickoff of the AEDT program, the INM DRG was discontinued and a new DRG was formed in 2007 to incorporate members of the INM and EDMS DRGs plus additional stakeholders. The subsequent AEDT DRG meetings have allowed the FAA and its contractors to present plans and progress on the merging of the two models to interested stakeholders for review. Discussions have covered topics including user interface, features, and data harmonization.

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[75] MITRE Report, Comparison of FAA INM Flight Profiles with Observed Altitudes and velocities at Dulles Airport, MTR-80W00119.

[76] MITRE Report, Comparison of FAA INM Flight Profiles with Profiles Observed at Seattle-Tacoma Airport, MTR-81W00288.

[77] Miller, N.P., et al, "Examining INM Accuracy Using Empirical Sound Monitoring Data," Report Number: HMMH-294520.03, NAS 1.26:210113, NASA/CR-2000-210113, April 2000

[78] D. Forsyth (Boeing), J Gulding (FAA), J. DiPardo (FAA), Review of Integrated Noise Model (INM) Equations and Processes" May 2003, NASA/CR-2003-212414, 2003.

[79] FICAN, Assessment of Tools for Modeling Aircraft Noise in the National Parks, March 2005.

[80] Forsyth D, J. Follet, Improved Airport Noise Modeling for high Altitudes and Flexible Flight Operations, NASA/CR-2006-214511, October 2006.

5 INTEGRATION OF LAUNCH MODELING INTO THE INM

The examination of issues related to the integration of launch noise and sonic boom models into the INM contains four sections. The first gives a general overview of the INM. The next three sections discuss the input, computation methodology, and output of the INM. Each of these three sections will also discuss the feasibility of integrating launch noise and sonic boom model data and algorithms.

5.1 The Integrated Noise Model

The Integrated Noise Model (INM) is FAA's official airport noise model. It is developed and maintained by the FAA's Office of Environment and Energy (AEE-100), the Volpe National Transportation System Center (Volpe), and ATAC Corporation. Standards documents produced by the Society of Automotive Engineers (SAE) Aviation Noise Committee (A-21) are the basis of the current INM 7.0a noise model:

- SAE-AIR-1845, Procedure for the Calculation of Airplane Noise in the Vicinity of Airports, prepared by SAE Committee A-21, March 1986.
- SAE-AIR-5662, Method for Predicting Lateral Attenuation of Airplane Noise", April 2006.
- SAE-ARP-866A, Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity, August 1964, revised March 1975.

Additionally, INM 7.0a is designed to comply with standards set by the European Civil Aviation Conference (ECAC) Doc 29, titled "Report on Standard Method of computing Noise Contours Around Civil Airports" and by the International Civil Aviation Organization (ICAO) Circular 205, titled "Recommended Method for Computing Noise Contours Around Airports."

The INM is specifically designed for computing long-term average noise values in the vicinity of airports. On a single-event basis, the INM may disagree with measurements due to complex local acoustical effects which are ignored in the model. The INM implements the modeling of long-term average conditions through the use of the concept of the "average annual-day". That is, the output is computed based on the average daily operations and weather conditions over the year of interest.

5.1.1 How Does the INM Work?

The INM produces contours or detailed noise level reports as its output. The INM divides its input into two general categories, physical and operational input. Physical input includes:

- Airport location and elevation
- Runway coordinates and elevation
- Flight path ground track
- Weather: temperature, pressure, and relative humidity

Operational input includes:

- Type of aircraft
- Number of operations
- Runway which is utilized
- Flight path which is utilized
- Time of day

In essence, a particular case or scenario within the INM applies a set of operational input to the full set of physical inputs. To compute the noise levels for this input set, the INM relies on an extensive database of information for hundreds of aircraft models. These data include noise (spectral shape and Noise-Power-Distance (NPD) curves) as well as aircraft performance (profile) characteristics.

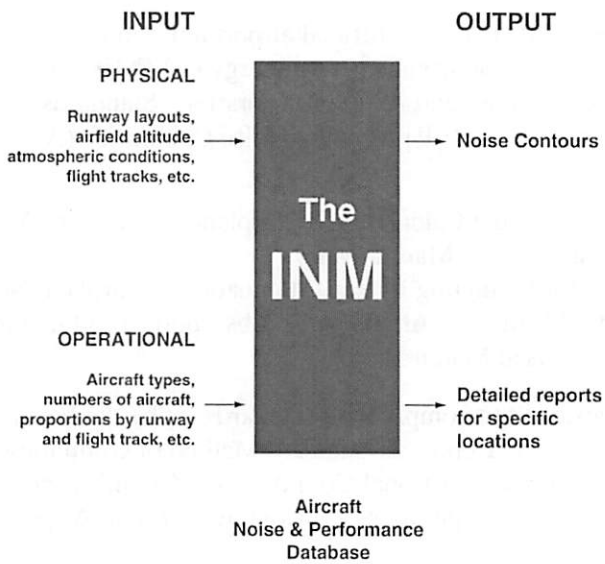

Figure 1 INM Input and Output

To create noise contours, the INM computes noise levels at finite points on a grid, using the physical and operational parameters specified and the noise and performance data for each flight. The noise levels for all of the flights are then summed at each point to produce the noise level for the requested metric.

A simplistic grid is shown below. After computing noise levels at these points, the INM will produce contours and/or noise level reports depending on the parameters specified by the user.

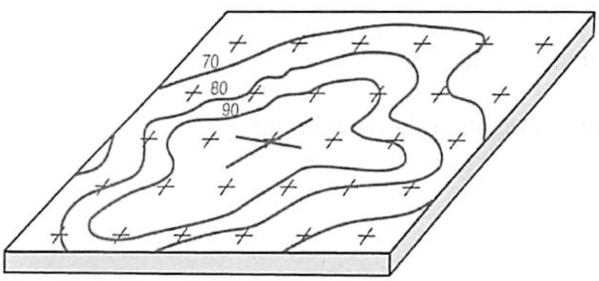

Figure 2 INM Contour Grid Output

5.1.1.1 Physical Input Data Requirements

The physical input data such as the runway layout and flight tracks determine the location and general shape of the noise contours. Runway layout includes the coordinates and elevation of the runway ends as well as parameters such as displaced thresholds, threshold crossing heights, and glide slope. These parameters determine the locations for start of takeoff and touch-down. Additionally, the INM uses the runway end elevations to modify take-off roll distances based on the computed runway gradient.

The airport elevation and average airport weather conditions are utilized by the INM to modify the aircraft performance characteristics. The INM considers the annual average relative humidity as well as the temperature at the study airport in its computation of aircraft noise propagation, if this option is invoked by the user. This enhancement is possible due to the addition of spectral classes (discussed below), since attenuation is a function of frequency. Versions of the INM previous to INM 6.0 used temperature only to calculate the effect on aircraft performance; now temperature and relative humidity are both used to compute the attenuation (atmospheric absorption) due to weather. The propagation algorithms used to modify the NPD curves are based on SAE Aerospace Recommended Practice (ARP) 866A (SAE ARP 886A).

The INM defines flight tracks in two dimensions in the form of a ground track, which is the projection of an aircraft's flight path on the ground. Aircraft with differing climb performance characteristics may utilize the same flight track since it contains no altitude information. The aircraft and the specific profiles are applied to the model flight track in the operations data. The flight track may be defined in two forms, a points-type track or a vector track. A point-type track is simply a listing of successive coordinates which the aircraft will fly from point to point. These tracks can be entered through a graphical interface. Vector tracks are sets of instructions which include straight and curved segments. Departures and arrivals start or end on runway heading, respectively with the lengths of the straight segments and the angles and radii of the curved segments determining the complete flight path. These tracks are entered through a text dialog box.

5.1.1.2 Operational Input Data Requirements

The operational input data, such as the number and type of operations, determine the overall size of the noise contours. To model the operations of each aircraft type in the INM, the following operational data are required:

- Specific aircraft type
- Operation (arrival or departure)
- Profile (altitude, speed, thrust)
- Runway used
- Flight track used
- Number of operations (daytime, evening, night)

To compute contours depicting DNL (or other 24-hour metrics) for all operations at a facility, a modeler will typically collect a years' worth of data for all operations, calculate the activity on an average day, and produce INM input which contains operations numbers for every permutation of these parameters.

It is important to identify operations separately according to the time period in which they occur (i.e., day, evening, and night) in order to compute DNL, CNEL, or other time-corrected noise metrics properly. Since nighttime operations are assessed a 10 dB penalty in the computation of DNL and

CNEL (equivalent to ten times as many operations), small changes in the estimate of nighttime activity can have a large effect.

For example, if there are 10 operations by a certain aircraft type during a 24-hour period, and only one of those operations is at night, the "effective" number of total operations is 19 (9 daytime plus 10*1 nighttime). If, on the other hand, the actual number of nighttime operations is 2, or even 1.5, the effective number of operations changes to 28 or 23.5, resulting in changes of 1.7 or 0.9 dB, respectively, in the DNL.

5.1.1.3 INM Database

INM Version 7.0a contains a database of over 270 aircraft with noise level vs. distance curves. For over 240 of these aircraft, the database contains aircraft performance profiles. The remaining aircraft are all military types adapted from the NOISEMAP program. INM 7.0a includes standard profiles for some of the NOISEMAP types. However, the user must develop performance profiles in order to use the remaining aircraft in a study.

Aircraft Type

An aircraft type designator links the noise data and performance data together for modeling. Most of the crucial noise modeling data lie within the database such as noise curves or profiles database files. There are a number of INM aircraft codes available for some aircraft types. For example, the database contains two different types for modeling the 737-300: with either the CFM 56-3B-1 engines or the CFM56-3B-2 engines. The INM also has standard substitutions for many aircraft types. Additionally, users may custom define new aircraft types.

