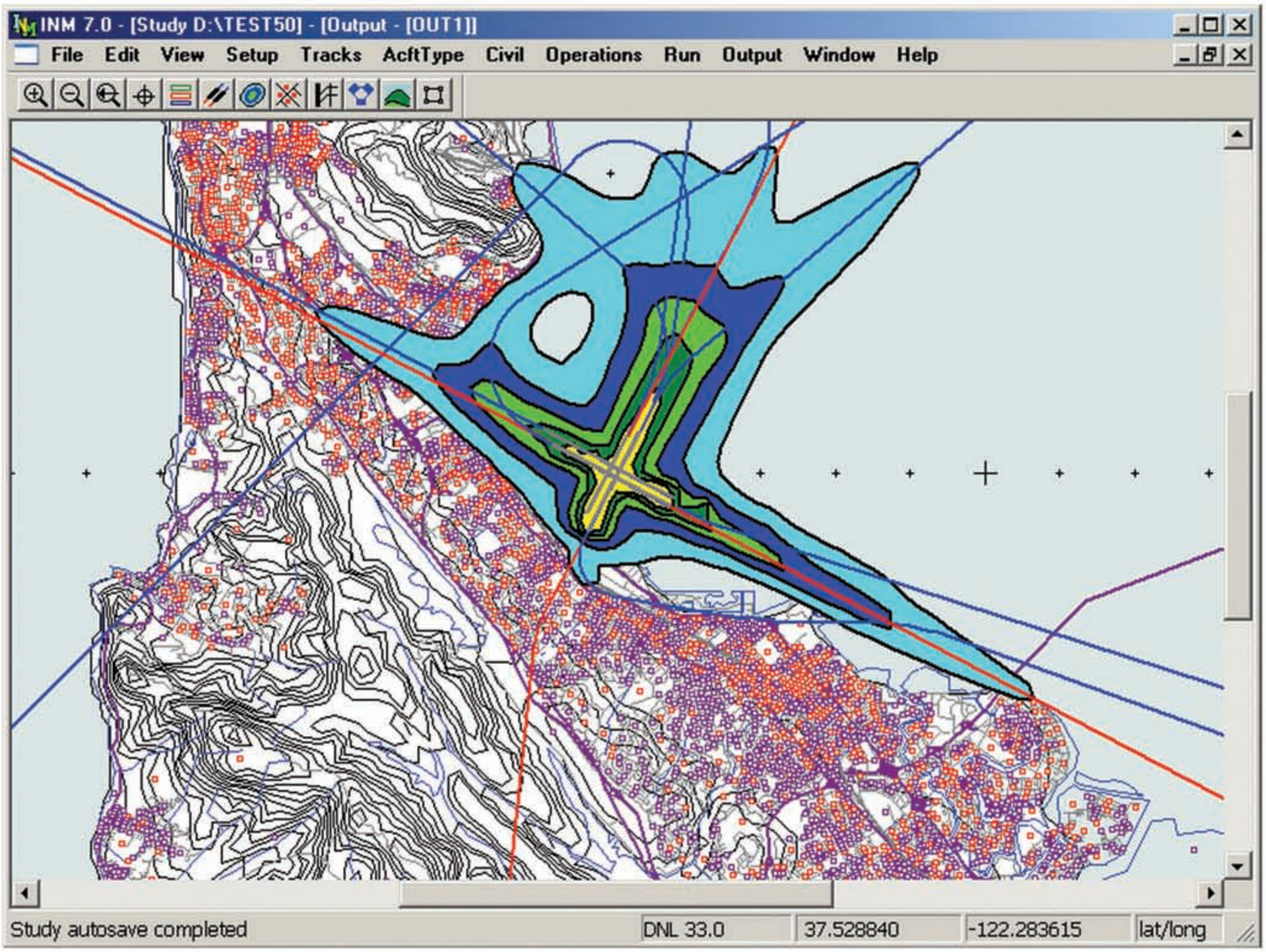
INM *Technical Manual*

Office of Environment and Energy



INTEGRATED NOISE MODEL 7.0

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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).

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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

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PREFACE

This document is the Technical Manual for the FAA's Integrated Noise Model (INM) Version 7.0 computer software, which is designed to predict noise impact in the vicinity of airports. This is a full revision to the INM Version 6.0 Technical Manual. In addition to the algorithms for modeling helicopter noise, the INM Version 7.0 Technical Manual presents the methodology employed to design aircraft flight paths and to compute noise-level and time-based metrics based upon the finite flight-segment data. Those technical updates not only made INM Version 7.0 more compliant with the new international standards, but also prepared INM for integrated modeling of both noise and emission – the FAA's ongoing development of Aviation Environmental Design Tool (AEDT).

The ATAC Corporation, the John A. Volpe National Transportation Systems Center Acoustics Facility (Volpe Center), and the Federal Aviation Administration (FAA) Office of Environment and Energy Noise Division (FAA AEE-100) have jointly prepared this document

DISCLAIMER

This document was produced by ATAC Corporation and the John A. Volpe National Transportation Systems Center Acoustics Facility staff, who are responsible for the facts and accuracy of the material presented herein. The contents do not necessarily reflect the official views or policy of the U.S. Department of Transportation or the Federal Aviation Administration. This INM Technical Manual does not constitute a standard, specification, or regulation.

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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

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* 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: .

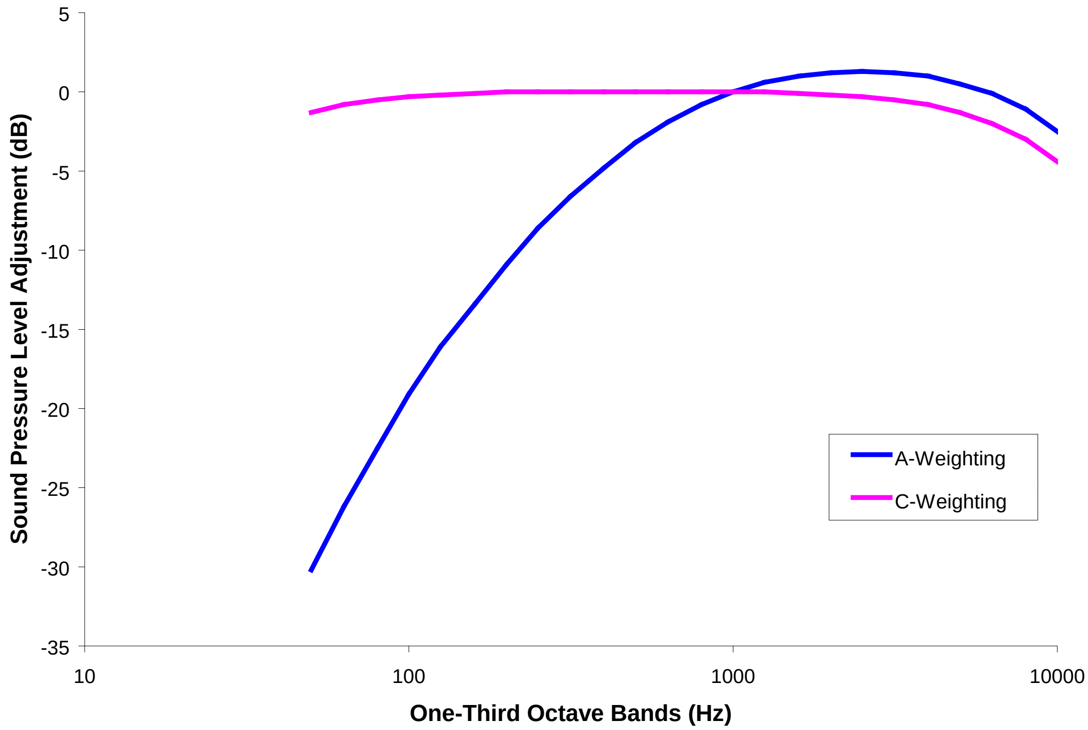

Figure 1-1: A-weighted and C-weighted Adjustment Curves

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:

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

where

$p(t)_{AS}{}^{2}$	**A-weighted** mean-square pressure using slow exponential time,
$p_A{}^{2}$	**A-weighted** mean-square pressure,
τ	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 μPa. 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.

