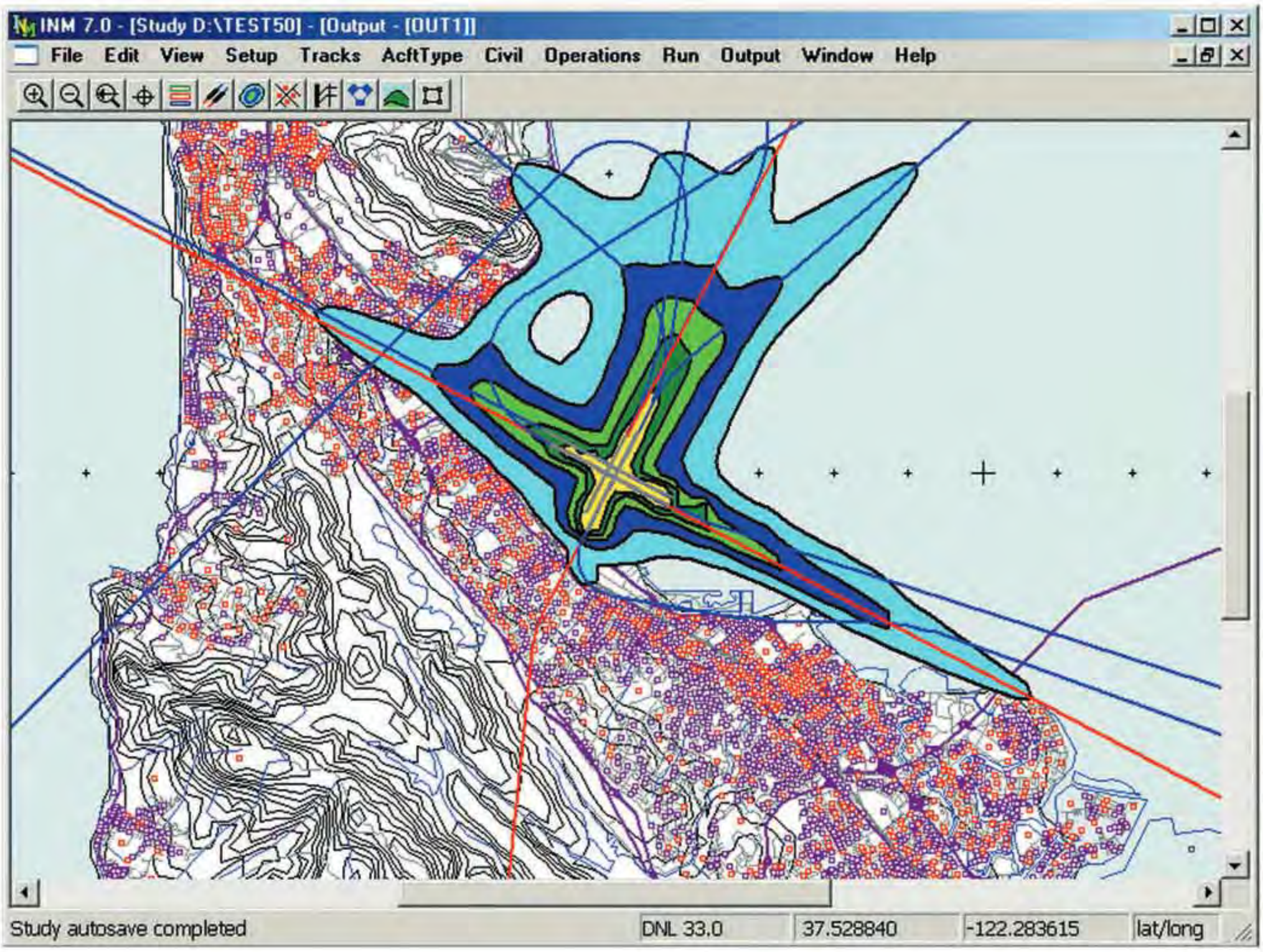
INM *Technical Manual*

Office of Environment
and Energy



INTEGRATED NOISE MODEL
7.0

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE January 2008	3. REPORT TYPE AND DATES COVERED Final Jan 02 – Mar 08

4. TITLE AND SUBTITLE
Integrated Noise Model (INM) Version 7.0 Technical Manual

5. FUNDING NUMBERS
FA-4T/ES205
DTFAAC-05-D-00075
Task Orders 4, 6, 10

6. AUTHOR(S)
Eric R. Boeker[1], Eric Dinges[2], Bill He (FAA Program Manager), Gregg Fleming[1], Christopher J. Roof[1], Paul J. Gerbi[4], Amanda S. Rapoza[1], Justin Hemann[2]

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
1 U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center Acoustics Facility, RTV-4F
Kendall Square
Cambridge, MA 02142-1093

2 ATAC Corporation
755 N. Mathilda Ave Ste 200
Sunnyvale, CA 94085

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAMES AND ADDRESS
3 U.S. Department of Transportation
Federal Aviation Administration
Office of Environment and Energy
800 Independence Avenue, S.W.
Washington, DC 20591

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
FAA-AEE-08-01

11. SUPPLEMENTARY NOTES
4 CSC Corporation
Kendall Square
Cambridge, MA 02142

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This report is part of the INM Version 7.0 software release.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The Federal Aviation Administration, Office of Environment and Energy (FAA, AEE-100) has developed Version 7.0 of the Integrated Noise Model (INM) with support from the John A. Volpe National Transportation Systems Center, Acoustics Facility (Volpe Center) for development of the acoustic computation module, and from the ATAC Corporation for systems integration, development of the graphical interface, and methods for computing aircraft flight profiles and constructing flight paths, which are processed by the acoustics module.

This Technical Manual describes the core technical components in INM Version 7.0, including the flight-path methodology (Chapter 2), along with the basic methodology employed by the INM to compute noise levels or time-based metrics at a single, user-specified observer, or at an evenly-spaced, regular grid of observers (Chapter 3).

The noise/time computation methodology includes a description of: (1) computation of the flight-segment geometric and physical parameters; (2) flight-segment noise-level interpolation process; (3) atmospheric absorption adjustment; (4) acoustic impedance adjustment; (5) flight-segment noise-fraction adjustment for exposure-based metrics; (6) aircraft speed adjustment for exposure-based metrics; (7) updated lateral attenuation adjustment; (8) ground-based directivity adjustment for observers behind start-of-takeoff-roll, as well as for computing metrics associated with run-up operations; (9) new helicopter noise modeling capabilities and associated adjustments (including advancing tip mach number, lateral directivity, static directivity and static duration adjustments); (10) metric computation process; and (11) development of a recursively-subdivided irregular grid methodology, which is used for computing noise contours (Chapter 4).