Aircraft Profiles

Aircraft performance profiles consist of three components relating distance to actual performance characteristics. These include:

- Altitude (Climb or Descent) profiles that depict the altitude of the aircraft (in feet, relative to the airport elevation) as a function of track distance (i.e., distance from start of takeoff roll);
- Power level (Thrust) profiles that depict the aircraft engine thrust (in pounds or percent of maximum) as a function of track distance; and
- Speed profiles that depict the aircraft's speed (in knots) as a function of track distance.

The following figures depict Altitude, Thrust and Speed profiles for the A300B4-203 (A300B4-200 with CF6 50C2 engines), stage length[81] 1 (0 to 500 nmi) departure.

[81] Stage length is the trip distance. It is used as a surrogate for takeoff weight because longer flights typically carry more fuel (weight), which affects aircraft performance.

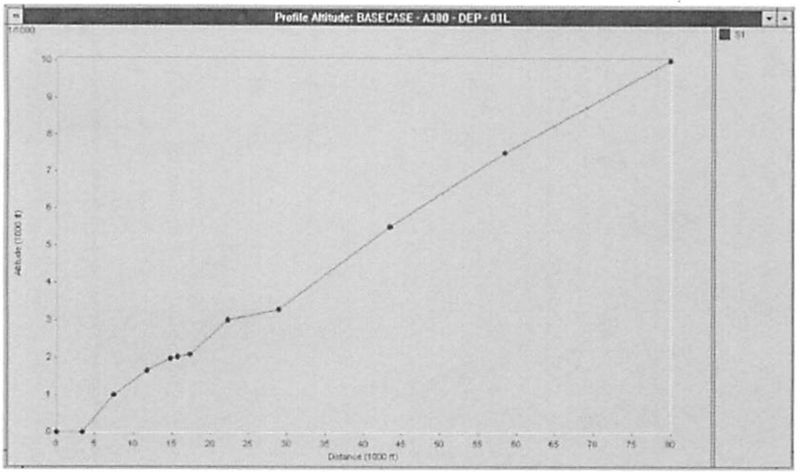

Figure 3 Aircraft Performance: Takeoff Altitude Profile

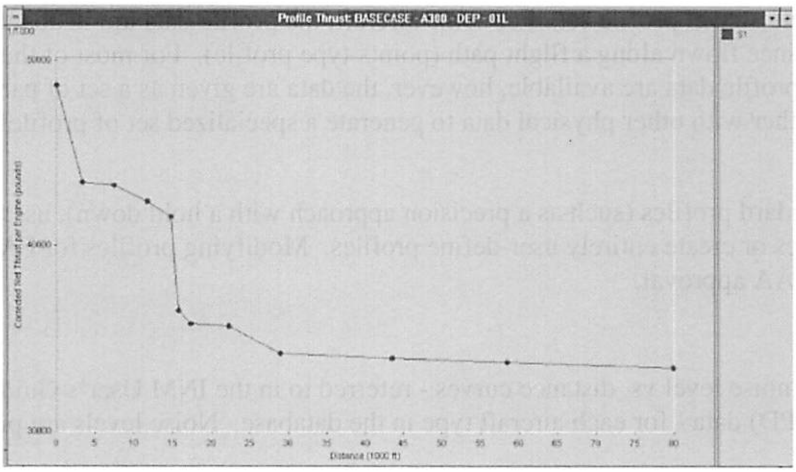

Figure 4 Aircraft Performance: Takeoff Thrust Profile

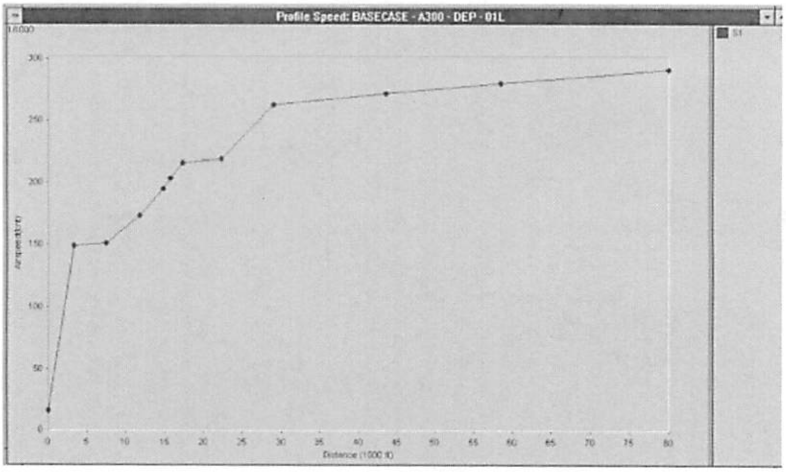

Figure 5 Aircraft Performance: Takeoff Speed Profile

The database includes a complete departure profile set for each stage length identified for the aircraft type, and a complete arrival profile set. For some aircraft, the profile data are in absolute terms in relation to the distance flown along a flight path (points-type profile). For most of the standard aircraft for which profile data are available, however, the data are given as a set of parameters that the INM uses together with other physical data to generate a specialized set of profiles (procedural profiles).

To model non-standard profiles (such as a precision approach with a hold down), users can modify the standard profiles or create entirely user-define profiles. Modifying profiles for FAA reviewed projects requires FAA approval.

Noise Curves

The INM contains noise level vs. distance curves - referred to in the INM User's Guide as noise-power-distance (NPD) data - for each aircraft type in the database. Noise levels are provided for the following metrics:

- Sound Exposure Level (SEL)
- Estimated Perceived Noise Level (EPNL)
- Maximum A-weighted level (LAMAX), and
- Maximum Perceived Tone-Corrected Level (PNLTM).

The database does not contain noise level data for all four of the above-listed metrics for all aircraft types; however, it does contain SEL and EPNL data for all aircraft types. For those cases where LAMAX and/or PNLTM data do not exist but are required for certain calculations, the INM uses SEL or EPNL data to derive the LAMAX or PNLTM. Also note that the database does not contain any C-weighted data. These data are created by the INM from the A-weighted data and the spectral data.

INM 7.0a has at least two noise curves (of each type) for each aircraft type, representing different engine thrust levels. NPD curves are defined as either "takeoff" or "approach" curves. NPD curves are defined by a series of discrete noise levels at given slant distances, for a given thrust setting. The INM interpolates or extrapolates (linearly) to determine noise levels at other thrust settings. The distances shown in the noise curves represent the slant distance (slant range[82]), not the track distance (distance from brake release).

The spectral class for each aircraft type is defined for approach and departure. INM 7.0a contains 82 spectral classes: 34 approach classes and 34 departure classes. An additional 14 classes are used to represent level flight conditions or afterburners for military aircraft. Each class contains aircraft types that produce noise levels of similar spectral shape.

The graph below depicts the noise curves for the A300B4-203 aircraft, which are supplied for three different thrust values. The top curve is for a thrust of 40,000 pounds, the middle for 25,000 and the bottom for 10,000 pounds of thrust. At other thrust levels, the INM interpolates or extrapolates from these three curves. INM 7.0a limits this extrapolation to 5 dB below the lowest noise curve.

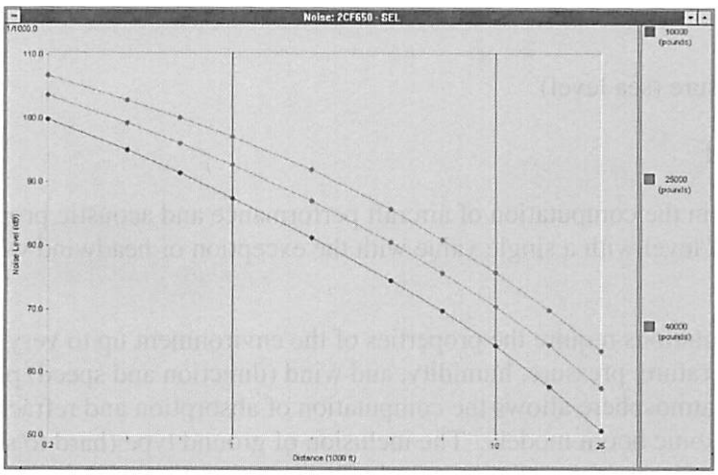

Figure 6 Aircraft Noise: Noise-Power-Distance Curves

5.1.1.4 Directory Structures

INM model runs are organized in a simple directory structure with folders for the study-level physical parameters and sub-directories for the operational input for a particular modeling run. Output data are also stored in study subdirectories. The INM stores the majority of the input data in database (dbf) files which may be modified through the user interface or directly with a database management tool. In addition, the INM program stores its own database information and auxiliary programs in a number of different files in a dedicated INM program directory structure.

The INM 7.0 Users Guide provides a complete description of every data field in each input and output database file, including data type and number of characters.

[82] Direct line distance from a point on the ground to the flight track.

5.2 INM and Launch Noise Input

Similar data are necessary for the computation of launch noise and sonic booms and aircraft noise levels: characteristics of the environment, vehicle properties, and a flight trajectory. Noise characteristics of the vehicle are more commonly computed from vehicle properties for launch noise, while the INM database contains noise curves which are part of the model input.

5.2.1 Launch Environment

The INM has five parameters which define the airport environment for a particular model run:

- Airfield elevation
- Temperature
- Atmospheric pressure (sea level)
- Relative humidity
- Average headwind

These values are used in the computation of aircraft performance and acoustic propagation. They are defined only at ground level with a single value with the exception of headwind which can be varied by runway end.