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

where

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

p_o 20 μPa.

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**.

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

where

E **sound exposure** (Pa^2s),
E_o $(20\ \mu Pa)^2(1\ s)$ for **A-weighted** and **C-weighted sound exposure**, and
E_o $(20\ \mu Pa)^2(10\ s)$ 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^2s),
E_o reference **sound exposure** (Pa^2s), 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/δ	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 $(20\ \mu Pa)^2(1\ s)$
L_{Aeq24h}	24-hour average noise level, dB re $(20\ \mu Pa)^2(1\ s)$
L_{ASmx}	maximum A-weighted sound level, dB re $(20\ \mu Pa)^2$
L_{CE}	C-weighted sound exposure level, dB re $(20\ \mu Pa)^2(1\ s)$
L_{CSmx}	maximum C-weighted sound level, dB re $(20\ \mu Pa)^2$
L_d	15-hour (0700-2200) day-average noise level, dB re $(20\ \mu Pa)^2(1\ s)$
L_{den}	Community noise equivalent level, dB re $(20\ \mu Pa)^2(1\ s)$
L_{dn}	Day-night average noise level, dB re $(20\ \mu Pa)^2(1\ s)$
L_n	9-hour (2200-0700) night-average noise level, dB re $(20\ \mu Pa)^2(1\ s)$
L_{NEF}	Noise exposure forecast, dB re $(20\ \mu Pa)^2(10\ s)$
L_{PNTSmx}	maximum tone-corrected perceived noise level, dB re $(20\ \mu Pa)^2$
L_{EPN}	effective tone-corrected perceived noise level, dB re $(20\ \mu Pa)^2(10\ s)$
L_{WECPN}	Weighted equivalent continuous perceived noise level, dB re $(20\ \mu Pa)^2(10\ s)$
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

2 FLIGHT-PATH COMPUTATION METHODOLOGY

The fundamental components for computing noise in INM are a flight path segment and an observer. For a given observer location, noise computations are performed on a flight-segment by flight-segment basis. This Chapter presents the methods used to compute flight path segments, and Chapter 3 presents the methods used to compute noise at an observer position.

Chapter 2 contains the following sections:

Section #	**Description**
Section 2.1	Summarizes all the input data that are required for noise computation
Section 2.2	Describes the input database used in conjunction with a flight path or runup position to compute noise at an observer position.
Section 2.3	Describes flight profiles and also methods used to calculate them based on profile procedure steps.
Section 2.4	Describes helicopter flight profiles and also methods used to calculate them based on profile procedure steps.
Section 2.5	Describes methods used to merge ground tracks with flight profiles to produce three-dimensional flight path segments.
Section 2.6	Describes methods used to calculate aircraft bank angle.
Section 2.7	Describes the effects of bank angle on aircraft performance.

The aircraft performance equations in this chapter are based the equations presented in SAE-AIR-1845.[1] In anticipation of an update to SAE-AIR-1845, these equations have been modified to comply with both ICAO Circular 205 [3] and ECAC Doc 29 [2], where applicable.

2.1 Summary of Input Data for Noise Computation

The noise computation process requires case information about airport conditions, aircraft types, operational parameters, geometry between the observer/flight-segment pair, and noise metric information. Appendix A presents an example file of these data.

2.1.1 Airport/Heliport Information

The following airport/heliport information is required for noise computations:

- Latitude and longitude of the airport/heliport reference point (decimal degrees);
- Runway end-point and/or helipad center point positions in x,y relative to the reference point (feet), or in latitude and longitude (decimal degrees);
- Airport/heliport elevation (feet MSL);
- Airport/heliport average annual day temperature (degrees Fahrenheit);

- Airport/heliport average annual day relative humidity (percent), when the atmospheric absorption correction is invoked; and
- Airport/heliport average annual barometric pressure (inches of mercury re MSL).

As an option, terrain data can be used in the noise computations. Terrain elevation data are provided in one of several possible formats including 3CD, National Elevation Dataset (NED) GridFloat, and Digital Elevation Model (DEM)*. The different formats can provide different resolutions of terrain data, and require a different number of files to cover a desired geographical area. For example, 3CD terrain elevations are given in meters three arc-seconds apart. A single 3CD file covers one degree in latitude by one degree in longitude (1201 x 1201 points). NED GridFloat data is available in 1/3 arc-second resolution and the area covered by a single file can vary. The spacing between points depends on the specific location. For example, the three arc-second spacing in the Boston area is about 224 feet in the x (east-west) direction by 304 feet in the y (north-south) direction, while the three arc-second spacing in the San Francisco area is about 241 feet by 303 feet. The accuracy of U.S. terrain data is typically within 10 feet of actual elevation. However, inaccuracies of a large as 70 feet have been documented. Nevertheless, in areas of varying elevations, improvements in INM computational accuracy are obtained when the terrain enhancement is invoked.

2.1.2 Aircraft Information

The following aircraft information is required for noise computations:

- Aircraft flight operation type: approach, departure, touch-and-go, circuit flight, overflight, taxi, or runup.
- Number of flight operations for each of three time periods (day, evening, and night) during an average annual day.
- For a flight operation, the three-dimensional flight path of the aircraft, as represented by a series of straight-line flight path segments containing position, direction, length, speed, and either thrust information (for fixed wing aircraft) or operational mode information (for helicopters). Sections 2.3, 2.4 and 2.5 present details of how a three-dimensional flight path is constructed.
- For a runup operation, the position of the aircraft on the runup pad (x,y values in feet), the aircraft heading (degrees clockwise from true north), the corrected net thrust per engine (pounds or percent), and the duration of the runup operation (seconds).
- NPD and spectral class data, as presented below in Section 2.2.

2.1.3 Observer Information

Information about observer locations is required for noise computations. INM observer locations are expressed in the form a regular grid of points or a recursively-subdivided irregular grid of

* 3CD terrain data is available for purchase from the Micropath Corporation, for more information go to http://www.micropath.com. NED Gridfloat data is available from the United States Geological Survey (USGS) website at http://seamless.usgs.gov/website/seamless/products/3arc.asp. USGS has stopped offering DEM data as of November 14, 2006 however INM continues to support the DEM format. Information about DEM data is available from the USGS website at http://edc.usgs.gov/products/elevation/dem.html.

points.