14. SUBJECT TERMS
Airport Noise, Computer Model, Noise Contours, Integrated Noise Model, INM, Noise-Level Prediction, Noise-Level Metric, Day-Night Average Sound Level, L_{dn}, DNL, Heliport Noise Model, Helicopter Noise, FAR Part 150, Impact, Land Use Planning, SAE-AIR-1845, ECAC Doc 29, SAE-AIR-5662

15. NUMBER OF PAGES
210

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-550

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

1 INTRODUCTION

Since 1978, the FAA's standard methodology for noise assessments has been the Integrated Noise Model (INM). INM is a computer program used by over 1000 organizations in over 65 countries, with the user base increasing every year. The program can be used directly to assess noise impact with different metrics for various scenarios such as: (1) new or extended runways or runway configurations; (2) new traffic demand and fleet mix; (3) revised routings and local airspace structures; (4) alternative flight profiles; and (5) modifications to other operational procedures. INM is also used as a noise engine or add-on in many other models, both within and outside FAA. FAA models such as the Area Equivalent Method (AEM), the Noise Integrated Routing System (NIRS), and the Model for Assessing Global Exposure to the Noise of Transport Aircraft (MAGENTA) all use INM as their noise engine. The methodologies employed in INM constitute key components for FAA's future integrated noise and emission model – the Aviation Environmental Design Tool (AEDT)[*].

The guidance and underlying database/noise calculation methodology for INM are given in three related documents. These include the Society of Automotive Engineers (SAE) Aerospace Information Report (AIR), SAE-AIR-1845, titled "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports"[1] This document shares similar material with European Civil Aviation Conference (ECAC) Doc 29[2] and the to be published replacement International Civil Aviation Organization (ICAO) Circular 205[3 †].

The release of INM Version 7.0 in April 2007[4] represents a significant step forward in the capability to model potential noise impacts due to aviation sources. INM Version 7.0, developed jointly by the FAA's Office of Environment and Energy (AEE-100), the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) Acoustics Facility, and the ATAC Corporation, includes several enhancements to its core capabilities. The capabilities previously in FAA's Heliport Noise Model (HNM) Version 2.2[5] are now directly integrated into INM. The integration of HNM adds helicopter noise computation methodologies to INM, including more comprehensive directivity and operational modeling functionality, improving upon the helicopter modeling capabilities introduced in INM Version 6.0c.

The noise, aircraft flight profile and flight path computation methodologies implemented in INM Version 7.0 are compliant with European Civil Aviation Conference (ECAC) Doc 29 (3rd Edition) "Report on Standard Method of Computing Noise Contours around Civil Airports"[2]; which includes the new SAE-AIR-5662 "Method for Predicting Lateral Attenuation of Airplane

---

* AEDT is a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. The main goal of the effort is to develop a new capability to assess the interdependencies between aviation-related noise and emissions effects, and to provide comprehensive impact and benefit-cost analyses of aviation environmental policy options. More information on all of the FAA noise models may be found at: http://www.faa.gov/about/office_org/headquarters_offices/aep/models/

† In February 2007, ICAO/CAEP agreed to publish a new manual containing the "Recommended Method for Computing Noise Contours around Airports", which would replace the present Circular 205. This agreement is documented in CAEP/7-WP/68, Committee on Aviation Environmental Protection (CAEP), Seventh Meeting, Montreal, 5 to 16 February 2007.

Noise”[6], updated thrust reverser implementation, bank angle implementation, updated flight path segmentation, and additional procedural profile step types. Other computational enhancements since the INM Version 6.0 Technical Manual include supplemental noise metrics in support of noise modeling in National Parks, ambient screening analysis, and the ability to account for line-of-sight blockage between the noise source and receiver.

The Windows-based graphical user interface that was developed for INM Version 6.0 has been extended to support the functions in INM Version 7.0, including helicopter noise modeling capabilities. A new INM study format was also introduced in INM Version 7.0. The “Study-Scenario-Case” format allows for a more detailed categorization of an INM study, and allows for annualization, where a user may adjust noise contributions of individual Cases in a Scenario by a scale factor and/or an annualization percentage. The methods for computing aircraft flight profiles and constructing flight paths have also been updated. Other performance and user interface related enhancements since INM Version 6.0 include the ability to implement a boundary and/or distance-based analysis cutoff distance, as well as extensive database updates.

Following a similar content structure in the INM Version 6.0 Technical Manual, this revision describes in Chapter 1 the metric types available for computation, in Chapter 2 the flight-path segmentation methodology, and in Chapter 3 the methodology employed to compute metrics at an evenly spaced regular grid of observer positions. Chapter 4 describes the methodology used to develop the recursively-subdivided irregular grid required for computing noise contours. The Appendices present the derivation of INM algorithms and the development of spectral classes.

1.1 Terminology

This section presents pertinent terminology used throughout the document. The terms are arranged alphabetically. **Bold** text indicates that a term is defined within this section.

A-Weighted. A-weighted **noise** levels emphasize sound components in the frequency range where most speech information resides; yielding higher levels in the mid-frequency (2000 to 6000 Hz) range and lower levels in both low frequency and high frequency ranges. A-weighted **noise** level is used extensively for measuring and predicting community and transportation **noise**. The A-weighted and **C-weighted** adjustment curves are presented in Figure 1-1: .

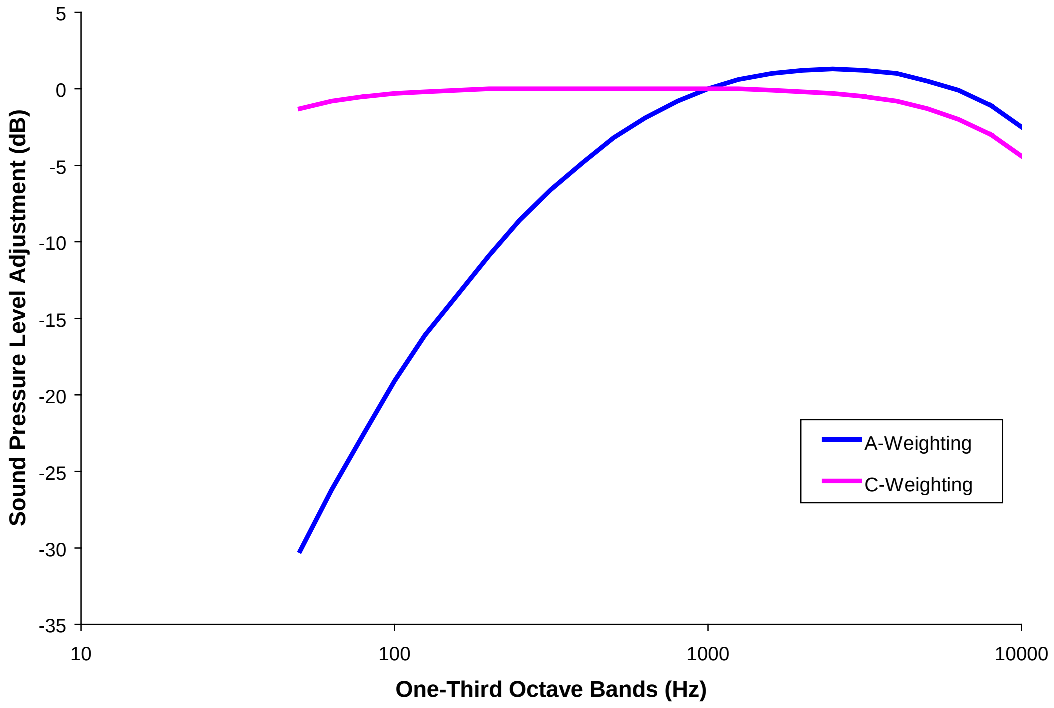


Figure 1-1: A-weighted and C-weighted Adjustment Curves

Above Field Elevation. Altitude relative to the elevation of the runway end or helipad used for a given flight operation.