Detailed launch computations require the properties of the environment up to very high altitudes. Specification of temperature, pressure, humidity, and wind (direction and speed) profiles for a horizontally stratified atmosphere allows the computation of absorption and refraction effects and the ray tracing utilized in sonic boom models. The inclusion of ground type (hard to soft) at each grid computation point is necessary for realistic ground effects. Integration of these data would require the addition of files to the INM.

5.2.2 Vehicle Definition

The INM utilizes a database of noise curves which are referenced to particular aircraft types. For launch noise, the physical characteristics of the vehicle are utilized in the computation of the noise emitted by the vehicle. Relevant vehicle characteristics for noise computations include:

- Exhaust exit velocity
- Nozzle diameter (or effective nozzle diameter)
- Acoustic efficiency
- Sound speed in throat

Additional parameters for sonic boom modeling include:

- Weight
- Length
- Shape-factor

The INM has three vehicle definition files, one each for civil fixed-wing aircraft, military fixed-wing aircraft, and helicopters. Since the necessary fields of data for launch vehicles are quite different, integration into the INM would require an additional vehicle definition file.

5.2.3 Trajectory

To adequately compute both launch noise and sonic boom the following trajectory parameters are necessary:

- Position (x,y,z)
- Speed
- Magnitude of the acceleration
- Magnitude of the derivative of acceleration
- Thrust
- Time

With the exception of the two higher order position derivatives and time, the INM utilizes similar information in its points-type profiles. However, the INM separates the trajectory information into two forms: a ground track and a set of profiles. Conversion of the launch trajectory into INM format would simply require the storage of the x and y components of the position as the ground track, the computation of track distance from the x and y components of the position, and the storage of the remaining parameters as profiles.

The INM currently contains three points-type profile files, one each for civil fixed-wing aircraft, military fixed-wing aircraft, and helicopters. Integration into the INM would require a similar file for launch vehicles with additional fields for the two higher-order position derivatives and time. Launch vehicle ground tracks could be stored within the existing flight track database files.

5.3 INM and Launch Noise Computation Methodology

As outlined previously, the INM applies a database of noise curves, and profiles to an operation on a defined flight track to compute the noise level at a grid of points on the ground. A simplified listing of the acoustic computation tasks for each flight segment follows:

- Interpolate/extrapolate noise level from noise curves
- Compute atmospheric absorption adjustment
- Compute acoustic impedance adjustment
- Compute noise fraction adjustment
- Compute duration adjustment
- Compute lateral attenuation adjustment

INM noise curves are referenced to an infinite, straight pass-by at 160 knots under specific atmospheric conditions. The atmospheric absorption and acoustic impedance adjustments account for the particular atmospheric conditions in the modeling run. The noise fraction adjustment accounts for the actual length of the segment and its orientation relative to the computation point. The duration adjustment accounts for the actual speed of the aircraft. The lateral attenuation adjustment covers the three areas of ground reflections, refraction, and fuselage shielding in a single parameter.

Launch noise models differ from the INM computations in nearly every way. A basic outline of the launch noise modeling process would include:

- Estimate sound power from mechanical power and acoustic efficiency
- Compute spectrum from rocket parameters
- Adjust for propagating frequencies based on vehicle velocity
- Compute directivity from ambient and jet sound speeds
- Adjust for forward flight effects
- Propagate sound (atmospheric and ground effects)

The INM's computation methods are designed to empirically fit aircraft. The built-in directivity and fuselage shielding algorithms are suitable for typical aircraft with wing or fuselage mounted engines. The directivity of launch vehicles is different. Additionally, the INM has no method to account for the shift in the frequencies of propagation due to the motion of the launch vehicle. The current INM computations would also not account for propagation effects within a fully defined stratified atmosphere. It is worth noting that published launch noise papers vary on the application of atmospheric absorption with at least one paper recommending the use of an ANSI standard[83], another recommending no adjustment[84], and another specifically noting that use of SAE ARP 866A (as per INM) would substantially overestimate the losses[85]. Integration of launch noise modeling methodologies into the INM would primarily involve the addition of completely separate computations.

Sonic boom computations rely on ray tracing methods that bear no resemblance to the computations within the INM. Integration would involve the addition of entirely separate calculation methods.

5.4 INM and Launch Noise Output

As discussed in Section 3.2, day-night average sound level (DNL) is the primary noise metric for the computation of significant noise impact in a NEPA-compliant environmental document. Order 1050.1 E and the Desk Reference list other metrics which may be useful for computing impacts to 4(f) properties or for response to particular community concerns. With the exception of one-third octave band sound level, the INM computes all of these metrics. Thus, integration of launch model output would be possible for all of these metrics.

The INM's output includes both noise levels at user-designated points on the ground (grid points) and contours of equal noise exposure over a defined area. The grid-point computations allow the reporting of one or more metrics at each point. Additionally, the user may elect to run the grid points and receive a detailed report for each point listing the contribution of each individual aircraft operation to each noise metric.

[83] Plotkin, K.J., L.C. Sutherland, M. Moudou, Predictions of Rocket Noise During Boost Phase, slide show for the American Institute of Aeronautics and Astronautics, 1997.

[84] McInerny, S., Rocket Noise - a Review , AIAA 13th Aeroacoustics Conference, AIAA-90-3981, October 1990.

[85] Sutherland, L.C., Progress and Problems in Rocket Noise Prediction for Ground Facilities, 15th AIAA Aeroacoustics Conference, AIAA-93-4383, October 1993.

To generate noise contours, the INM computes the noise levels at a grid of regularly spaced points. Run settings can be varied to insert points within the grid where greater detail is necessary. The INM enlists the program NMPlot to generate noise contours from the grid of computed noise levels. NMPlot is free software produced and made available over the web by Wasmer Consulting.

Integration of grid point or contour grid results for any noise model with the INM grid point results would be straightforward using logarithmic addition for exposure-based metrics. In the case of maximum level metrics or time-above metrics, the maximum or arithmetic sum of the two results, respectively, would be computed. NMPlot can add, subtract, average, and merge grid files. For direct input, without the use of the binary grid file format, NMPlot has a simple text file grid format which is well defined in its documentation. Users of any model can use this NMPlot format to generate contours or to add their results to the results of another model.

Results for sonic boom computations (such as peak overpressure values) are not added to computed noise levels. These results would be presented separately with additional results tables or contours generated by NMPlot.

5.5 Summary

Integration of a launch noise model into the INM faces several roadblocks. As discussed in Section 5.2 many additional parameters will be required. As discussed in Section 5.3 the launch noise computation engine will be quite different than that currently present in the INM. As the INM is an integrated model and the launch noise model requires simulation in order to generate time histories, there will be little to no sharing of computations between aircraft and launch noise modeling. Section 5.4 discusses the relative ease of integrating the noise results using NMPlot and the fact that sonic boom results will stand alone. A stand-alone launch noise model would allow the same easy integration of results without the expense and difficulty of integrating the model into the INM.

Two additional factors also point to the utility of a stand-alone model. Firstly, the added complexity in the INM will only be used by a small subset of users. Users interested only in aircraft noise or only in launch noise will have many less menus and dialogs to wade though if the launch noise model is not integrated into the INM. Second, the FAA is currently in the process of combining the models for airport noise (INM), regional aircraft noise (NIRS), and emissions (EDMS) into a single Aviation Environmental Design Tool (AEDT). The first version of AEDT is slated to be released in 2011[86]. Thus, at the earliest, the process of adding a launch noise model would not likely begin for many years.

Likewise, integration of a sonic boom model into the INM would offer little benefit. The models would have no calculation algorithms in common and the output would be presented separately in any case. A stand-alone model for sonic boom is recommended.

[86] Federal Aviation Administration Office of Environment and Energy, AEDT News, October 2008.

APPENDIX A INTRODUCTION TO ACOUSTICS AND AVIATION NOISE TERMINOLOGY

Noise impact criteria rely largely on a measure of daily aircraft noise exposure, called the Day-Night Average Sound Level (DNL) using the calculated annual-average DNL from an entire year of daily aircraft operations. However, DNL does not provide an adequate description of noise for many other purposes. A variety of other measures are available to address essentially any issue of concern, specifically related to the effects of noise.

This chapter introduces the following acoustic metrics, which are all related to DNL, but provide bases for evaluating a broad range of noise situations.

- Sound Pressure Level, SPL;
- Maximum Sound Level, L_{max};
- Sound Exposure Level, SEL;
- Single-Event Noise Exposure Level, SENEL;
- Equivalent Sound Level, L_{eq}; and
- Day-Night Average Sound Level, DNL.

A.1 Sound Pressure Level, SPL

All sounds come from a sound source – a musical instrument, a voice speaking, or an airplane as it flies overhead. It takes energy to produce sound. The sound energy produced by any sound source is transmitted through the air in sound waves – tiny, quick oscillations of pressure just above and just below atmospheric pressure. These oscillations, or sound pressures, impinge on the ear, creating the sound we hear. The true definition of sound is any pressure variation the human ear can detect. Therefore, sound is pressure variations people hear.

Our ears are sensitive to a wide range of sound pressures. The loudest sounds that we hear without pain have about one million times more energy than the quietest sounds we hear. But our ears are incapable of detecting small differences in these pressures. Thus, to better match how we hear this sound energy, we compress the total range of sound pressures to a more meaningful range by introducing the concept of Sound Pressure Level (SPL). Sound pressure level is a measure of the sound pressure of a given noise source relative to a standard reference value (the quietest sound that a young person with good hearing can detect).