Observer locations for a regular grid are defined by the location of the lower-left corner of the grid (feet), the distance between grid points in the two directions (feet), the number of grid points in the two directions, and the angle that the grid is rotated relative to the x,y axes (degrees counter-clockwise). Unlike other types, regular grids used for contour calculations cannot be rotated.

A special case of a regular grid is a grid consisting of a single observer location, in which the starting point for the grid is given, the distance between grid points is zero, and the size of the grid is one-by-one. These types of regular grids may be used to assess points of interest that may be considered noise-sensitive.

The computation of "population points" and "locations points" are also performed by using the single-grid-points method. The number of single points is an input parameter and their x,y values are listed in the input file.

Recursively-subdivided irregular grid points are generated by an algorithm that is based on a regular grid, as explained later in Chapter 4. The observer locations for the grid are determined by four corner points of the scenario analysis window and by a grid spacing of one nautical mile that is recursively subdivided into smaller grids.

2.1.4 Noise Metric Information

The following noise metric information is required for noise computations for regular grid points and/or contours:

- Metric identifier (DNL, SEL, etc.);
- Metric type (exposure-based, max-level, time-above);
- Metric weighting factors (day, evening, night);
- For an exposure-based metric, the averaging time constant (dB);
- For a time-above metric, the threshold level(s) (dB); and
- For time audible, a study-specific, FAA-approved binary ambient file, as described in the INM Version 7.0 User's Guide (if computing time audible with a relative threshold, the threshold level (dB) is also required).

An indicator (yes or no) that contours are to be generated. If contours are to be generated, the following parameters are required:

- Recursive or regular grid selection;
- Boundary file selection (if selected, a boundary file is also required, as described in the INM Version 7.0 User's Guide);
- Refinement level (1-14) or fixed-spacing value (ft);
- Tolerance value (dB or minutes);
- Low cutoff contour level (dB or minutes); and
- High cutoff contour level (dB or minutes).

2.2 Input Database

INM contains an acoustic database of noise vs. power (or operational mode for helicopters) vs. distance (NPD) values, augmented by a database of spectral characteristics. While the underlying databases for both fixed-wing aircraft and helicopters are based on the same data format (noise in conjunction with spectral data), there are several key differences between the fixed wing aircraft and helicopter data in the INM database that warrant a more detailed description.

The NPD data for a fixed-wing aircraft, which is usually obtained from the INM database but can be user-defined, consists of a set of decibel levels for various combinations of aircraft engine power states and slant distances from observer to aircraft. An underlying assumption is that the NPD data represent an aircraft proceeding along a straight flight path of infinite length and parallel to the ground.

Although helicopter noise-distance data are (1) delineated according to operational mode instead of thrust/power setting, (2) not interpolated on between multiple operational modes, and (3) come in sets of three curves for the dynamic operational modes, they are referred to as NPD curves in order to maintain consistency with the fixed-wing aircraft noise-distance data.

The noise-distance data for a helicopter, either from the INM database or user-defined, is organized according to dynamic and static operational modes. For dynamic operational modes, three sets of noise levels for various combinations of helicopter operational modes (instead of thrust levels) and slant distances from observer to helicopter. This set of three NPD curves is used to account for the asymmetrical directivity associated with helicopter noise. For static operational modes, a single set of noise levels for various combinations of helicopter operational modes and slant distances from observer to helicopter. This single set of NPD curves is used in conjunction with a helicopter-specific directivity adjustment to account for static operational mode directivity. As with fixed-wing aircraft, an underlying assumption is that the NPD data represent an aircraft proceeding along a straight flight path of infinite length, parallel to the ground.

The spectral data consist of a set of sound pressure level vs. one-third octave-band frequency (50 Hz to 10 kHz) values measured at the time of L_{ASmx} and corrected to a reference distance of 1000 feet (305 meters) using the SAE AIR-1845 atmospheric absorption coefficients[1]. These spectral data are used to compute the following:

1. actual atmospheric absorption adjustment based on airport temperature and relative humidity;
2. C-weighted noise metrics;
3. time audible; and
4. line-of-sight blockage adjustment due to terrain.

2.2.1 Noise-Power-Distance Data Sets

Four kinds of NPD input data sets are available:

L_{AE}	A-weighted sound exposure level,
L_{ASmx}	Maximum A-weighted sound level with slow-scale exponential time weighting,
L_{EPN}	Effective tone-corrected perceived noise level, and
L_{PNTSmx}	Maximum tone-corrected perceived noise level with slow-scale exponential time weighting.

All metrics in INM, including C-weighted, time-above and time audible metrics, are computed using these four basic noise-level metrics.

For fixed-wing aircraft, NPD data consist of two or more noise curves for each operational mode, such as departure or approach. A noise curve is associated with an engine power parameter (in units of pounds or percent corrected net thrust or some other power state parameter), an operational mode, and noise levels at the following ten INM distances: 200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, and 25000 feet.

To obtain noise levels that lie between thrust values or between distance values, linear interpolation on thrust and logarithmic interpolation on distance are used. Extrapolation is used to obtain levels outside of the bounding thrust or distances values, as presented in Section 3.3.

Afterburner NPD data are also available for some NOISEMAP[18] aircraft.

For helicopters, NPD data consist of a set of three noise curves for dynamic modes and a single noise curve for static modes. A noise curve is associated with a helicopter operational mode for either dynamic modes (depart, approach, level flight, accelerate, decelerate, etc.) or static modes (ground idle, flight idle, as well as hover, vertical ascent, and vertical descent in or out of ground effect), and contains noise levels at the ten INM distances. The sets of three NPD curves for dynamic helicopter modes represent the asymmetric directivity associated with helicopter noise, and correspond to noise levels at locations directly below the helicopter (center) and at approximately 45 degrees to either side (left/right) of the centerline.

The noise levels in the NPD data (for all aircraft types) have been adjusted for time-varying aircraft speed (exposure-based noise levels only), atmospheric absorption, distance-duration effects (if the simplified adjustment process is used for exposure-based noise levels), and spherical divergence in accordance with the methodology presented in Reference 1 and summarized in Reference 19.

For NOISEMAP military aircraft, NPD data were developed using the simplified data adjustment procedure, and distance duration effects were computed using an empirically-derived $6.0 \log_{10}[d/d_{ref}]$ relationship. In contrast, NPD data for civilian aircraft that were corrected using the simplified procedure were adjusted using an empirically-derived $7.5 \log_{10}[d/d_{ref}]$ relationship. It was decided that the 6-log relationship would be maintained for the military aircraft in INM, since it represents a best-fit empirical relationship for those aircraft.

2.2.2 Spectral Data Sets

A spectral class is used to represent the spectrum at time of maximum sound level for a group of aircraft deemed to have similar spectral characteristics. The starting point in any empirical model such as INM is a reference database. In Version 5.2 and earlier, the reference noise database consisted of noise level data expressed as a function of aircraft power and aircraft-to-receiver distance, i.e., noise-power-distance data. Beginning with INM Version 6.0, the data and noise computation algorithms moved to a system that considers the spectral shape of the noise produced by the aircraft. This change allowed INM to incorporate noise propagation algorithms that more accurately account for frequency-dependent effects, namely non-standard atmospheric conditions (Versions 6.0 and higher), and attenuation due to line-of-sight blockage caused by undulating terrain (Versions 6.2 and higher). Spectral classes also give a user the ability to compute C-weighted and time audible noise metrics. The spectral shape of the noise produced by the aircraft was incorporated into INM by assigning a spectral class to each aircraft. A spectral class is a group of aircraft which share similar spectral characteristics. Each group of aircraft is represented in the INM by a single, 'representative' one-third octave-band spectrum.