Acoustically Hard Surface. Any highly reflective surface where the phase of the incident sound is essentially preserved upon reflection; example surfaces include water, asphalt, and concrete.

Acoustic Impedance Adjustment. An acoustic impedance adjustment, computed as a function of **observer** temperature, pressure, and elevation, is applied to **noise-power-distance (NPD) noise** levels. Specific acoustic impedance is the product of the density of air and the speed of sound, and is related to the propagation of sound waves in an acoustic medium.

Acoustically Soft Surface. Any highly absorptive surface where the phase of the incident sound is changed substantially upon reflection; example surfaces include ground covered with dense vegetation or freshly-fallen snow.

Advancing Tip Mach Number. The relative airspeed (in Mach) of the advancing blade tip of a helicopter's main rotor, accounting for airspeed, temperature and/or rotor RPM.

Advancing Tip Mach Number Adjustment. See Source Noise Adjustment Due to **Advancing Tip Mach Number** .

Air-to-Ground Attenuation. See Refraction-Scattering Effects.

Airport Pattern. A defined **flight path** (**ground track** and altitude above the airport) used by aircraft for **touch-and-go** operations.

Aircraft Speed Adjustment. An adjustment made to exposure-based **noise** levels when aircraft speed differs from 160 knots, the **reference speed** for the INM **NPD**s.

Ambient. The composite, all-inclusive sound associated with a given environment, excluding the analysis system's electrical **noise** and the sound source of interest. Several definitions of ambient **noise** have been adopted by different organizations depending on their application; such as natural ambient (natural sound condition in an area, excluding all human and mechanical sounds), existing ambient without aircraft (all-inclusive sound associated with a given environment, excluding the analysis system's electrical **noise** and the sound source of interest; aircraft), etc. Ambient data implementation in INM utilizes different formats specific to different metrics.

Approach. A **flight operation** that begins in the terminal control area, descends, and lands on an airport runway, possibly exerts reverse thrust, and decelerates to taxi speed at some location on the runway.

Atmospheric Absorption. The change of acoustic energy into another form of energy (heat) when sound passes through the atmosphere. Several parameters such as temperature, pressure, and humidity are needed to specify the amount of atmospheric absorption, which is dependent upon the frequency of the sound as well. **NPD** data are corrected for atmospheric absorption in accordance with the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 866A[7] and SAE Aerospace Information Report (AIR) 1845[1].

Audibility. The measure of ability for an attentive listener to hear a particular acoustic event such as aircraft **noise**. Audibility is based on **detectability** from signal detection theory, and depends on both the actual aircraft sound level ("signal") and the **ambient** sound level (or "**noise**"). The metric associated with audibility in INM is **Time Audible**.

Average Annual Day. The user-defined best representation of the typical long-term (or annual) conditions for the case airport. These conditions include the number and type of operations, runway usage, the routing structure, the temperature, and the atmospheric pressure etc.

Bank Angle. The angle between an aircraft's lift vector and a vector in the vertical plane. In the INM two assumptions are applied to banking aircraft: level flight and coordinated turns where the aircraft velocity vector is aligned with the aircraft fuselage. Under these assumptions the bank angle is determined entirely from the aircraft speed and the turn radius. By convention a left turn has a positive bank angle and a right turn has a negative bank angle. Bank angle is presented in Figure 3-6.

C-Weighted. C-weighted **noise** levels, as compared with **A-weighted noise** levels, emphasize sound components between 100 Hz and 2 kHz. C-weighting is intended to simulate the sensitivity of the human ear to sound at levels above about 90 **dB**. C-weighted **noise** levels are commonly used for assessing scenarios dominated by low-frequency sound, e.g., locations behind start-of-takeoff roll. The **A-weighted** and C-weighted adjustment curves are presented in Figure 1-1: .

Calibrated Airspeed (CAS). The indicated airspeed of an aircraft (as read from a standard airspeed indicator), corrected for position and instrument error. Calibrated airspeed is equal to **true airspeed** in standard atmosphere at sea level.

Change in Exposure (Delta Dose or DDOSE). The difference between the cumulative, **A-weighted**, **sound exposure level** (L_{AE}) due to aircraft **noise** and the user-specified **A-weighted ambient** level at a given receiver location over a user-specified time period*.

Circuit Flight. A **flight operation** that combines a **departure** from and an **approach** to the same runway, with level-flight and/or varying-altitude segments in between.

Contour. An analysis of an area in the vicinity of an airport encompassed by a graphical plot consisting of a smooth curve, statistically regressed through points of equal **noise** level or time duration.

Corrected Net Thrust Per Engine. The net thrust per engine divided by the ratio of the **ambient** air pressure at aircraft altitude to the **International Standard Atmosphere** (**ISA**) air pressure at mean sea level.

Cutoff Levels. A test that determines when to end **noise** level (or time) computations during a **contour** analysis. The point at which computations are stopped is based on user-defined lowest and highest **noise** level (or time) **contours**. Similar to the **tolerance** and **refinement level** tests, the reason for performing this test is to reduce runtime during a **contour** analysis.

Decibel (dB). A unit of measure for defining a **noise** level or a **noise exposure** level. The number of decibels is calculated as ten times the base-10 logarithm of the ratio of mean-square pressure or **noise exposure**. The reference root-mean-square pressure is 20 µPa, the threshold of human hearing.

Departure. A **flight operation** that begins on a runway, proceeds down the runway, and climbs and accelerates to altitudes at specified distances.

Depression Angle. The angle between a line along the span of the aircraft's wing and a line parallel to the **ground plane**, which is a combination of the aircraft **bank angle** and **elevation angle**. Depression angle is presented in Figure 3-6.

Detectability. The ability to detect a signal in the presence of **noise**, based on signal detection theory. For the purposes of INM modeling the terms "**audibility**" and "detectability" are used

---

* It is important to note that in INM, Change in Exposure uses a default time period of 12 hours. In addition, Change in Exposure levels below the specified threshold level will be reported as 0.0 dB, and levels are capped at 150 dB.

interchangeably.