A.1.1 The decibel, dB

Sound pressure levels are measured in decibels (abbreviated dB). Decibels are logarithmic quantities – logarithms of the ratio of the two pressures, the numerator being the pressure of the sound source of interest, and the denominator being the reference pressure (the quietest sound we can hear).

$$SPL = 10 * LOG\left(\frac{P^2_{source}}{P^2_{reference}}\right) dB$$

The logarithmic conversion of sound pressure to sound pressure level means that the quietest sound we can hear (the reference pressure) has a sound pressure level of about zero decibels, while the loudest sounds we hear without pain have sound pressure levels of about 120 dB. Most sounds in our day-to-day environment have sound pressure levels from 30 to 100 dB.

Because decibels are logarithmic quantities, they do not behave like regular numbers with which we are more familiar. For example, if two sound sources each produce 100 dB and they are operated together, they produce only 103 dB – not 200 dB as we might expect. Four 100 dB sources operating simultaneously result in a total sound pressure level of 106 dB. In fact, for every doubling of the number of equal sources, the sound pressure level goes up another three decibels. A tenfold increase in the number of sources makes the sound pressure level increase 10 dB. A hundredfold increase makes the level go up 20 dB, and it takes a thousand equal sources to increase the level 30 dB!

If one source is much louder than another, the two sources together will produce the same sound pressure level (and sound to our ears) as if the louder source were operating alone. For example, a 100 dB source plus an 80 dB source produce 100 dB when operating together. The louder source "masks" the quieter one, but if the quieter source gets louder, it will have an increasing effect on the total sound pressure level. When the two sources are equal, as described above, they produce a level three decibels above the sound of either one by itself.

From these basic concepts, note that one hundred 80 dB sources will produce a combined level of 100 dB; if a single 100 dB source is added, the group will produce a total sound pressure level of 103 dB. Clearly, the loudest source has the greatest effect on the total

A.1.2 A-weighted decibel

Another important characteristic of sound is its frequency, or "pitch". For example, a whistle is often perceived as having a high pitch whereas a thunderclap has a low pitch. This is the rate (in cycles per second) of repetition of the sound pressure oscillations as they reach our ear. Frequency is expressed in units known as Hertz (Hz).

Most people hear from about 20 Hz to about 10,000 to 15,000 Hz. People respond to sound most readily when the predominant frequency is in the range of normal conversation (the speech frequencies), around 1,000 to 2,000 Hz. Acousticians have developed "filters" to match our ears' sensitivity and help us to judge the relative loudness of sounds made up of different frequencies. The so-called "A" filter does the best job of matching the sensitivity of our ears to most environmental noises. Sound pressure levels measured through this filter are referred to as A-weighted levels. A-weighting significantly de-emphasizes noise at low frequencies (below about 500 Hz) and also de-emphasizes high frequencies (above about 10,000 Hz) where we do not hear as well. Because this filter generally matches our ears' sensitivity, sounds having higher A-weighted sound levels are usually judged to be louder than those with lower A-weighted sound levels, a relationship which does not always hold true for unweighted levels. It is for these reasons, along with the recommendation[87] from the Environmental Protection Agency (EPA), that A-weighted sound levels are normally used to evaluate environmental noise.

Other weighting networks include the B, C, and D filters. They correspond to four different level ranges of the ear. The rarely used B-weighting attenuates low frequencies (those less than 500 Hz),

[87] Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, U.S. EPA Report No. 550/9-74-004, March 1974.

but to a lesser degree than A weighting. C weighting is nearly flat throughout the audible frequency range, hardly de-emphasizing low frequency noise. C-weighted levels can be preferable in evaluating sounds whose low-frequency components are responsible for secondary effects such as the shaking of a building, window rattle, or perceptible vibrations. Uses include the evaluation of blasting noise, artillery fire, and in some cases, aircraft noise inside buildings.

The D-weighting network, also used only rarely, is similar to the B-weighting at low frequencies, but includes a significant amplification of the sound (up to about 10 dB) in the 2,000 to 8,000 Hz range.

Figure 7 compares these various weighting networks.

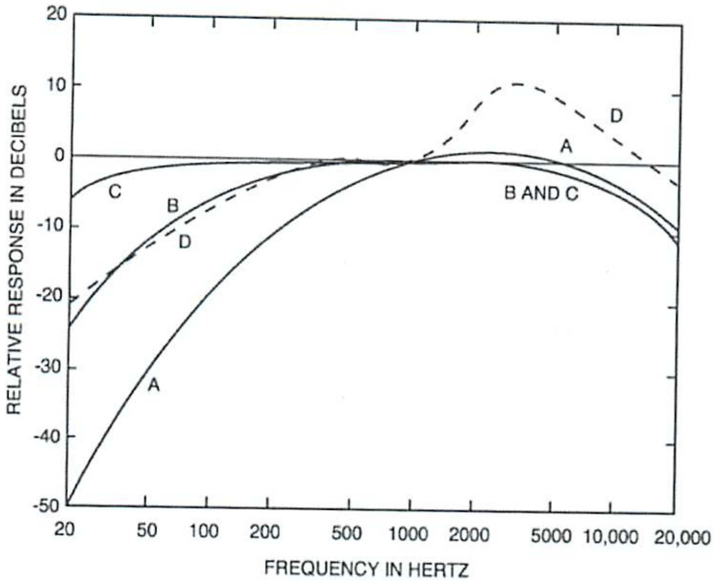

Figure 7 Frequency-Response Characteristics of Various Weighting Networks

Source: Harris, Cyril M., editor; Handbook of Acoustical Measurements and Noise Control, (Chapter 5, "Acoustical Measurement Instruments"; Johnson, Daniel L.; Marsh, Alan H.; and Harris, Cyril M.); New York; McGraw-Hill, Inc.; 1991; p. 5.13

Because of the correlation with our hearing, the A-weighted level has been adopted as the basic measure of environmental noise by the U.S. Environmental Protection Agency (EPA) and by nearly every other federal and state agency concerned with community noise. Figure 8 presents typical A-weighted sound levels of several common environmental sources.

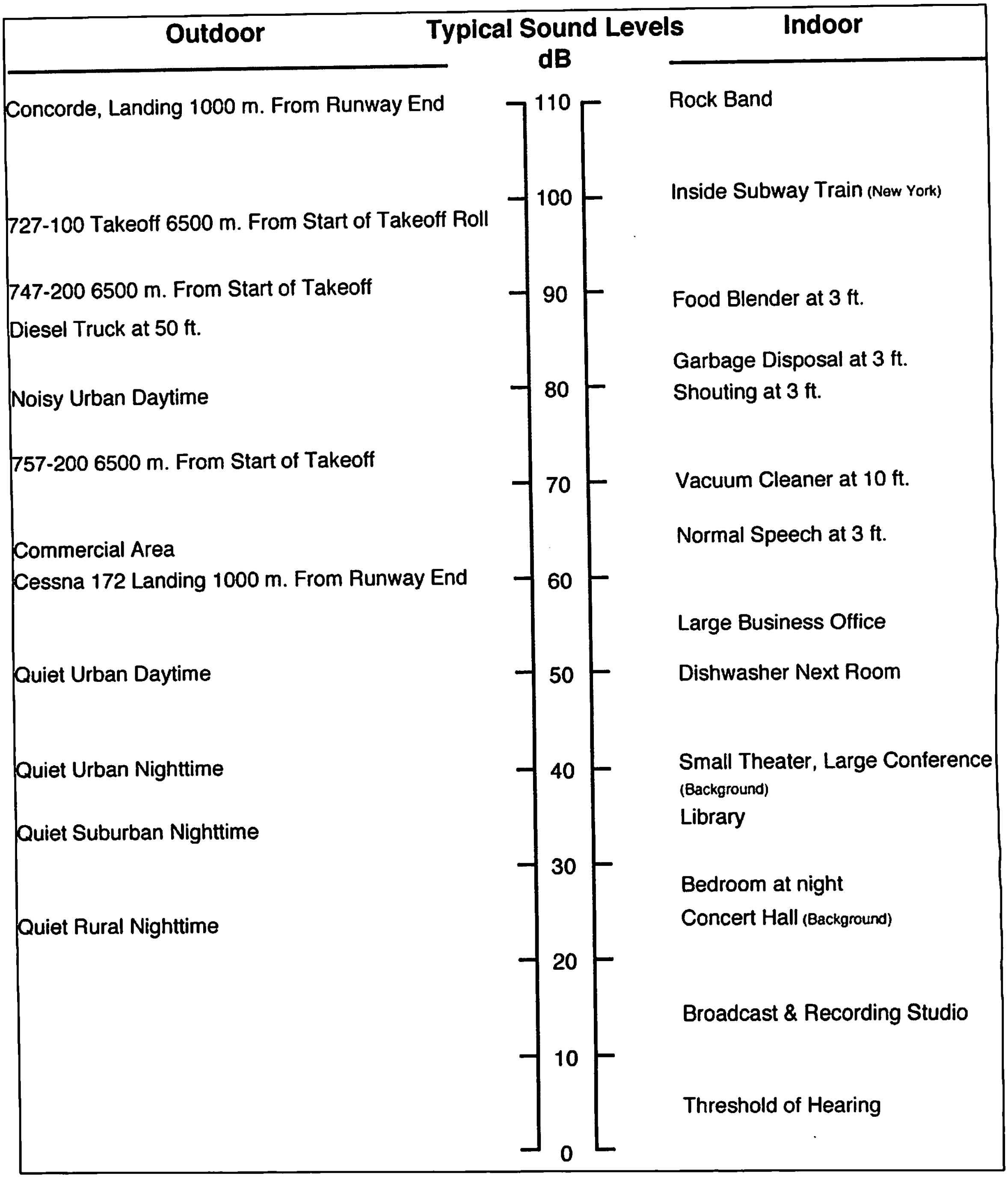

Figure 8 Common Environmental Sound Levels

Source: HMMH (Aircraft noise levels from FAA Advisory Circular 36-3H)

An additional dimension to environmental noise is that A-weighted levels vary with time. For example, the sound level increases as an aircraft approaches, then falls and blends into the background as the aircraft recedes into the distance (even though the background varies as birds chirp or the wind blows or a vehicle passes by). Figure 9 illustrates this concept.