Reference 19, which is the source for most NPD curves developed prior to INM Version 6.0, also contains one-third octave-band spectra (50 Hz to 10 kHz) measured at the time of L_{ASmx} and corrected to a distance of 1000 feet (305 meters) using the SAE AIR-1845 atmospheric absorption coefficients. Spectral classes are not frequency-weighted in INM. For aircraft developed for INM Version 6.0 and later, the INM database request form (See Appendix G) has been updated to request the one-third octave band data necessary for determining a spectral class.

Similar spectral data for military aircraft were taken from the Noisefile Database in the United States Air Force NOISEMAP computer program. NOISEMAP is used for computing noise exposure at facilities dominated by military operations. The military data also exist in the form of one-third octave-band spectra measured at the time of L_{ASmx}. These data were corrected to a distance of 1000 feet (305 meters) using the SAE AIR-1845 atmospheric absorption coefficients to maintain similarity with Reference 19.

Although the above references included spectral data for the majority of INM aircraft, it is not considered necessary to support a separate spectrum for each INM aircraft. Based on validation tests, it was determined that maintaining separate spectral data for each aircraft would result in a negligible improvement in computational accuracy, whereas grouping similar spectra offers the desired enhancement for more advanced acoustical algorithms[20]. Based on the above sources, Reference 21 provides the spectral class assignments for INM aircraft developed before Version 6.0. Aircraft added to INM since the release of Version 6.0 have been found to fit within spectral classes developed for Reference 21. Appendix D presents an overview of the development of the spectral classes.

Sensitivity and validation tests were conducted to identify spectra that could be grouped together, referred to herein as a "spectral class". During the initial development process, aircraft were grouped together by engine type and/or number of engines (i.e., low-bypass ratio jet, high-bypass ratio jet, four engine jet, turboprop, piston, etc.), and then the groups were broken down further by spectral shape. Some groups were partitioned further to eliminate the presence of widely used aircraft in the same group. For instance, the 737300 and the MD80 were placed in separate groups, even though their spectral shapes are similar. Aircraft added since the initial development were assigned to a spectral class based on a series of tests to determine the class which provided the best fit. The best fit was based on spectral shape and similarities in atmospheric absorption and line-of-sight blockage calculations, rather than on aircraft type (although in the majority of cases, the best fit spectral class proved to contain aircraft of similar types). This process is documented in the soon to be published replacement to ICAO Circular 205.[3]

Once the spectra were grouped together, a representative spectrum was determined for the group. The spectrum was calculated from a departure-weighted arithmetic average of the individual aircraft spectra in the group for commercial aircraft. For military aircraft, aircraft inventory data were collected and each spectral class was represented by the single military aircraft which had the highest number in inventory. Some single- and twin-engine turboprops and turbojets (i.e., business jets) have commercial, military, and private usages. For these aircraft, the representative spectrum was calculated using an equally weighted arithmetic average of all of the individual aircraft spectra. Reference 21 summarizes the aircraft included within each spectral class and their weighting towards the representative spectrum.

INM Version 7.0 contains 81 unique spectral classes: 34 classes for departure (classes 101-134); 34 classes for approach (classes 201-234); and 7 classes for level flyover (classes 301-307, applicable to helicopters only). All spectral class data in INM are normalized to 70 dB at 1000 Hz

2.2.3 Maximum Noise Level Approximation

For several aircraft in the INM database, measured L_{ASmx} and L_{PNTSmx} NPD data do not exist, and they are approximated using empirical equations expressed as a function of distance and sound exposure. These equations were developed from a statistical analysis of NPD data for aircraft in which all four base noise-level metrics exist in the INM database. The equations are as follows:

For INM aircraft:

$$L_{ASmx} = L_{AE} - 7.19 - 7.73 \cdot \log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 2-1}$$

$$L_{PNTSmx} = L_{EPN} + 1.12 - 9.34 \cdot \log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 2-2}$$

For NOISEMAP aircraft:

$$L_{ASmx} = L_{AE} - 7.84 - 6.06 \cdot \log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 2-3}$$

$$L_{PNTSmx} = L_{EPN} + 2.51 - 5.84 \cdot \log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 2-4}$$

where

SLR_{pth} slant range (feet) to the closest-point-of-approach of an aircraft on a straight and level flight path.

2.2.4 C-Weighted Metric Approximation

The introduction of a spectral database into INM allows a user to calculate noise exposure in terms of C-weighted metrics. C-weighted metrics are calculated using a simplified adjustment procedure, consistent with FAR Part 36 [11] and ICAO Annex 16 [22], as follows:

1. The aircraft spectral class is used to create two weighted spectral classes: A-weighted and C-weighted.
2. Both weighted spectral classes are corrected back to the source (from the 1000 feet reference) using SAE-AIR-1845.[1] These are the two weighted source spectra.
3. Each weighted source spectrum is corrected to the ten standard INM NPD distances using the standard INM atmosphere (in SAE-AIR-1845). This yields ten A-weighted spectra and ten C-weighted spectra.
4. The 24 one-third octave band values of each spectrum are logarithmically summed at each INM distance, yielding a distance-specific, weighted sound pressure level ($L_{A, d}$ and $L_{C, d}$). These levels are then arithmetically subtracted for each INM distance ($L_{A, d}$ - $L_{C, d}$). This delta represents the difference between an A-weighted metric and a C-weighted metric at each distance.
5. Each distance-specific delta is applied to the appropriate A-weighted NPD values ($NPD_{A, d} + (L_{A, d} - L_{C, d})$) at the corresponding INM distance, resulting in a C-weighted NPD.

2.2.5 NPD Data Development Criteria

For fixed-wing aircraft, criteria for development of NPD data for use by INM include the following:[23]

- Acoustically soft ground under the measurement microphone, similar to the terrain around the microphone during aircraft noise certification tests.[11, 22]

- For L_{AE} and L_{EPN} values, an integrated adjustment procedure (involving time integration over the full spectral time history) as compared with a simplified adjustment procedure (involving the spectrum measured at the time of maximum noise level only) for airplanes where adequate field data are available.

- Reference-day air attenuation coefficients as specified by SAE-ARR-866A[7]. Note that standard-day conditions of 59 degrees Fahrenheit and 70 percent relative humidity were used prior to INM Version 3.9.

- L_{AE} and L_{EPN} values time-integrated over the upper 10 dB of the noise event as prescribed by FAA[11] and SAE[1]. (The time interval from t_1 to t_2 designates the time in seconds, from the beginning to the end of the integration period for the sound produced by an airplane. The duration $[t_2 – t_1]$ should be long enough to include all significant contributions to the total noise exposure. Sufficient accuracy is usually achieved by integration over the time interval during which the frequency-weighted sound level is within ten dB of its maximum value.)