Directivity Adjustment. A **noise** level adjustment resulting from the normalized **noise** pattern defined by a 360-degree area in the horizontal plane around a **noise** source. In INM, measurement-based directivity is accounted for in takeoff ground roll and **runup** operations for fixed wing aircraft with the **Ground-Based Directivity Adjustment** (DIR_{ADJ}). It is also accounted for in all static helicopter operating modes with the **Static Directivity Adjustment** (DIR_{HELI_ADJ}).

Distance Duration. An empirically-derived effect, expressed as a function of distance, which relates exposure-based **noise** levels to maximum-based **noise** levels. This effect is taken into account in the INM **NPD** data only for data corrected using the simplified data adjustment procedure in SAE-AIR-1845[1].

Duration Adjustment. A **noise** level adjustment to exposure-based metrics to account for the effect of time-varying aircraft speed other than 160 knots (the **NPD reference speed**). Both acceleration and deceleration are accounted for with the Duration Adjustment (DUR_{ADJ}). It is not applied to **maximum noise level** metrics since they are mostly independent of speed. Helicopters also utilize duration adjustments, however they are based on a helicopter-specific **reference speeds**. In addition, helicopters have a specific **Static Operation Duration Adjustment** (t_{HELI_static}) to account for duration effects due to **static operations** such as Hover, **Ground Idle**, and **Flight Idle**.

Elevation Angle. The angle between the line representing the propagation path between the aircraft source and receiver (at the aircraft's closest point of **approach**) and the line from the receiver to the projection of the **flight path** on the ground. Elevation angle is presented in Figure 3-6.

Engine Breakpoint Temperature. The ambient air temperature (degrees F) above which the thrust output from a flat-rated engine begins to decrease.

Engine Installation Effect. A component of the **lateral attenuation adjustment** that takes into account the directivity of the sound from an aircraft as a function of engine/aircraft type (jet, prop, helicopter), engine mounting location (fuselage or wing), and **depression angle**.

Extended Flight-Path Segment. A mathematical extension from either end of a geometrical flight-path segment to infinity.

Flight Idle. A static helicopter operation, where the helicopter is on the ground and operating at a high power setting, that is approximately the same power setting used for hover operations. Flight idle is also used for modeling taxi operations for helicopters with wheels.

Flight Operation. A moving (or dynamic) aircraft operation. There are five kinds of flight operations for fixed-wing aircraft in INM: **approach**, **departure**, **touch-and-go**, **circuit flight**, and **overflight**. There are three kinds of flight operations for helicopters in INM: **approach**, **departure**, and taxi.

Flight Path. A set of **flight path segments** describing geometrical and physical parameters used to model the movement of an aircraft in three-dimensional space. Each flight path point contains: (1) the geographical location (x- and y-value) relative to the origin of the airport, (2) the aircraft altitude **above field elevation**, (3) the aircraft speed relative to the ground (**true airspeed** without wind), (4) the **corrected net thrust per engine** or equivalent parameter used to access the **NPD** curves, (5) duration (seconds) of the flight path segment following the point, and (6) aircraft **bank angle** for the flight path segment following the point (if applicable).

Flight Path Segment. A directed straight line in three-dimensional space, which includes the aircraft speed and **corrected net thrust per engine** at the beginning point of the line, and change in speed and thrust along the line to the end point.

Flight Profile. A set of points that models the geometrical and physical characteristics of an aircraft **flight operation** in the vertical plane. Each profile point contains: (1) the ground distance (x-value) relative to the origin of the operation, (2) the aircraft altitude **above field elevation**, (3) the aircraft **true airspeed**, and (4) the **corrected net thrust per engine** or equivalent parameter used to access the **NPD** curves. **Profile points** representing static operating modes within a helicopter profile also include the duration of time spent at the defined profile point.

Ground-Based Directivity Adjustment. See Directivity Adjustment.

Ground Effects (or Ground-to-Ground Attenuation). A component of the **lateral attenuation adjustment** that takes into account the effects of sound propagating along the ground surface considered to be “acoustically soft” (such as grass) as a function of **lateral distance**.

Ground Idle. A static helicopter operation, where the helicopter is on the ground and operating at a low power setting.

Ground Plane. Without terrain elevation processing, the ground plane is the geometric, horizontal plane at the elevation of the airport. With terrain elevation processing, the elevation of the ground plane is determined using the user-selected elevation data for the area surrounding the airport.

Ground Speed. That component of aircraft speed obtained by projecting the aircraft velocity vector on the horizontal plane.

Ground-to-Ground Attenuation. See Ground Effects.

Ground Track. The trace of the **flight path** on the horizontal plane. Flight tracks are described as vector-type tracks consisting of one or more straight or curved segments, or point-type tracks consisting of an array of x,y points.

Hover in Ground Effect (HIGE). A static helicopter operation, where the helicopter is hovering with the skids 5 feet above ground level, where the **ground effects** may still have a dramatic impact on **noise** levels. HIGE is also used for modeling taxi operations for helicopters without wheels.

Hover out of Ground Effect (HOGE). A static helicopter operation, where the helicopter is hovering with the skids at an altitude above ground level equal to or greater than 2.5 times the helicopter's main rotor diameter, where the **ground effects** will have a less pronounced impact on **noise** levels.

Integrated Adjustment Procedure. The preferred adjustment procedure used for developing INM **NPD** data from measured **noise** level data. It is based on **noise** level data measured over the full spectral time history of an event. In the integrated procedure, off-reference aircraft speed, **atmospheric absorption** effects, and **spherical divergence** are considered. This adjustment procedure provides data consistent with Type 1 quality, as defined in SAE-AIR-1845.[1] See the definition of the **Simplified Adjustment Procedure** for comparison.

International Standard Atmosphere (ISA). Internationally standardized functions of air temperature, pressure, and density versus aircraft altitude above mean sea level. The ISA is intended for use in calculations in the design of aircraft, in presenting test results of aircraft and their components under identical conditions, and to facilitate standardization in the development and calibration of instruments.[8]

Irregular Grid. See Recursively Subdivided Irregular Grid.

Lateral Attenuation Adjustment. An adjustment that results from the attenuation of **noise** at grid points laterally displaced from the ground projection of an aircraft **flight path**. It is a combination of attenuation due to **ground effects**, attenuation due to **refraction-scattering effects** and **engine installation effects**, as defined in SAE-AIR-5662.[6]

Lateral Directivity Adjustment. An adjustment that results from the linear interpolation between two of the three sets of helicopter **NPD**s (left, center and right), to account for helicopter in-flight directivity effects at a receiver location where the **elevation angle** is between -45° and 45°.