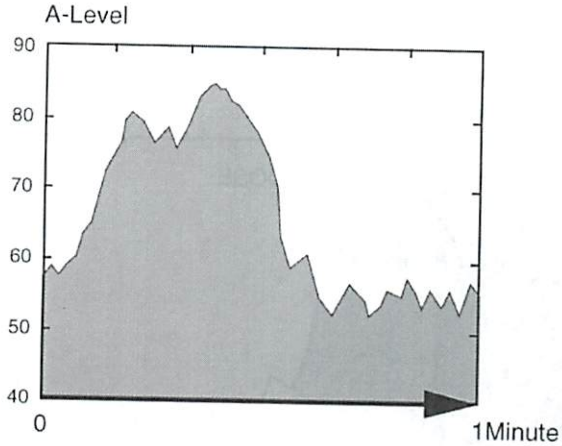

Figure 9 Variations in the A-Weighted Sound Level Over Time

Source: HMMH

A.1.3 Maximum Sound Level, L_{max}

The variation in sound level over time often makes it convenient to describe a particular noise "event" by its maximum sound level, abbreviated as L_{max}. In Figure 9, it is approximately 85 dB.

The maximum level describes only one dimension of an event; it provides no information on the cumulative noise exposure. In fact, two events with identical maxima may produce very different total exposures. One may be of very short duration, while the other may continue for an extended period and be judged much more annoying. The Sound Exposure Level and Single-Event Noise Exposure Level metrics correct for this deficiency.

A.1.4 Sound Exposure Level, SEL

The most frequently used measure of noise exposure for an individual aircraft noise event (and the measure that Part 150 specifies for this purpose) is Sound Exposure Level, or SEL. SEL measures the total noise energy produced during an event, from the time when the level first exceeds the background, to the time that it drops back below. To compare noise events with different durations, SEL "normalizes" the duration in every case to one second; that is, it is expressed as the steady noise level with a one-second duration that includes the same amount of noise energy as the actual longer duration, time-varying noise. In lay terms, SEL "squeezes" the entire noise event into one second.

Because SEL is normalized to one second, it always is larger than the L_{max} for events longer than one second. For most aircraft overflights, the SEL is on the order of 7 to 12 dB higher than L_{max}. Because SEL takes duration into account, a long duration flyby in relatively quiet aircraft, such as propeller models, can have the same or higher SEL than louder but faster planes, such as jets.

Figure 10 depicts the transformation of a complete noise event into an SEL value. The shaded area represents the energy included in an SEL measurement for the noise event, where the threshold is set to 60 dB. The darkly shaded vertical bar, which is 90 dB high and just one second long (wide), contains exactly the same sound energy as the full event. In this case, the SEL is 90 dB; the L_{max} is approximately 85 dB.

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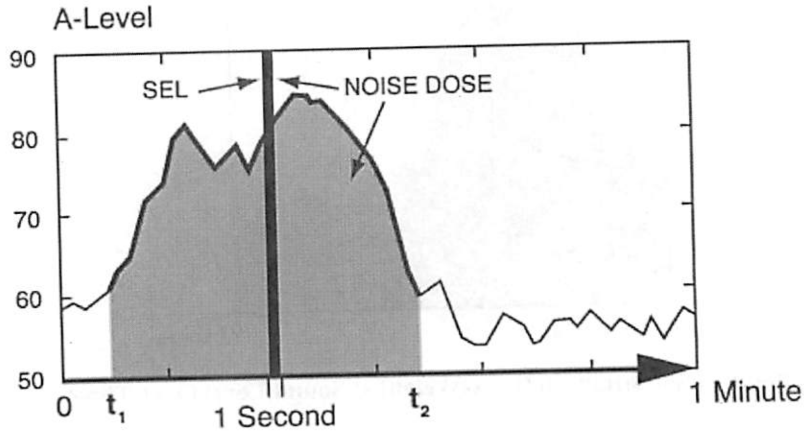


Figure 10 Single-Event Noise Exposure Level

Source: HMMH

The L_{max}, and SEL quantify the noise associated with individual events. The remaining metrics in this section describe longer-term cumulative noise exposure that often include many events.

A.1.5 Equivalent sound level, L_{eq}

The equivalent sound level (L_{eq}), is a measure of exposure resulting from the accumulation of sound levels over a particular period of interest; for example, one hour, an eight hour school day, nighttime, or a full 24-hour day. Because the length of the period can differ, the applicable period should always be identified or clearly understood when discussing the metric. Such durations are often identified through a subscript, for example $L_{eq(8)}$ or $L_{eq(24)}$.

L_{eq} is equivalent to the constant sound level over the period of interest that contains as much sound energy as the actual varying level. This is illustrated in Figure 11.

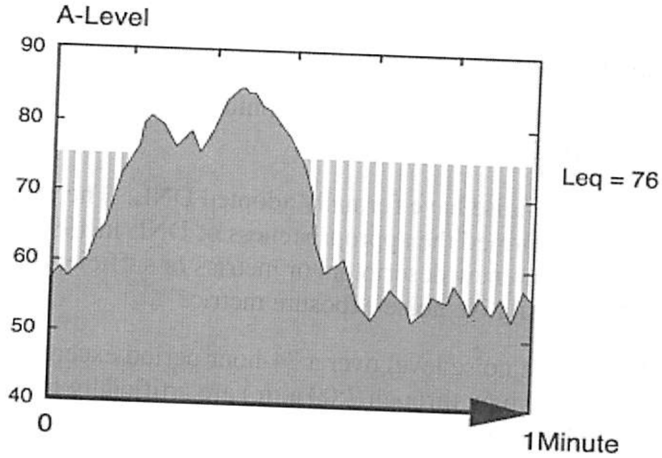


Figure 11 Example of a One Minute Equivalent Sound Level

Source: HMMH

Both the solid and striped shaded areas in the figure have a one-minute L_{eq} value of 76 dB. It is important to recognize, however, that the two signals (the constant one and the time-varying one) would sound very different in real life. Also, be aware that the "average" sound level suggested by L_{eq} is not an arithmetic value, but a logarithmic, or "energy-averaged" sound level. Thus, loud events dominate L_{eq} measurements.

In airport noise studies, L_{eq} is often presented for consecutive one-hour periods to illustrate how the exposure rises and falls throughout a 24-hour period, and how individual hours are affected by unusual activity, such as rush hour traffic or a few loud aircraft.

A.1.6 Day-Night Average Sound Level, DNL

Federal aircraft noise impact criteria require a slightly more complicated measure of noise exposure to describe cumulative noise exposure during an average annual day: the Day-Night Average Sound Level, DNL or L_{dn}. The U.S. Environmental Protection Agency (EPA) identified DNL as the most appropriate means of evaluating airport noise based on the following considerations[88]:

1. The measure should be applicable to the evaluation of pervasive long-term noise in various defined areas and under various conditions over long periods of time.
2. The measure should correlate well with known effects of the noise environment and on individuals and the public.
3. The measure should be simple, practical and accurate. In principal, it should be useful for planning as well as for enforcement or monitoring purposes.
4. The required measurement equipment, with standard characteristics, should be commercially available.
5. The measure should be closely related to existing methods currently in use.

[88] Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, U.S. EPA Report No. 550/9-74-004, March 1974.

6. The single measure of noise at a given location should be predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.
7. The measure should lend itself to small, simple monitors, which can be left unattended in public areas for long periods of time.

Most federal agencies dealing with noise have formally adopted DNL. The Federal Interagency Committee on Noise (FICON) reaffirmed the appropriateness of DNL in 1992. The FICON summary report stated; "There are no new descriptors or metrics of sufficient scientific standing to substitute for the present DNL cumulative noise exposure metric."

In simple terms, DNL is the average noise level over a 24-hour period except that noise events occurring at night (defined as 10:00 p.m. through 7:00 a.m.) are artificially increased by 10 dB (equivalent to 10 times the number of noise events or aircraft operations). This weighting reflects the added intrusiveness of nighttime noise events attributable to the fact that community background noise levels decrease at night.

DNL can be measured or estimated. Measurements are practical only for obtaining DNL values for relatively limited numbers of points, and, in the absence of a permanently installed monitoring system, only for relatively short time periods. Most airport noise studies are based on computer-generated DNL estimates depicted in terms of equal-exposure noise contours (much as topographic maps have contours of equal elevation). Figure 12 depicts typical DNL values for a variety of noise environments.