- L_{AE} and L_{EPN} values normalized to reference aircraft speed of 160 knots.

- Noise levels specified as a function of power, usually corrected net thrust per engine.

In addition, criteria for development of helicopter NPD data for use by INM also include the following:

- L_{AE} and L_{EPN} values normalized to helicopter- and operation-specific reference speeds.

- Noise levels specified as a function of helicopter mode at the three microphone locations for dynamic modes. A single microphone location may be utilized for static modes. Noise levels may also be specified as a function of angle around the helicopter for static modes, in order establish helicopter directivity during this configuration (see Section 3.6.3).

It is important to note that the civil aircraft noise and performance data that make up the INM database are also included in ICAO's Aircraft Noise and Performance (ANP) database. The ANP database is maintained by EUROCONTROL, and may be accessed via the internet at: http://www.aircraftnoisemodel.org.

The FAA position is to adhere closely to the above criteria both for the development and validation of the INM NPD data. Diligent compliance is needed to ensure confidence in having consistent and comparable aircraft NPD and performance data. More information on the INM data validation is presented in the forthcoming replacement to International Civil Aviation Organization (ICAO) Circular 205.[3]

The complete INM Database Submittal Forms may be found in Appendix G.

2.3 Civil and Military Fixed-Wing Aircraft Flight Profiles

INM supports two kinds of flight profile input data: (1) an ordered set of profile points, and (2) an ordered set of procedure steps. Civil fixed-wing aircraft may use either profile type; military fixed-wing aircraft use profile points exclusively. The first section below presents the structure of profile point data, and the remaining sections discuss how profile points are calculated from procedure steps.

2.3.1 Profile Point Input Data

An ordered set of profile points specifies a two-dimensional trajectory. For each point, the following data are given:

d horizontal coordinate (feet) relative to an origin,
z altitude of the aircraft above the airport (feet AFE),
v_T aircraft true airspeed at the point (knots), and

F_n/δ corrected net thrust per engine (lb, %, or other units) at the point.

The origin is where the d-coordinate is equal to zero, and it depends on the kind of flight operation:

- An approach origin is at the touchdown point, and d-values are negative during descent and positive during rollout on the runway.
- A departure origin is at the start-roll point on a runway, and d-values are positive.
- A touch-and-go origin is similar to an approach; the origin is where the aircraft touches down on the runway.
- A circuit flight origin is similar to a departure; the origin is at the start-roll point.
- An overflight origin is at the first point, and d-values are positive.
- A taxi origin is the start-roll point on a runway or the center of a helipad, and d-values are positive. Taxi operations are only available for helicopters.

For all types of operations, d-values increase as an airplane flies along its profile.

Profile speed is the speed at the profile point; it is the magnitude of the aircraft velocity vector. It is the same as true airspeed with no wind, and the sections below refer to profile speed as true airspeed (TAS). Profile speed is approximately equal to ground speed, except when climbing or descending at steep angles.

The corrected net thrust per engine is described in units of pounds, percent, or some other unit that is consistent with the noise curves. If the aircraft NPD curves are in percent, thrust-setting is a percentage of the aircraft static thrust value. In the sections that follow, corrected net thrust (F_n/δ) is in pounds, but for some aircraft, the pounds are changed to percent before writing out the flight data.

When profile-point input data are used, INM does not correct for non-standard temperature and pressure. This means that the input values of F_n/δ are directly used in the noise tables.

2.3.2 Procedure Step Input Data

When a flight profile is specified in terms of procedure steps, INM processes the steps one at a time to calculate profile points, putting them in the same format as presented above.

Procedure steps are prescriptions for how to fly a profile. For example, the following set of procedure steps describes how to fly a jet departure profile:

1. Takeoff using 15-deg flaps and max-takeoff thrust.
2. Climb to 1000 feet AFE, using 15-deg flaps and max-takeoff thrust.
3. Accelerate to 175 knots CAS, while climbing at 2000 fpm (feet-per-minute) and using 15-deg flaps after cutting back to max-climb thrust.
4. Accelerate to 195 knots CAS, while climbing at 1000 fpm and using 5-deg flaps and using max-climb thrust.
5. Climb to 3000 feet AFE, using zero flaps and max-climb thrust.
6. Accelerate to 250 knots CAS, while climbing at 1000 fpm and using zero flaps and max-

climb thrust.
7. Climb to 5500 feet AFE, using zero flaps and max-climb thrust.
8. Climb to 7500 feet AFE, using zero flaps and max-climb thrust.
9. Climb to 10000 feet AFE, using zero flaps and max-climb thrust.

Each procedure step is of a specific type (takeoff, climb, accelerate), and contains parameters relative to its type (15-deg flaps, 1000 feet AFE, 2000 fpm, max-climb thrust, etc.). The sections below show how each type of procedure step is processed to compute segment end-point values of altitude, speed, and thrust. Also, methods are presented to compute the segment horizontal distance, which is used to develop the d-coordinates for the set of profile points.

In general, one procedure step produces one profile point, but there are several exceptions. For example, a takeoff step produces two points (start-roll and takeoff rotation). Also, whenever there is a change in thrust setting (for example, going from max-takeoff to max-climb), an extra profile point is created so that thrust changes continuously over a small distance (1000 ft), rather than discontinuously at a point.

Sometimes, data from a current procedure step are combined with data from the previous step before a profile point can be computed. For example, a user inputs the starting descent altitude, speed, and angle. INM processes the next descent step to find its starting altitude, which is the ending altitude for the first step. In the development of procedure step methods that follow, these algorithmic details are not described. Instead, the production of profile points is presented in terms of "initial" and "final" points that define a profile segment.

Before detailing the individual procedure step methods, the following two sections present equations that are used throughout.

2.3.3 Non-ISA Model for Atmospheric Ratios

This section presents the INM equations for calculating atmospheric ratios of temperature, pressure, and density. "Non-ISA" means that the atmospheric ratios are different than those specified in the International Standard Atmosphere (ISA) model, as specified by the INM user.[8] These user-specified, atmospheric parameters are used to calculate aircraft performance, and atmospheric absorption coefficients. The later is discussed in Section 3.4.1. In general, the use of "Non-ISA" atmospheric conditions is recommended for studies where there are significant variations from the default atmospheric conditions (~70-80°F, ~70% RH).

The input parameters for the INM atmospheric ratio equations are:

- T airport temperature (°F),
- P airport pressure (inches-Hg) MSL,
- E airport elevation (feet) MSL, and
- A aircraft altitude (feet) MSL.

Ambient temperature at the aircraft is calculated using input airport temperature and a constant temperature gradient above the airport, which is assumed to be the same as the ISA lapse rate of –0.003566°F per foot. INM calculates the absolute temperature ratio (θ) at aircraft altitude by the equation:

$$\theta = \frac{[459.67 + T - 0.003566 \cdot (A - E)]}{518.67} \qquad \text{Eq. 2-5}$$

where

θ ISA temperature ratio when the input airport temperature T = 59°F and the airport elevation E = 0 feet MSL. (A-E) represents AFE – Above Field Elevation.