Lateral Distance. The perpendicular distance from an aircraft's **ground track** to a receiver.

Line-of-Sight Blockage Adjustment. An adjustment that results from the attenuation due to line-of-sight (LOS) blockage from terrain features, and is based on the difference in propagation path length between the direct path and propagation path over the top of terrain features, known as path length difference.

Maximum Noise Level. The maximum of a series of modeled sound pressure levels from a single flight.

Mean-square Sound Pressure. A running time-average of frequency-weighted, squared instantaneous acoustic pressure. For example:

$$p(t)_{AS}^{\ 2} = \int_{-\infty}^{t} p_A^{\ 2}(\ ) \cdot e^{-\frac{\ }{t_0}} \frac{d}{t_0} \qquad \text{Eq. 1-1}$$

where

$p(t)_{AS}^2$	**A-weighted** mean-square pressure using slow exponential time,
p_A^2	**A-weighted** mean-square pressure,
	time, and
t_0	initial time = 1 second.

Mean-Square Sound Pressure Ratio. The mean-square sound-pressure ratio is the ratio of the **mean-square sound pressure** divided by the square of the reference pressure 20   Pa. It is equivalent to $10^{SPL / 10}$, where **SPL** is the **sound pressure level**.

Metric Family. A set of **noise**-level and time-based metrics differentiated by frequency weighting, either **A-weighted**, **C-weighted**, or **tone-corrected perceived**.

Metric Type. A metric belongs to one of three types: exposure-based, maximum-level-based, or time-based.

Noise. Any unwanted sound. “Noise” and “sound” are used interchangeably in this document.

Noise Fraction. The ratio of **noise exposure** at a grid point due to a flight segment, and the **noise exposure** at the same grid point due to a straight, infinite **flight path** extended in both directions from the segment. The noise fraction methodology is based upon a fourth-power 90-degree dipole model of sound radiation.

Noise Fraction Adjustment. An adjustment that is a function of the ratio of the **noise exposure** at a grid point due to a flight-path segment, and the **noise exposure** at the same grid point due to a straight, infinite **flight path**, extended in both directions from the segment. The application of the noise fraction adjustment to the **NPD** data facilitates the modeling of a three-dimensional **flight path**, using straight flight-path segments.

Noise-Level Threshold. A **noise** level specified by the user that is the boundary value above which **time-above** calculations are performed.

Noise-Power-Distance (NPD) Data. A set of **noise** levels, expressed as a function of: (1) engine power, usually the **corrected net thrust per engine**; and (2) distance. The INM NPD data are corrected for aircraft speed, **atmospheric absorption**, **distance duration**, and divergence. For helicopters, **noise** levels are presented as a function of: (1) operation mode; and (2) distance.

Noise Significance Tests. Tests performed by INM to determine if a **flight operation** is acoustically significant. Two types of tests are used: the **relative noise-level/time test** and the **segment proximity test**. The reason for performing these tests is to decrease runtime during a **contour** analysis. They are only performed when irregularly spaced grids are used.

Observer. A receiver or grid point at which **noise** or time values are computed.

One-Third Octave-Bands. A method of characterizing the audio **spectrum** according to a series of frequency bands with constant-percentage-bandwidths, as described in ANSI S1.6-1984 (R2006) "Preferred Frequencies, Frequency Levels and Band Numbers for Acoustical Measurements" [9] and ANSI S1.11-2004 "Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters." [10] The standard one-third octave-bands used in INM are presented in Table 1-1.

Table 1-1: Definition of One-Third Octave-Bands

One-Third Octave-Band Number	Nominal Center Frequency (Hz)
17	50
18	63
19	80
20	100
21	125
22	160
23	200
24	250
25	315
26	400
27	500
28	630
29	800
30	1000
31	1250
32	1600
33	2000
34	2500
35	3150
36	4000
37	5000
38	6300
39	8000
40	10000

Overflight. A **flight operation** that begins in the air, and remains in the air, in the vicinity of the airport, with optional user-specified changes in altitude and speed during the flight.

Percent Time-Above. The percentage of time that a time-varying sound level is above a given sound level threshold.

Procedure Steps. A prescription for flying a profile. Procedures include climbing at constant **calibrated airspeed** to a given altitude, accelerating to a given airspeed while climbing at a given vertical rate, etc.

Profile Points. The set of points that make up a **Flight Profile**. Profile Points can be input directly into the INM or can calculated by the INM from a set of **Procedure Steps**.

Recursively-Subdivided Irregular Grid. A grid of **observer** points created by one or more subdivisions of an existing regular or **irregular grid**, based on the user-specified **refinement level** and **tolerance**.

Refinement Level. The number of levels of subdivision of a **regular grid** making up a recursively-subdivided **irregular grid**. Each successive refinement level beyond level three represents one level of subdivision.

Reference Day Conditions. The atmospheric conditions corresponding to 77 degrees Fahrenheit (25 degrees Celsius), 70 percent relative humidity, and 29.92 in-Hg (760 mm-Hg). These are the atmospheric conditions to which aircraft **noise** certification data are corrected in accordance with Federal Aviation Regulation Part 36.[11] These conditions are commonly referred to as **ISA** plus 10 degrees Celsius (**ISA**+10).

Reference Speed. The **noise**-exposure reference speed in INM is 160 knots. Thus, L_{AE} and L_{EPN} values in the **NPD** database are referenced to 160 knots. The L_{ASmx}, L_{CSmx}, and L_{PNTSmx} values are assumed to be independent of aircraft speed.

Refraction. Change in the direction of sound propagation as a result in spatial changes in the speed of sound in a medium.

Refraction-Scattering Effects (or Air-to-Ground Attenuation). A component of the **lateral attenuation adjustment** that takes into account the effects of **refraction** and **scattering** as sound propagates through the air to the receiver as a function of **elevation angle**.

Regular Grid. A **noise** analysis of one or more **noise**-level and/or time-based metrics, for a set of **observer** points spaced at fixed intervals, over a specified area in the vicinity of the case airport.

Relative Noise-Level/Time Test. A noise significance test in which all flight segments of all operations are sorted high-to-low according to the **noise** (time) contribution of each segment at a **regular grid** point. Segments considered significant are those whose cumulative **noise** (time) first equals or exceeds 97 percent of the total mean-square sound-pressure ratio (total time) at the grid point.

Runup. An activity in which an aircraft is in a stationary position on the ground, with aircraft thrust held constant for a time period.

Scattering. Irregular reflection or diffraction of sound in many directions.

Scenario Analysis Window. The user-defined rectangular area around an airport within which a **contour** analysis is performed.

Segment Proximity Test. A **noise** significance test in which a flight segment, which is first determined to be insignificant by the flight segment **noise** test, is further tested based on its distance to a **regular grid** point. If it is determined that the flight segment is within a certain distance of the grid point, the flight segment regains its significance status. This distance is based on the diagonal distance between base grid points (one times the diagonal distance for most metrics) as an acceptance criterion.