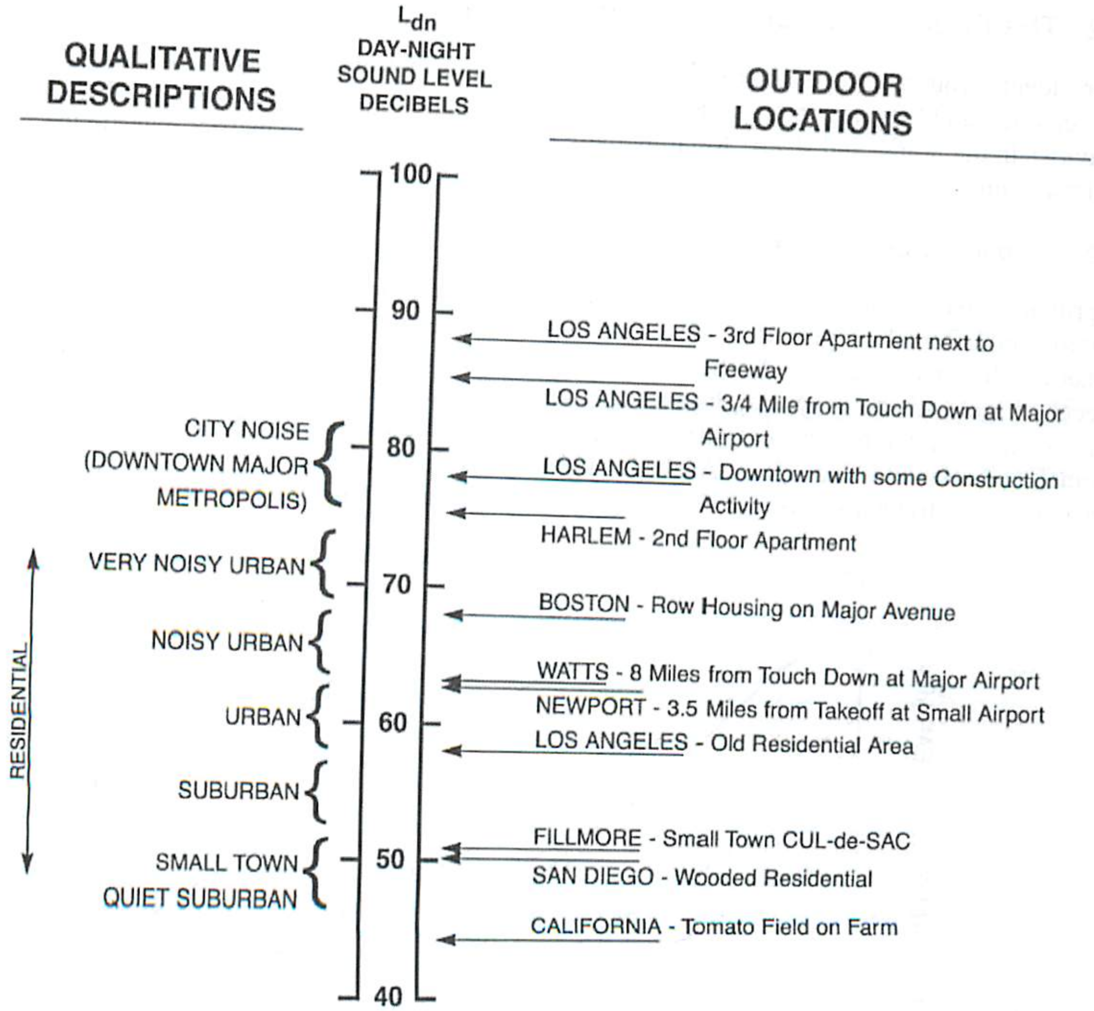


Figure 12 Examples of Day-Night Average Sound Level, DNL

Source: United States Environmental Protection Agency, Information on Levels of Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, March 1974, p. 14.

A.1.7 Community Noise Equivalent Level, CNEL

Similar to the DNL, the Community Noise Equivalent Level (CNEL) is the average noise level over a 24-hour period with a 10-dB increase to nighttime noise levels. CNEL differs from DNL during the evening hours (7:00 p.m. to 10:00 p.m.) by providing an additional weighting factor equivalent to three times the number of operations. This artificially increases the level of noise events occurring by nearly 5 dB (4.77 dB). The FAA accepts CNEL in place of DNL for studies conducted within California since the State has adopted the CNEL as the standard for assessing cumulative community noise exposures. DNL and CNEL are therefore interchangeable in the literature for use in California.

A.2 The Effects of Aircraft Noise on People

To residents around airports, aircraft noise can be an annoyance and a nuisance. It can interfere with conversation and listening to television and it can disrupt classroom activities in schools, schoolwork activities in the home, and sleep. Relating these effects to specific noise metrics helps in the understanding of how and why people react to their noise environment.

A.2.1 Speech interference

A primary effect of aircraft noise is its tendency to drown out or "mask" speech, making it difficult to carry on a normal conversation. The sound level of speech decreases as the distance between a talker and listener increases. As the background sound level increases, it becomes harder to hear speech. Figure 13 shows typical distances between talker and listener for satisfactory outdoor conversations, in the presence of different steady A-weighted background noise levels for raised, normal, and relaxed voice effort. As the background level increases, the talker must raise his/her voice, or the individuals must get closer together to continue hearing the conversation.

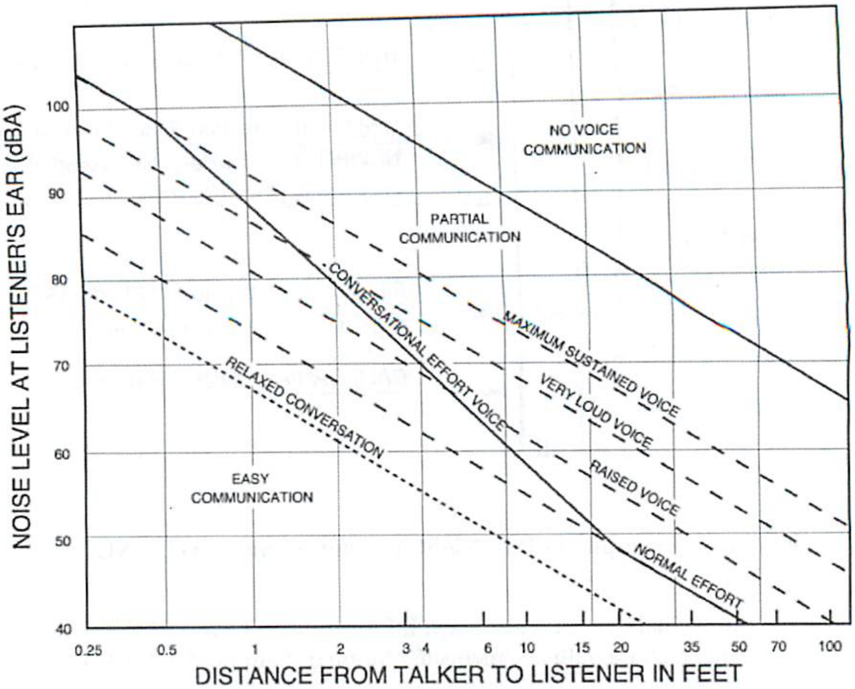


Figure 13 Outdoor Speech Intelligibility

Source: United States Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, March 1974, p. D-5.

As indicated in the figure, "satisfactory conversation" does not always require hearing every word; 95% intelligibility is acceptable for many conversations. Listeners can infer a few unheard words when they occur in a familiar context. However, in relaxed conversation, we have higher expectations of hearing speech and generally require closer to 100% intelligibility. Any combination of talker-listener distances and background noise that falls below the bottom line in the figure (thus assuring 100% intelligibility) represents an ideal environment for outdoor speech communication and is considered necessary for acceptable indoor conversation as well.

One implication of the relationships in Figure 13 is that for typical communication distances of 3 or 4 feet, acceptable outdoor conversations can be carried on in a normal voice as long as the background noise outdoors is less than about 65 dB. If the noise exceeds this level, as might occur when an aircraft passes overhead, intelligibility would be lost unless vocal effort was increased or communication distance was decreased.

Indoors, typical distances, voice levels, and intelligibility expectations generally require a background level less than 45 dB. With windows partly open, California housing typically provides about 10 to 15 dB of interior-to-exterior noise level reduction. With windows closed, 15 to 20 dB of attenuation is typical. Thus, if the outdoor sound level is 60 dB or less (70 dB with windows closed), there is a reasonable chance that the resulting indoor sound level will afford acceptable conversation inside.

A.2.2 Sleep interference

Research on sleep disruption from noise has led to widely varying observations. In part, this is because (1) sleep can be disturbed without awakening, (2) the deeper the sleep the more noise it takes to cause arousal, (3) the tendency to awaken increases with age, and other factors.

Figure 8 shows a summary of findings on the topic.