INM calculates the pressure ratio (δ) at aircraft altitude by the equation:

$$\delta = \left[\left(\frac{P}{29.92} \right)^{\frac{1}{5.256}} - \left(\frac{0.003566A}{518.67} \right) \right]^{5.256} \qquad \text{Eq. 2-6}$$

where

δ ISA pressure ratio when the input airport pressure P = 29.92 inches of mercury relative to mean sea level.

INM calculates the air density ratio (sigma) at aircraft altitude by the Ideal Gas Law:

$$\sigma = \frac{\delta}{\theta} \qquad \text{Eq. 2-7}$$

where

σ ISA air density ratio when both θ and δ are ISA values.

2.3.4 Corrected Net Thrust Per Engine

This section describes the calculations for two types of thrust utilized in INM: Jet aircraft corrected net thrust per engine and Propeller-driven aircraft corrected net thrust per engine.

Jet aircraft corrected net thrust per engine

Jet aircraft corrected net thrust per engine is calculated by using a modified version of SAE-AIR-1845 [1] equation (A1):

$$\frac{F_n}{\delta} = E + (F \cdot v) + (G_A \cdot h) + (G_B \cdot h^2) + (H \cdot T_C) \qquad \text{Eq. 2-8}$$

where

- F_n/δ corrected net thrust per engine (pounds),
- v equivalent/calibrated airspeed (knots),
- h pressure altitude (feet) MSL,
- T_C temperature (°C) at the aircraft, and
- E, F, G_A, G_B, H regression coefficients that depend on power state (max-takeoff or max-climb power) and temperature state (below or above engine breakpoint temperature).

INM uses a quadratic estimate for the altitude term ($G_A \cdot h + G_B \cdot h^2$), rather than the linear estimate ($G \cdot h$) specified in SAE-AIR-1845.

Calibrated airspeed is assumed to equal equivalent airspeed (SAE-AIR-1845).

Pressure altitude is defined as ISA altitude at a given pressure ratio. INM calculates pressure altitude at the aircraft by the equation:

$$h = \left(\frac{518.67}{0.003566}\right) \cdot \left(1 - \delta^{\frac{1}{5.256}}\right) \qquad \text{Eq. 2-9}$$

where

- h pressure altitude (feet) MSL, and
- δ pressure ratio at aircraft altitude.

When the input airport pressure is 29.92 inches-Hg MSL, pressure altitude is equal to aircraft altitude (h = A).

The INM H-coefficient is in units of pounds per degree Celsius. Temperature at the aircraft in Fahrenheit is calculated by the equation:

$$T_F = T - 0.003566 \cdot (A - E) \qquad \text{Eq. 2-10}$$

and converted to Celsius by:

$$T_C = \left(\frac{5}{9}\right) \cdot \left(T_F - 32\right) \qquad \text{Eq. 2-11}$$

where

- T_C temperature (°C) at the aircraft,
- T_F temperature (°F) at the aircraft,
- T airport temperature (°F),
- E airport elevation (feet) MSL, and
- A aircraft altitude (feet) MSL.

INM models a jet engine by using sets of coefficients that are tailored for specific profile steps, such as takeoff, climb or idle steps. Many aircraft have two sets of coefficients for max-takeoff power and two sets for max-climb power. For a given power state, INM models the effect of jet engine breakpoint temperature by using coefficients $(E, F, G_A, G_B, H)_{low}$ for ambient temperatures below the breakpoint temperature and coefficients $(E, F, G_A, G_B, H)_{high}$ above breakpoint. INM calculates both $(F_n/\delta)_{low}$ and $(F_n/\delta)_{high}$ and then uses the smaller of the two values as the corrected net thrust for a given power state.

If the high-temperature coefficients do not exist in the database, INM calculates high-temperature corrected net thrust by the equation:[24]

$$\left(\frac{F_n}{\delta}\right)_{high} = F_{low} \cdot v + (E_{low} + H_{low} \cdot T_{BC}) \frac{(1 - 0.003 \cdot T_F)}{(1 - 0.003 \cdot T_{BF})} \qquad \text{Eq. 2-12}$$

where

- $(F_n/\delta)_{high}$ high-temperature corrected net thrust (pounds),

E_{low}, F_{low}, H_{low}	regression coefficients for the low-temperature equation,
v	calibrated airspeed (knots),
T_F	temperature (°F) at the aircraft, and
T_{BC}, T_{BF}	breakpoint temperature, T_{BC} = 30°C, T_{BF} = 86°F.

<u>Propeller-driven aircraft corrected net thrust per engine</u>

Propeller-driven aircraft corrected net thrust per engine is calculated by using SAE-AIR-1845 equation (A4):

$$\frac{F_n}{\delta} = \frac{\left(\dfrac{325.87 \cdot \eta \cdot P}{v_T}\right)}{\delta} \qquad \text{Eq. 2-13}$$

where

F_n/δ	corrected net thrust per engine (pounds),
325.87	units conversion: horsepower/knots to pounds,
η	propeller efficiency, which depends on the power state,
P	net power per engine (horsepower, MSL standard day), which depends on the power state (max-takeoff or max-climb),
v_T	true airspeed (knots), and
δ	pressure ratio at aircraft altitude.

True airspeed is calculated by using SAE-AIR-1845 equation (A5):

$$v_T = v \cdot \sigma^{-1/2} \qquad \text{Eq. 2-14}$$

where

v_T	true airspeed (knots),
v	calibrated airspeed (knots), and
σ	air density ratio at aircraft altitude.

Corrected net thrust per engine is used as an input parameter for calculating noise level using NPD curves, and it also appears in several SAE-AIR-1845 flight profile equations.

2.3.5 Takeoff Ground Roll Segment

For the takeoff ground roll segment, the initial and final values of aircraft altitude are given (the runway-end elevation), the initial and final values of speed and thrust are calculated, and the horizontal distance is calculated.

For jets, the corrected net thrust per engine $(F_n/\delta)_1$ at the <u>start-roll point</u> is calculated by using the departure thrust equation with v_1 = 0 knots. For props, the corrected net thrust per engine $(F_n/\delta)_1$ at the start-roll point is set equal to the corrected net thrust per engine $(F_n/\delta)_2$ at the takeoff rotation point.

For jets and props, the corrected net thrust per engine $(F_n/\delta)_2$ at the <u>takeoff rotation point</u> is calculated by using the departure thrust equations presented above. The calibrated airspeed at the rotation point, which is used in the thrust equation, is calculated by using SAE-AIR-1845 equation (A7):

$$v_2 = C_f \cdot W^{½} \qquad \text{Eq. 2-15}$$

where

v_2 calibrated airspeed (knots) at takeoff rotation,

C_f takeoff speed coefficient that depends on flaps setting, and

W departure profile weight (lb); weight is assumed to remain constant for the entire departure profile.

For jets or props, $(F_n/\delta)_1$ can be a user-input value. If so, $(F_n/\delta)_2$ is set equal to this value.

Takeoff ground-roll distance is calculated by using SAE-AIR-1845 equation (A6):

$$S_g = \frac{B_f \cdot \theta \cdot \left(\frac{W}{\delta}\right)^2}{\left[N \cdot \left(\frac{F_n}{\delta}\right)_2\right]} \qquad \text{Eq. 2-16}$$

where

S_g ground-roll distance (feet),

B_f ground-roll coefficient, which depends on the flaps setting,

θ temperature ratio at the airport elevation,

W departure profile weight (lb),

δ pressure ratio at the airport,

N number of engines, and

$(F_n/\delta)_2$ corrected net thrust per engine (lb) at takeoff rotation.