Simplified Adjustment Procedure. An adjustment procedure used for developing INM data from measured **noise** level data. In contrast to the **integrated adjustment procedure**, the simplified adjustment procedure is based on **noise**-level data measured at the time of the **maximum noise level** only. In the simplified adjustment procedure, off-reference aircraft speed, **atmospheric absorption**, **distance duration** effects, and **spherical divergence** are considered. This adjustment procedure provides data consistent with Type 2 quality as defined in SAE-AIR-1845.[1]

Slant Range Distance. The line-of-sight distance between a receiver and a **flight path segment**.

Sound Pressure Level (SPL). Ten times the base-10 logarithm of the ratio of the **mean-square sound pressure**, in a stated frequency band, to the square of the reference sound pressure of 20 µPa, which is the threshold of human hearing.

$$SPL = 10 \cdot \log_{10} \frac{p^2}{p_0{}^2} \qquad \text{Eq. 1-2}$$

where

p^2 mean-square pressure (Pa^2), and

p_o 20 Pa.

Sound Exposure (Noise Exposure). The integral over a given time interval ($t_2 - t_1$) of the instantaneous, frequency-weighted, squared sound pressure:

$$E_{12} = \int_{t_1}^{t_2} p^2(t)dt \qquad \text{Eq. 1-3}$$

where

E_{12} sound exposure (Pa^2s) over the time interval ($t_2 - t_1$).

Sound Exposure Level. Ten times the base-10 logarithm of the **sound exposure** divided by a reference **sound exposure**.

$$L_E = 10 \cdot \log_{10} \frac{E}{E_0} \qquad \text{Eq. 1-4}$$

where

E **sound exposure** (Pa^{2}s),

E$_o$ (20 Pa)^2(1 s) for **A-weighted** and **C-weighted sound exposure**, and

E$_o$ (20 Pa)^2(10 s) for **tone-corrected perceived sound exposure**.

Sound Exposure Ratio. Commonly called "energy". The ratio of **sound exposure** over a reference **sound exposure**, or ten raised to power of one tenth the **sound exposure level**:

$$\frac{E}{E_0} = 10^{\frac{L_E}{10}} \qquad \text{Eq. 1-5}$$

where

E **sound exposure** (Pa^{2}s),

E$_o$ reference **sound exposure** (Pa^{2}s), and

L$_E$ **sound exposure level** (**dB**).

Source Noise Adjustment Due to Advancing Tip Mach Number. A **noise** adjustment based upon the change in Mach number of the advancing rotor blade of a helicopter. This adjustment is only applied during level flight segments, and accounts for airspeed, temperature and/or rotor RPM which deviate from helicopter-specific reference values.

Spectrum. A set of sound pressure levels in component frequency bands, usually one-third octave bands.

Spectral Class. A set of aircraft spectra which are grouped together based on similar spectral characteristics for similar operational modes.

Spherical Divergence. Spherical divergence, which is taken into account in the INM **NPD** data, is defined as the transmission loss of **mean-square sound pressure**, which varies inversely with the square of the distance from a point source. In contrast, cylindrical divergence is the transmission loss of **mean-square sound pressure**, which varies inversely with distance from a line source.

Standard Day Conditions. The atmospheric conditions corresponding to 59 degrees Fahrenheit (15 degrees Celsius), 70 % relative humidity, and 29.92 in-Hg (760 mm-Hg). The values for temperature and atmospheric pressure are sea-level conditions for the **International Standard Atmosphere** (**ISA**).

Static Directivity Adjustment. See Directivity Adjustment.

Static Operation. A stationary aircraft operation. **Runup operations are the only kind of static operations available for fixed-wing aircraft in INM.** There are four kinds of static operational modes for helicopters in INM: **flight idle**, **ground idle**, **hover in ground effect**, and

hover out of ground effect. Static helicopter operations are utilized in conjunction with a **static directivity adjustment**.

Static Operation Duration Adjustment. See Duration Adjustment.

Static Thrust. Maximum thrust (lbs) produced by a stationary engine at sea-level, **International Standard Atmosphere (ISA)** conditions.

Thrust Reverser Adjustment. An empirically-derived **noise** adjustment to account for **noise** from thrust reverser deployment during the landing ground roll.

Time-Above. The duration that a time-varying sound level is above a given sound level threshold.

Time Audible (TAUD). The duration that a time-varying sound level may be detected in the presence of **ambient** noise as audible by a human **observer** with normal hearing, who is actively listening for aircraft **noise**.

Time-Averaging Constant. A constant **decibel** value that is ten times the base-10 logarithm of the time interval associated with the metric divided by a reference time interval, which is usually one second. The time-averaging constant is equal to:

$$\textit{Time-Averaging Constant} = 10\log_{10}[N_T] \qquad \text{Eq. 1-6}$$

where

$$N_T = \frac{T_i}{T_{ref}} \qquad \text{Eq. 1-7}$$

T_i time interval associated with a particular metric (s), and
T_{ref} reference time interval (s).

Using L_{dn} as an example, T_i is 86400 seconds in 24 hours, T_{ref} is1 second, and the time-averaging constant is 49.37 **dB**. The time-averaging constant is subtracted from the **sound exposure level** to compute an equivalent or average sound level.

Tolerance. The allowable maximum difference in **dB** or minutes between computed **noise** or time values and linearly-interpolated **noise** levels or time values at a given **observer** point.

Tone-Corrected Perceived. Tone-corrected perceived **noise** levels are used to estimate human-perceived **noise** from broadband sound sources, such as aircraft, which contain pure tones or other major irregularities in their frequency spectra. It is calculated by applying an adjustment to the **noise** level that is related to the degree of irregularity that may occur among contiguous one-third octave band sound pressure levels of aircraft **noise**, as described in Federal Aviation Regulation Part 36.[11]

Touch-and-Go. A **flight operation** that begins with a level flight in the terminal control area, descends and lands on an airport runway, and then takes off immediately after landing and returns to level flight.

True Airspeed (TAS). The speed of an aircraft relative to the undisturbed air mass.

Weighting Factor. A numeric value that multiplies the **sound exposure ratio** associated with a time period for a given metric. For the exposure-based metrics, the weighting factor acts as a penalty for operations that occur during a specific time period. Usually larger penalties are applied during the night-time period when people are most sensitive to **noise**. For the maximum-level and time-based metrics, the weighting factors are either zero or unity. As such, they act as a binary switch allowing the user to select specific time periods for computation.

1.2 Grid-Point Computations

INM can compute noise-level or time-based metrics in the vicinity of an airport. Each metric is presented as numeric values at a regular grid of observer points, or as contour levels. Contours may be based on values from either a regular or irregular grid, which are described as follows:

Regular grid observer locations are arranged in the form of a user-defined rectangular grid of points, with fixed distances between the points. A regular grid can be rotated with respect to the coordinate system as long as it is not being used specifically for contour calculations.