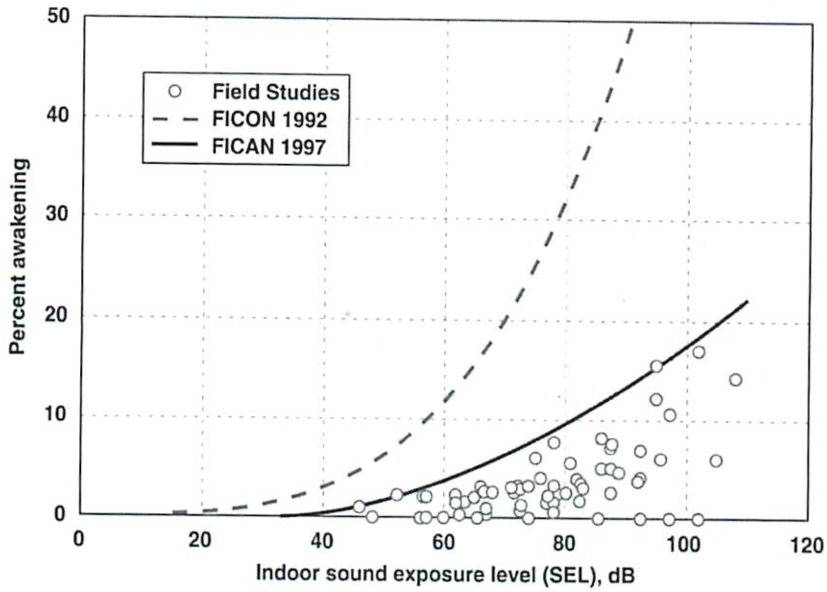


Figure 14 Sleep Interference

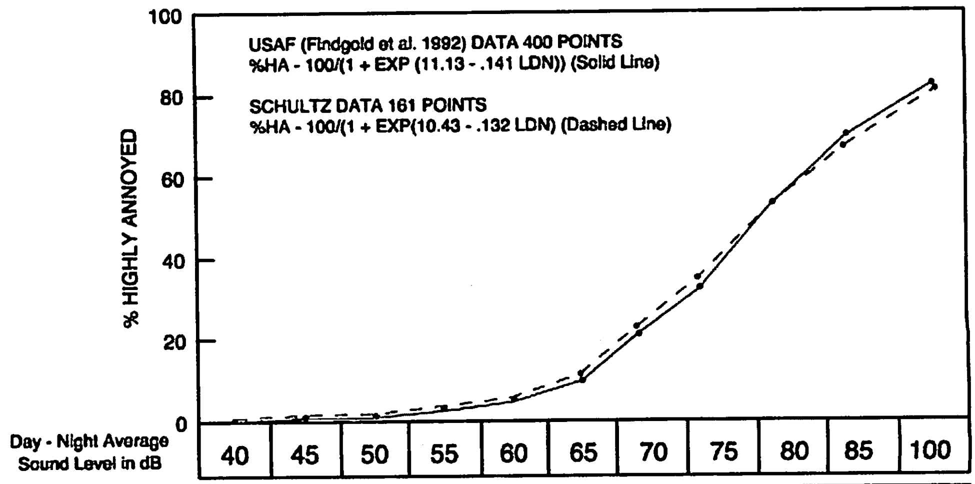
Source: Federal Interagency Committee on Aviation Noise (FICAN), "Effects of Aviation Noise on Awakenings from Sleep", June 1997, page 6.

Figure 14 uses indoor SEL as the measure of noise exposure; recent work supports the use of this metric in assessing sleep disruption. An indoor SEL of 80 dB results in a maximum of 10% awakening. Assuming the typical windows-open interior-to-exterior noise level reduction of approximately 12 dB, and a typical L_{max} value for an aircraft flyover 12 dB lower than the SEL value, an interior SEL of 80 dB roughly translates into an exterior L_{max} of the same value.

In December 2008, FICAN updated this guidance for predicting awakenings from aircraft noise. FICAN now recommends use of ANSI S12.9-2008, "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." This standard enables estimation of awakenings from an entire night of noise events, and may include not only level (SEL) and number of individual aircraft noise events, but also time of night of the occurrence of each event.

A.2.3 Community Annoyance

Social survey data make it clear that individual reactions to noise vary widely for a given noise level. Nevertheless, as a group, people's aggregate response is predictable and relates well to measures of cumulative noise exposure such as DNL. Figure 15 shows the most widely recognized relationship between environmental noise and annoyance.



Calculated %HA Points												
Day - Night Average Sound Level in dB		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 15 Percentage of People Highly Annoyed

Source: Federal Interagency Committee on Noise. "Federal Agency Review of Selected Airport Noise Analysis Issues". August 1992. (From data provided by USAF Armstrong Laboratory). pp. 3-6.

Based on data from 18 surveys conducted worldwide, the curve indicates that at levels as low as 55 dB DNL, approximately five percent of the people will still be highly annoyed, with the percentage increasing more rapidly as exposure increases above 65 dB DNL.

Separate work by the EPA has shown that overall community reaction to a noise environment is also dependent on DNL. This relationship is shown in Figure 16. Levels have been normalized to the same set of exposure conditions to permit valid comparisons between ambient noise environments. Data summarized in that figure suggest that little reaction would be expected for intrusive noise levels five decibels below the ambient, while widespread complaints can be expected as intruding noise exceeds background levels by about five decibels. Vigorous action is likely when the background is exceeded by 20 dB.

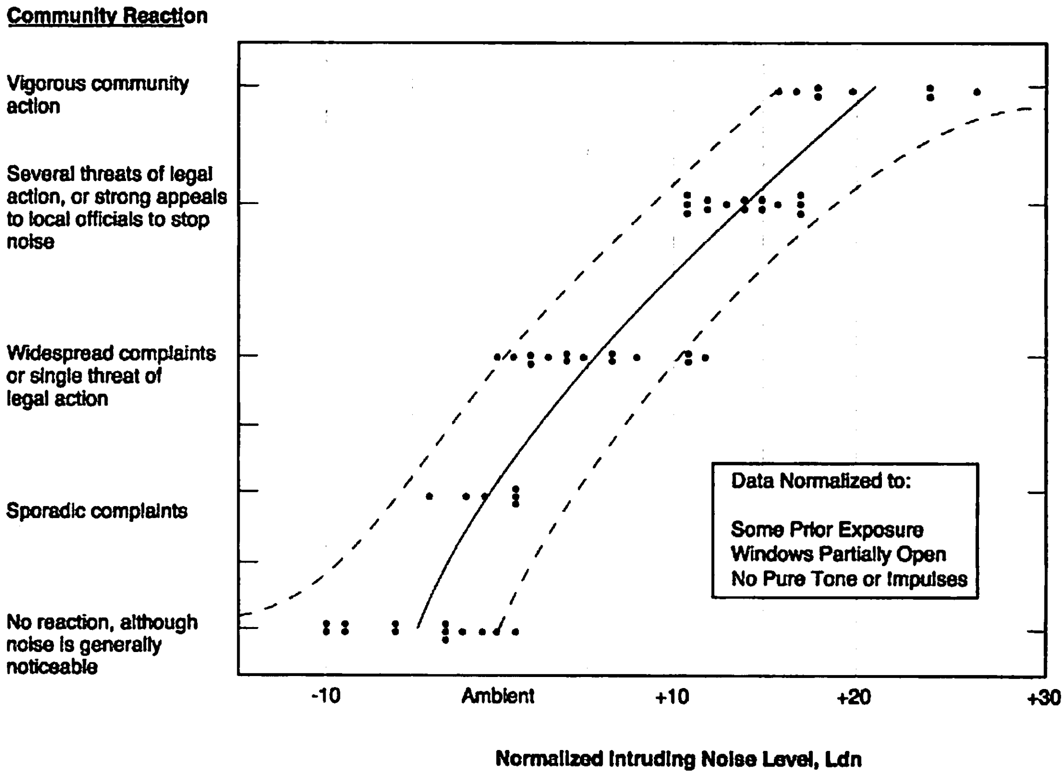


Figure 16 Community Reaction as a Function of Outdoor DNL

Source: Wyle Laboratories, Community Noise, prepared for the U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20406, December 1971, page 63.

A.3 Noise / Land Use Compatibility Guidelines

The degree of annoyance that people experience from aircraft noise varies, depending on their activities at any given time. People are usually less disturbed by aircraft noise when they are shopping, working, or driving than when they are at home. Transient hotel and motel residents seldom express as much concern with aircraft noise as do permanent residents. The concept of "land use compatibility" has arisen from this systematic variation in community reaction to noise. Cumulative noise exposure estimates, in terms of DNL, provide a quantitative basis for identifying potential noise impacts.

A.3.1 FAA Land Use Guidelines

Part 150 provides the FAA's recommended guidelines for noise-land use compatibility evaluation. Table 11 reproduces these guidelines.

Table 11 FAR Part 150 Noise / Land Use Compatibility Guidelines

Source: FAR Part 150, Appendix A, Table 1

	Yearly Day-Night Average Sound Level, DNL, [or Community Noise Equivalent Level, CNEL], in dB (Key and notes on following page)					
Land Use	<65	65-70	70-75	75-80	80-85	>85
Residential Use						
Residential other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home park	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail--building materials, hardware and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade--general	Y	Y	Y(2)	Y(3)	Y(4)	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables, and water recreation	Y	Y	25	30	N	N

Key to Table 11

SLUCM: Standard Land Use Coding Manual.

Y(Yes): Land use and related structures compatible without restrictions.

N(No): Land use and related structures are not compatible and should be prohibited.

NLR: Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.

25, 30, or 35: Land use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structure.

Notes for Table 11

The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses.

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus, the reduction requirements are often started as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.

(2) Measures to achieve NLR of 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(3) Measures to achieve NLR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(4) Measures to achieve NLR of 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(5) Land use compatible provided special sound reinforcement systems are installed.

(6) Residential buildings require an NLR of 25.

(7) Residential buildings require an NLR of 30

(8) Residential buildings not permitted.

The FAA's guidelines represent a compilation of the results of scientific research into noise-related activity interference and attitudinal response. Part 150 guidelines indicate that all uses normally are compatible with aircraft noise at exposure levels below 65 dB DNL. This limit is supported in a formal way by standards adopted by the U. S. Department of Housing and Urban Development (HUD). The HUD standards address whether sites are eligible for Federal funding support. These standards, set forth in 24 CFR Part 51, define areas with DNL exposure not exceeding 65 dB as acceptable for funding. Areas exposed to noise levels between 65 dB and 75 dB DNL are "normally unacceptable," and require special abatement measures and review. Those at 75 dB and above are "unacceptable" except under very limited circumstances.

APPENDIX B INM EVENTS TIMELINE[89]

For INM versions before 5.0, the first number referred to major upgrades to the model and the second number to the database version (i.e. 3.9 = Model version 3, with database 9)

Version 1.0 was released in January of 1979. Originally developed to provide an analysis tool to assist in assessing the impact of airport noise in the vicinity of airports.

Version 2.0 Database 7 was released in September of 1979. This release included modifications to expand the models capabilities and ease of use of the model, including and expanded database, addition of user data and improved documentation.