The takeoff ground-roll distance is corrected for headwind, which may be different than the standard 8 knots per user input, by using SAE-AIR-1845 equation (A16):

$$S_{gw} = \frac{S_g \cdot (v_2 - w)^2}{(v_2 - 8)^2} \qquad \text{Eq. 2-17}$$

where

S_{gw} ground-roll distance (feet) corrected for headwind,

S_g ground-roll distance (feet) uncorrected,

v_2 calibrated speed (knots) at takeoff rotation, and

w headwind (knots).

The takeoff ground-roll distance is also corrected for runway gradient by using the equations:

$$S_{gc} = \frac{S_{gw} \cdot a}{(a - 32.17 \cdot G)} \qquad \text{Eq. 2-18}$$

$$a = \frac{(v_2 \cdot \sigma^{-½})^2}{(2 \cdot S_{gw})} \qquad \text{Eq. 2-19}$$

$$G = \frac{(E_2 - E_1)}{L} \qquad \text{Eq. 2-20}$$

where

S_{gc} ground-roll distance (feet) corrected for headwind and runway gradient,
S_{gw} ground-roll distance (feet) corrected for headwind,
a average acceleration (feet/s^2) along the runway,
v_2 calibrated speed (knots) at takeoff rotation,
G runway gradient; G is positive when taking-off uphill,
E_1,E_2 runway end elevations (feet) MSL, and
L runway length (feet).

In INM Version 7.0, the corrected ground-roll distance S_{gc} is divided into sub-segments with variable lengths, each segment covering an aircraft speed change of 20 knots. The number of sub-segments N_{segs} for the ground roll is calculated as:

$$N_{segs} = \text{int}\left(1 + \frac{v_2}{20}\right) \qquad \text{Eq. 2-21}$$

where

N_{segs} number of sub-segments,
v_2 calibrated speed (knots) at takeoff rotation, and
int(x) function that returns the integer part of x.

Acceleration is assumed to be constant, and each segment is calculated to cover an equal time period. The time t on each segment is calculated as:

$$t = \frac{2 \cdot S_{gc}}{v_2 \cdot N_{segs}} \qquad \text{Eq. 2-22}$$

where

t time (sec) spent on each sub-segment,
S_{gc} ground-roll distance (feet) corrected for headwind and runway gradient,
v_2 calibrated speed (feet/s) at takeoff rotation, and
N_{segs} number of sub-segments.

The distance, speed, and thrust values at the N_{segs} segment end points are calculated by linear interpolation on time. .

2.3.6 Touch-and-Go Power-On Ground Roll Segment

For that portion of a touch-and-go ground roll segment when an aircraft is accelerating to takeoff, the initial and final altitudes are given (the airport elevation), the initial calibrated speed v_{T1} is given (a user-defined value), and the final speed, initial and final thrusts, and horizontal distance are calculated.

The takeoff rotation speed v_{T2} is calculated by:

$$v_{T2} = C_f \cdot W^{½} \cdot \sigma^{-½} \qquad \text{Eq. 2-23}$$

where

C_f takeoff speed coefficient that depends on flaps setting,
W touch-and-go profile weight, and
σ density ratio at the airport.

The thrusts $(F_n/\delta)_1$ and $(F_n/\delta)_2$ are calculated by using the departure thrust equations at the airport elevation and for calibrated speeds v_1 and v_2.

The power-on ground-roll distance is calculated by:

$$S_g = \frac{(v_{T2}{}^2 - v_{T1}{}^2)}{(2 \cdot a)} \qquad \text{Eq. 2-24}$$

$$a = \frac{C_f{}^2 \cdot N \cdot \left(\frac{F_n}{\delta}\right)_2}{2 \cdot B_f \cdot \left(\frac{W}{\delta}\right)} \qquad \text{Eq. 2-25}$$

where

S_g distance (feet) of that portion of the touch-and-go ground-roll that begins when accelerating power is applied and ends when takeoff rotation occurs,
v_{T1} initial true speed (knots),
v_{T2} final true speed (knots),
a average acceleration (feet/s^2) along the runway, which is assumed to be the same acceleration as available for takeoff,
C_f takeoff speed coefficient that depends on flaps setting,
N number of engines,
$(F_n/\delta)_2$ corrected takeoff thrust (lb),
δ pressure ratio at the airport,
B_f ground-roll coefficient that depends on flaps setting, and
W touch-and-go profile weight (lb).

For the touch-and-go case, corrections for headwind, runway gradient, and segment subdivision are similar to those for the takeoff case.

2.3.7 Climb Segment

For a climb segment, the initial and final altitudes are given (A_1 is from the previous segment and A_2 is user input), the initial and final speeds are calculated using the final calibrated airspeed on the previous segment, the initial thrust $(F_n/\delta)_1$ is given from the previous segment, the final thrust is calculated, and the horizontal distance is calculated.

A climb segment is flown at constant calibrated airspeed v, climbing from altitude A_1 to altitude A_2. Even though a climb segment uses constant calibrated airspeed, the true airspeeds v_{T1} and v_{T2} at the segment end points are different because the air densities σ_1 and σ_2 are different. The speeds are calculated by:

$$v_{T1} = v \cdot \sigma_1{}^{-½} \qquad \text{Eq. 2-26}$$

$$v_{T2} = v \cdot \sigma_2^{-½} \qquad \text{Eq. 2-27}$$

The nominal corrected net thrust per engine F_n/δ is usually calculated by using the departure thrust equations at the mid-point altitude $A_m = ½(A_1 + A_2)$. Likewise, a nominal value of the pressure ratio δ is usually calculated at the mid-point altitude A_m.

The final corrected net thrust per engine $(F_n/\delta)_2$ is usually calculated by using the departure thrust equations at calibrated airspeed v and altitude A_2. However, there are three cases when this method is not used:

1. When a "user-value" thrust is specified, the nominal value of corrected net thrust per engine is set to the specified value, F_n/δ = user-value thrust. The nominal value of the pressure ratio δ is calculated at the mid-point altitude.

   The calculated initial corrected net thrust per engine $(F_n/\delta)_1$ is retained from the previous step, but the final corrected net thrust per engine is also set to the user-value thrust.

2. When "user-cutback" thrust is specified, the nominal value of corrected net thrust per engine is set to the specified value, F_n/δ = user-cutback thrust. The nominal value of the pressure ratio δ is calculated at the mid-point altitude.

   The climb segment is calculated and then it is broken into two sub-segments, both having the same climb angle. The first sub-segment is assigned a 1000-foot ground distance, and the corrected net thrust per engine at the end of 1000 feet is set equal to the user-cutback value. (If the original horizontal distance is less than 2000 feet, one half of the segment is used to cutback thrust.) The final thrust on the second sub-segment is also set equal to the user-cutback thrust. Thus, the second sub-segment is flown at constant thrust.