Irregular grid observer locations are arranged in the form of a recursively-subdivided grid of points, with varying distances between points. Irregular grids may only be utilized for contour computations. The density of grid points is a function of a user-specified level of subdivision (called refinement), accuracy (called tolerance), and the lowest and highest contour levels desired (called cutoff levels). In general, contour accuracy increases as grid density increases. Irregular grids are typically used for contour calculations to reduce run times by decreasing the number of grid points computed in geographic areas which experience very little variation in noise levels.

The basic noise computation process used for the development of a recursively-subdivided irregular grid is similar to the process used for the development of a regular grid. In generating the irregular grid, a regular grid is first generated such that the distance between grid points is no greater than one nautical mile. User-specified refinement, tolerance, and program-generated knowledge about noise-significant flights, directs the process of subdividing the regular grid to improve contour accuracy.

1.3 Metric Families

The noise-level and time-based metrics computed by INM are associated with three fundamental groups or metric families.[12,13,14,15,16]

The first family of metrics is based on A-weighted sound levels, denoted by the symbol L_A. A-weighted sound levels de-emphasize the low and high frequency portions of the spectrum. This weighting provides a good approximation of the response of the human ear, and correlates well with an average person's judgment of the relative loudness of a noise event.

The second family of metrics is based on C-weighted sound levels, denoted by the symbol L_C. This weighting is intended to provide a means of simulating human perception of the loudness of sounds above 90 decibels, and is more prominent at low frequencies than A-weighting.

The third family of metrics is based on tone-corrected perceived noise levels, denoted by the symbol L_{PNT}. Tone-corrected perceived noise levels are used to estimate perceived noise from broadband sound sources, such as aircraft, which can have significant tonal qualities.

1.4 Metric Types

Within the three metric families, INM computes three types of metrics: (1) exposure-based metrics, including change in exposure, (2) maximum noise-level metrics, and (3) time-based metrics, which includes time above, percent time-above and time audible metrics. The noise metrics supported by INM Version 7.0 are shown in Table 1-2, which includes the corresponding American National Standards Institute (ANSI) metric names[15], and Table 1-3, which summarizes associated weightings and averaging times. For the maximum-level and time-based metrics, the weighting factors are either zero or unity. As such, they act as a binary switch allowing the user to select specific time periods for computation.

Table 1-2: Summary of INM Noise Metric Abbreviations and Definitions

Metric Type	INM Name	ANSI Name	Definition/Full Name
A-Weighted Noise Metrics			
Exposure Based	SEL	L_{AE}	A-Weighted Sound Exposure Level
	DNL	L_{dn}	Day Night Average Sound Level
	CNEL	L_{den}	Community Noise Equivalent Level
	LAEQ	L_{AeqT}	Equivalent Sound Level
	DDOSE	ΔL	Change in Exposure
Maximum Level	LAMAX	L_{ASmx}	A-Weighted Maximum Sound Level
Time-Above Based	TALA %TALA	TA_{LA} $\%TA_{LA}$	Time-Above / Percent Time-Above
Time Audible	TAUD %TAUD	TAud %TAud	Time Audible / Percent Time Audible
C-Weighted Noise Metrics			
Exposure Based	CEXP	L_{CE}	C-Weighted Sound Exposure Level
Maximum Level	LCMAX	L_{CSmx}	C-Weighted Maximum Sound Level
Time-Above Based	TALC %TALC	TA_{LC} $\%TA_{LC}$	Time-Above / Percent Time-Above
Tone-Corrected Perceived Noise Metrics			
Exposure Based	EPNL	L_{EPN}	Effective Perceived Noise Level
	NEF	L_{NEL}	Noise Exposure Forecast
	WECPNL	L_{WECPN}	Weighted Equivalent Continuous Perceived Noise Level
Maximum Level	PNLTM	L_{PNTSmx}	Tone-Corrected Maximum Perceived Noise Level
Time-Above Based	TAPNL %TAPNL	TA_{PNL} $\%TA_{PNL}$	Time-Above / Percent Time-Above

Table 1-3: INM Noise Metrics - Weighting and Averaging Factors

Noise Family	Metric Type	Noise Metric	Flight Multiplier			Averaging Time (hr)
			Day	Evening	Night	
A-Weighted	Exposure Based	SEL	1	1	1	--
		DNL	1	1	10	24
		CNEL	1	3*	10	24
		LAEQ	1	1	1	24
		LAEQD	1	1	0	15
		LAEQN	0	0	1	9
		DDOSE	1	1	1	12, or T
		User-defined	A	B	C	T
	Maximum Level	LAMAX	1	1	1	--
		User-defined	A	B	C	--
	Time-Based	TALA	1	1	1	--
		%TALA	1	1	1	--
		TAUD	1	1	1	--
		%TAUD	1	1	1	--
		User-defined	A	B	C	--
C-Weighted	Exposure Based	CEXP	1	1	1	--
		User-defined	A	B	C	T
	Maximum Level	LCMAX	1	1	1	--
		User-defined	A	B	C	--
	Time-Based	TALC	1	1	1	--
		%TALC	1	1	1	--
		User-defined	A	B	C	--
Tone-Corrected Perceived	Exposure Based	EPNL	1	1	1	--
		NEF	1	1	16.7	24
		WECPNL	1	3*	10	24
		User-defined	A	B	C	T
	Maximum Level	PNLTM	1	1	1	--
		User-defined	A	B	C	--
	Time-Based	TAPNL	1	1	1	--
		%TAPNL	1	1	1	--
		User-defined	A	B	C	--

1.4.1 Exposure-Based Metrics

The exposure-based metrics represent the total sound exposure for a given time period, often 24 hours, at an observer location based upon average annual day conditions at an airport.

* In accordance with the technical definition, a 5 dB penalty is added to evening operations when computing the L_{den} noise metric. The 5 dB penalty, expressed in terms of a weighting factor, is equivalent to 3.16, not 3. However, in Title 21, Subchapter 6, §5001 of California state law a factor of 3 is used. Since the state of California is the primary user of the L_{den} metric, it was decided that INM would be consistent with state law, rather than the traditional technical definition. The evening weighting factor in the L_{WECPN} metric was changed to 3 for consistency. It is anticipated that this small difference will be of no practical consequence in the computations.

INM standard sound exposure metrics are:

L_{AE}	A-weighted sound exposure level (SEL),
L_{CE}	C-weighted sound exposure level (CEXP), and
L_{EPN}	Effective tone-corrected perceived noise level (EPNL).

These standard sound exposure metrics are used by INM to generate average noise metrics by applying associated time-averaging constants and/or day, evening, and night-time weighting factors.