Agency/Industry Review - Summer 1979 – As part of MITRE's overall effort to check the validity of the results of INM computations for the FAA, tests were conducted at Dulles Airport and compared to the modeled results. This is presented in "Comparison of FAA INM Flight Profiles with Observed Altitudes and velocities at Dulles Airport" MTR-80W00119. This leads to several improvements in the database (database 7 was used for the evaluation)

Agency/Industry Review – December 1981 – As part of MITRE's overall effort to check the validity of the results of INM computations for the FAA, tests were conducted at Seattle-Tacoma Airport and compared to the modeled results. This is presented in "Comparison of FAA INM Flight Profiles with Profiles Observed at Seattle-Tacoma Airport" MTR-81W00288 this leads to several improvements in the database (database 8 was used for the evaluation)

Version 3.8 was released in October of 1982. This tool is now written in ANSI Fortran documented code which is machine-independent and highly portable (this begins the move to the PC environment). This version includes an update to the database a new and improved input and output system.

March 1986 - SAE A-21 committee releases "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports" known as SAE AIR 1845

Version 3.9 was released by the FAA in May of 1987 as a database update to Version 3.8. Model input was in ASCII text file format. This version was the first to adopt SAE AIR 1845 and ICAO report 208 procedures as standards for the noise model.

Version 3.10 was released by the FAA in June of 1992. Version 3.10 included updated noise and performance data for *all* aircraft included in the previous database, and included eighteen *new* aircraft types. There were no computational changes between Versions 3.9 and 3.10.

Version 4.11 was released in December of 1993. This version of the model included noise calculation improvements, an expanded database (with six additional aircraft types, but with *no changes* to the data already listed in database 10), and incorporated algorithms that alter aircraft performance assumptions (and, hence, noise) depending on user-defined temperature and airport elevation parameters.

[89] Prepared by Robert Mentzer, HMMH, September 2008.

Prior to version 5.0 the model was MS-DOS based. Version 5.0 and later are Windows based. The Version numbers now refer to a model version family with minor releases in between. (i.e. 6.0 = Version 6 family, release 0, with minor bug fixes or database updates have a letter added (6.0a)

During 1993 and 1994 FAA and ATAC rewrote the code in C++ for use with the Windows operating system. FAA also requested an extensive beta testing program where high level users of the software tested and suggested improvements to the model. This group became the Design Review Group (DRG) for INM. This group was made up of 26 members from FAA, other Government agencies, Corporations and International Organizations.

Version 5.0 was released in August 1995. Major enhancements included: a new graphics user interface, new data preparation and data input aids, new graphics and plotting capabilities, and improved and faster noise calculation algorithms. INM5.0 input files were in the form of a set of database and binary files, as opposed to ASCII text files as in the previous versions. **Version 5.01,** providing a limited number of corrections to bugs found in Version 5.0, was distributed in December 1995.

Version 5.1 was released in February 1997. Major improvements included incorporation of parts of the preprocessor program and access to NOISEMAP, a United States Air Force (USAF) aircraft noise model, data as well as fixes to problems with Version 5.01. Version 5.1 is compatible with Windows® 95[90] and with Windows® NT, but not with older versions of Windows. Version 5.1 also incorporated new and updated database files. Files created with Version 5.0/5.01 need to be converted before being used by 5.1.

Version 5.1a contained several corrections to Version 5.1 and was released in May of 1997.

Version 5.2 was released in May 1998. Three new aircraft were added to the database and twenty new substitution aircraft were added. Data for four aircraft were modified to correct various problems. Corrections were made to the conversion program from 4.11 to 5.2.

Version 5.2a was released in February 1999. It contained new noise and performance data for DC9 aircraft with hushkits (Stage 3), and the Embraer 145. It also provided fixes to a few program bugs.

Version 6.0 was released in October 1999. This was the first release in a new series of the INM. It included one new aircraft type and many algorithm improvements. It used a new version of NMPlot[91] (discussed in Session 3) and added several new options to the model.

Version 6.0a was released in May 2000. This was the first minor release in the INM 6 series; it added noise and performance data for the Airbus 340 and Embraer 120, as well as a series of bug fixes to the Version 6.0 release.

October 2000 - INM DRG beta tests Version 6.0b for FAA

Version 6.0b was released in January 2001. This second minor release of the INM 6 series contained noise and performance data for the Airbus 330, Boeing 737-700, the Cessna Citation 550 Bravo and several Cessna piston engine aircraft.

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[90] Windows is a registered trademark of Microsoft Corporation (www.microsoft.com)

[91] NMPlot was authored by Wasmer Consulting with sponsorship from the United States Air Force. (www.wasmerconsulting.com; www.wasmerconsulting.com/nmplot.htm).

Version 6.0c was released in September 2001; this version contained new noise and performance data for the A319-121 and A320-232; the Boeing 717-200, 777-300, and 767-400; the Cessna Citation X; and the Gulfstream GII, GIII, GIV, and GV.

November 2002 - INM DRG beta tests Version 6.1 for FAA

Version 6.1 was released in February 2003. It includes two new Boeing aircraft (737-800, 757-300) and four new Airbus aircraft (A300-622R, A310-304, A321-232, A330-343), as well as transient profiles for military aircraft that were previously imported from the USAF NOISEMAP. Data for several other aircraft were modified. It will allow users to export to ESRI[92] Shapefile format. One major computational change with the Version 6.1 is the incorporation of a new algorithm for addressing the effects of lateral attenuation. Lateral propagation of aircraft noise has two components: an air-to-ground component and a ground-to-ground component; the changes to the model for Version 6.1 are for the air-to-ground portion only. In simplest terms, the change to the lateral attenuation algorithm eliminates the previous assumption that the aircraft fuselage provides shielding for wing-mounted aircraft.

Agency/Industry Review - "Review of Integrated Noise Model (INM) Equations and Processes" May 2003, NASA/CR-2003-212414 D. Forsyth Boeing and J Gulding,, J. DiPardo FAA The object of this study is to evaluate INM assumptions against Boeing Source data, automate the manufacturers methods of data development to enable the maintenance of the INM database over time and supply new data for Boeing aircraft using these methods.

AEDT March 2004 - TRB holds first Workshop for the development of Aviation Environmental Design Tool. This new tool will combine the noise model (INM) with the emissions model (EDMS) to allow users to evaluate noise and emissions plus the tradeoffs between the two. This is also to support CAEP Cycles.

April thru July 2004 - INM DRG beta tests Version 6.2 for FAA

AEDT August 2004 - TRB holds second Workshop for development of AEDT. This workshop designed to tie in the other two projected models "Environmental Design Space" (EDS) and "Airport environmental Portfolio Management Tool" (APMT)

AEDT February 2005 - TRB holds third Workshop for development of AEDT. This workshop further looks at AEDT and APMT

Agency/Industry Review - "Assessment of Tools for Modeling Aircraft Noise in the National Parks" March 2005, FICAN sponsored project completed by Volpe and Wyle. This report compares INM and NMSIM model results to actual data from Grand Canyon National Park. Both models are evaluated against the "gold standard" audibility data and perform equally well. INM is determined to be FAA's recommended noise model for natural parks analysis. This study also leads to development in the model towards National Park data and metrics.

Version 6.2 was released in May of 2006. It contains modified noise and profile information for the Boeing 757-200 (PW and RR), 737-700, 777-200, and 747-400 to better reflect the current "in-service" fleet. Additionally data was added for seven helicopters and propeller aircraft: Piper PA28-161 Warrior, PA30 Twin Comanche, and PA31 Navajo, Raytheon Beech 1900D, Maule M-7-235,

[92] Environmental Systems Research Institute, Inc. (www.esri.com).

Eurocopter EC-130, and Robinson R-22. Two new noise metrics, time audible (TAUD) and delta dose (DDOSE), were added to assist the National Park Service with studies related to natural quiet. The terrain feature was upgraded to import more file types (GridFloat and Digital Elevation Model) and to calculate line of sight blockage. Version 6.2 also improved the level of information exported to ESRI shapefile format and added the capability to export to MapInfo[93] Data Interchange Format files.

Agency/Industry Review - "Improved Airport Noise Modeling for high Altitudes and Flexible Flight Operations" October 2006, NASA/CR-2006-214511 D. Forsyth and J Follet Boeing With two appendixes; Appendix A by HMMH " Comparing INM results from INM 5.0a though INM 6.2 Beta" and Appendix B by Wyle "Reduced Thrust departures from a high altitude airport using procedure steps and the INM"

Version 6.2a was released in November of 2006. It contains modified noise and/or profile information for nine Airbus aircraft, three MD80 series aircraft, and three Boeing 737 aircraft to better reflect the current "in-service" fleet. It also included two new utilities to read and write 3CD terrain data.

AEDT December 2006 – Final TRB Workshop – AEDT development to continue to move forward under the FAA and Design Review Group (DRG) to be formed.

AEDT Design Review Group (DRG) is formed in March 2007. This group is made up of the INM and EDMS DRG members plus additional stakeholders. The separate INM and EDMS DRG groups will no longer meet as those models begin to evolve into AEDT

New releases of INM and EDMS after this point will incorporate AEDT framework and architecture; this will allow the two models to function together in AEDT

November 2006 thru March 2007 - INM DRG beta tests Version 7.0 for FAA

Version 7.0 was released in May of 2007. The major changes include a shift from a study-case structure to a study-scenario-case structure, the addition of multi-processor computing capability, the complete integration of helicopter modeling, and the segregation of military, civil, and helicopter aircraft and operations data. It also contains new algorithms to compute lateral attenuation, determine noise due to thrust reverse, and account for aircraft bank angle.

AEDT DRG #2 Jan 2008 - Members meet to review recent releases of INM and EDMS, both of which now share a common database and aircraft performance engine. Updated schedule of AEDT is presented and mock ups of software architecture are released.

Version 7.0a was released on September 17, 2008. This update includes the addition of a Very Light Jet (VLJ) and several minor bug fixes.

[93] MapInfo Corporation (www.mapinfo.com)