INM standard average-level metrics in the A-weighted family are:

L_{dn}	Day-night average noise level (DNL),
L_{den}	Community noise equivalent level (CNEL),
L_{Aeq24h}	24-hour average noise level (LAEQ),
L_d	15-hour (0700-2200) day-average noise level (LAEQD),
L_n	9-hour (2200-0700) night-average noise level (LAEQN), and
ΔL	Change in exposure level over a user-specified time period (DDOSE), default of 12 hours.

INM standard average-level metrics for the tone-corrected perceived family are:

L_{NEF}	Noise exposure forecast (NEF), and
L_{WECPN}	Weighted equivalent continuous perceived noise level (WECPNL).

The day, evening, and nighttime weighting factors and the time-averaging periods for these metrics are shown in Table 1-3.

In addition to INM standard sound exposure and average sound level metrics, user-defined metrics for the three families are available. A user specifies the time-averaging constant and the day, evening, and nighttime weighting factors. Although there are no standard average-level metrics in the C-weighted family because such metrics are not commonplace, the user has the ability to define user-specific C-weighted metrics.

1.4.2 Maximum Noise Level Metrics

The maximum noise level metrics represent the maximum noise level at an observer location, taking into account a particular set of aircraft operations

INM standard maximum noise level metrics are:

L_{ASmx}	Maximum A-weighted sound level with slow-scale exponential weighting characteristics (LAMAX),
L_{CSmx}	Maximum C-weighted sound level with slow-scale exponential weighting characteristics (LCMAX), and
L_{PNTSmx}	Maximum tone-corrected perceived noise level with slow-scale, exponential weighting characteristics (PNLTM).

In addition to INM standard maximum noise level metrics, user-defined metrics are available. A user specifies the set of aircraft operations to be used for determining the maximum level.

1.4.3 Time-Based Metrics

The time-based metrics represent the time (minutes) or percentage of time that the noise level is above a specified threshold, taking into account aircraft operations for a particular time period (e.g., 24 hours).

INM standard time-based metrics are:

TA_{LA}	Time that the A-weighted noise level is above a user-specified sound level during the time period (TALA),
TA_{LC}	Time that the C-weighted noise level is above a user-specified sound level during the time period (TALC),
TA_{PNL}	Time that the tone-corrected perceived noise level is above a user-specified noise level during the time period (TAPNL),
$\%TA_{LA}$	Percent of time that the A-weighted noise level is above a user-specified sound level during the time period (%TALA),
$\%TA_{LC}$	Percent of time that the C-weighted noise level is above a user-specified sound level during the time period (%TALC), and
$\%TA_{PNL}$	Percent of time that the tone-corrected perceived noise level is above a user-specified noise level during the time period (%TAPNL).

A subset of the time-based metrics is time audible. Time audible (or audibility) is computed based on a comparison of aircraft noise against ambient noise to determine the time duration (or percentage of time duration) that the noise may be audible to a human observer. For these calculations, the observer is assumed to have normal hearing and to be actively listening for aircraft noise. Time audible also takes into account aircraft operations for a particular time period (e.g., 24 hours). The process is based on detectability theory and is supplemented with research that has assessed human auditory detectability in different environments. In order to represent these different environments, the time audible metrics require highly detailed inputs, including an FAA AEE-approved ambient noise file. More details on ambient noise file requirements can be obtained by contacting FAA AEE.

Appendix E provides additional specifics on the theory and background of the time audible computation. A detailed discussion of audibility calculations is also presented in the "Assessment of Tools for Modeling Aircraft Noise in the National Parks".[17]

INM standard time audible metrics are:

TAud	Time that aircraft are audible given study specific ambient noise (TAUD), and
%TAud	Percent of time that aircraft are audible given study specific ambient noise during the time period (%TAUD).

In addition to standard time-based metrics, user-defined metrics are available in INM. A user specifies the time period for determining the metric value.

1.5 Abbreviations

This section presents various abbreviations and acronyms used in the document.

AEDT	Aviation Environmental Design Tool
AFE	above field elevation (aircraft altitude)
AIR	Aerospace Information Report (SAE-AIR)
ARP	Aerospace Research Report (SAE-ARP)
C	degrees Celsius (temperature)
CAS	calibrated airspeed (corrected indicated airspeed)
CPA	closest point of approach to a line segment
dB	decibel (unit of sound level or sound exposure level)
ECAC	European Civil Aviation Conference
F	degrees Fahrenheit (temperature)
F_n/	corrected net thrust per engine (pounds)
ft	feet
HNM	Heliport Noise Model
ICAO	International Civil Aviation Organization
in-Hg	inches of mercury (barometric pressure)
INM	Integrated Noise Model
km	kilometers
kt	knots (international nautical miles per hour)
lb	pounds force or weight
ΔL	Change in exposure level over a given time period
L_{AE}	A-weighted sound exposure level, dB re (20 Pa)^2(1 s)
L_{Aeq24h}	24-hour average noise level, dB re (20 Pa)^2(1 s)
L_{ASmx}	maximum A-weighted sound level, dB re (20 Pa)^2
L_{CE}	C-weighted sound exposure level, dB re (20 Pa)^2(1 s)
L_{CSmx}	maximum C-weighted sound level, dB re (20 Pa)^2
L_d	15-hour (0700-2200) day-average noise level, dB re (20 Pa)^2(1 s)
L_{den}	Community noise equivalent level, dB re (20 Pa)^2(1 s)
L_{dn}	Day-night average noise level, dB re (20 Pa)^2(1 s)
L_n	9-hour (2200-0700) night-average noise level, dB re (20 Pa)^2(1 s)
L_{NEF}	Noise exposure forecast, dB re (20 Pa)^2(10 s)
L_{PNTSmx}	maximum tone-corrected perceived noise level, dB re (20 Pa)^2
L_{EPN}	effective tone-corrected perceived noise level, dB re (20 Pa)^2(10 s)
L_{WECPN}	Weighted equivalent continuous perceived noise level, dB re (20 Pa)^2(10 s)
m	meters
MSL	mean sea level (altitude above mean sea level, feet)
nmi	international nautical miles (1852 m)
NPD	Noise-Power-Distance
Pa	Pascal (unit of pressure, one Newton per square meter)
PCPA	perpendicular closest point of approach to an extended line segment
re	relative to
s, sec	second (time duration)
SAE	Society of Automotive Engineers

SLR	Slant Range Distance
TA_{LA}	Time above an A-weighted noise level (sec)
TA_{LC}	Time above a C-weighted noise level (sec)
TA_{PNL}	Time above a tone-corrected perceived noise level (sec)
$\%TA_{LA}$	Percent of time above an A-weighted noise level
$\%TA_{LC}$	Percent of time above a C-weighted noise level
$\%TA_{PNL}$	Percent of time above a tone-corrected perceived noise level
TAS	true airspeed (kt)
TAUD	time audible