   Another 1000-foot sub-segment restores the thrust from the user-cutback value to the calculated value $(F_n/\delta)_2$ at altitude A_2, but this sub-segment is created in the next climb or acceleration segment.

3. When engine-out "minimum-thrust" is specified, the nominal value of corrected net thrust per engine F_n/δ is calculated by using the engine-out procedure below. The nominal value of the pressure ratio δ is set to the final value calculated at altitude A_2.

   Two 1000-foot sub-segments are introduced in a manner similar to the user-cutback case.

The constant engine-out reduced thrust used for the cutback sub-segment is calculated by:

$$\frac{F_n}{\delta} = \frac{\left(\dfrac{W}{\delta_2}\right)\cdot\left\{\left[\dfrac{\sin\left(\tan^{-1}\left(\dfrac{G}{100}\right)\right)}{K}\right] + R_f\right\}}{(N-1)} \qquad \text{Eq. 2-28}$$

where

F_n/δ corrected net thrust per engine (lb) for an engine-out procedure,
W departure profile weight (lb),
δ_2 pressure ratio at altitude A_2,
G engine-out percentage climb gradient from FAR Part 25[25]:
G = 0% for aircraft with Automatic Thrust Restoration Systems; or if not,
G = 1.2% for 2-engine aircraft,
G = 1.5% for 3-engine aircraft,
G = 1.7% for 4-engine aircraft,
K speed-dependent constant:
K = 1.01 when climb speed ≤ 200 knots, and
K = 0.95 otherwise,
This constant accounts for the effects on climb gradient of climbing into an 8-knot headwind and the acceleration inherent in climbing at constant calibrated airspeed (true speed increases as air density diminishes with height),
R_f drag-over-lift coefficient that depends on the flaps setting, and
N number of engines (N>1).

The average climb angle is calculated by using SAE-AIR-1845 equation (A8):

$$\gamma = \sin^{-1}\left(K \cdot \left[\frac{N \cdot \left(\frac{F_n}{\delta} \right)}{\left(\frac{W}{\delta} \right)} - R_f \right] \right) \qquad \text{Eq. 2-29}$$

where

γ average climb angle,
K speed-dependent constant,
K = 1.01 when climb speed ≤ 200 knots, and K = 0.95 otherwise,
N number of engines,
F_n/δ nominal value of corrected net thrust per engine (lb),
δ nominal value of the pressure ratio,
W departure profile weight (lb), and
R_f drag-over-lift coefficient that depends on the flaps setting.

The above method of setting the constant K is slightly different than specified in SAE-AIR-1845, where the initial climb segment uses K = 1.01, and climb segments after acceleration and flaps-retraction use K = 0.95. The INM method is more useful for handling flight profiles where the order of climb and acceleration segments is mixed.

The climb angle is corrected for headwind by using SAE-AIR-1845 equation (A17):

$$\gamma_w = \frac{\gamma \cdot (v - 8)}{(v - w)} \qquad \text{Eq. 2-30}$$

where

γ_w average climb angle corrected for headwind,
γ average climb angle, uncorrected

v calibrated airspeed (knots) on the climb segment, and
w headwind (knots).

Finally, the horizontal distance for the climb segment is calculated by using SAE-AIR-1845 equation (A9):

$$S_c = \frac{(A_2 - A_1)}{\tan(\gamma_w)} \qquad \text{Eq. 2-31}$$

where

- S_c horizontal distance (feet) for the climb segment,
- A_1 initial altitude (feet) MSL,
- A_2 final altitude (feet) MSL, and
- γ_w average climb angle corrected for headwind.

2.3.8 Acceleration Segment

For an acceleration segment, the initial altitude A_1, initial true airspeed v_{T1}, and initial thrust $(F_n/\delta)_1$ are given from the previous segment. The final calibrated airspeed v_2 and the average climb rate v_{Tz} are user inputs. The final altitude, final true airspeed, final thrust, and horizontal flying distance are calculated.

Altitude, speed, thrust, and distance are calculated by using an iterative method. The final altitude $A_2 = A_1 + 250$ feet is used for the first iteration, and then A_2 is recalculated until the absolute difference between the current and next iteration A_2 values is less than one foot.

The horizontal distance is calculated by using SAE-AIR-1845 equation (A10):

$$S_a = \frac{0.95 \cdot k \cdot (v_{T2}^{\ 2} - v_{T1}^{\ 2})}{(G_m - G)} \qquad \text{Eq. 2-32}$$

where

- S_a current iteration horizontal distance (feet),
- k constant:

$$k = \frac{\frac{1}{2} \cdot \left(\frac{101.2686}{60} \right)^2}{32.17} = 0.0442758 \qquad \text{(feet/knots}^2\text{)}, \qquad \text{Eq. 2-33}$$

- v_{T1} input initial true airspeed (knots),
- v_{T2} final true airspeed (knots) at current iteration σ_2:

$$v_{T2} = \text{v}_2 \cdot \sigma_2^{\ -½} \ , \qquad \text{Eq. 2-34}$$

- v_2 input final calibrated airspeed (knots),
- σ_2 air density ratio at current iteration final altitude A_2,
- G_m maximum acceleration available (g's) for current iteration:

$$G_m = \frac{N \cdot \left(\frac{F_n}{\delta}\right)}{\left(\frac{W}{\delta}\right)} - R_f, \qquad \text{Eq. 2-35}$$

N number of engines,

F_n/δ average corrected net thrust per engine (lb) at the current iteration:

$$\left(\frac{F_n}{\delta}\right) = \frac{1}{2} \cdot \left[\left(\frac{F_n}{\delta}\right)_1 + \left(\frac{F_n}{\delta}\right)_2\right], \qquad \text{Eq. 2-36}$$

$(F_n/\delta)_1$ input initial corrected net thrust per engine (lb),

$(F_n/\delta)_2$ final corrected net thrust per engine (lb) at current iteration altitude A_2,

W departure profile weight (lb),

δ pressure ratio at current iteration mid-point altitude, $½(A_1 + A_2)$

R_f drag-over-lift coefficient that depends on the flaps setting,

G climb gradient for the current iteration value of v_{T2}:

$$G = \frac{v_{T_z}}{[101.2686 \quad ½ \cdot (v_{T1} + v_{T2})]} \qquad \text{Eq. 2-37}$$

v_{Tz} input climb rate (feet/min).

The next-iteration final altitude A_2' is calculated by using SAE-AIR-1845 equation (A11):

$$A_2' = A_1 + \frac{S_a \cdot G}{0.95} \qquad \text{Eq. 2-38}$$

When $|A_2' - A_2| < 1$ foot, the current iteration values of final altitude A_2, final true airspeed v_{T2}, final corrected net thrust per engine $(F_n/\delta)_2$, and horizontal distance S_a are used for the acceleration segment.

If during the iteration process $(G_m - G) < 0.02$, the acceleration is considered to be too small to achieve the desired v_2 in a reasonable distance. INM issues a warning message and then limits the climb gradient to $G = G_m - 0.02$. In effect, the desired climb rate is reduced so that the airplane can maintain a minimum acceleration. If $G < 0.01$, INM issues an error message and stops computing the profile. This is because there is not enough thrust to both accelerate and climb, as required by the segment parameters.

The acceleration segment distance is corrected for headwind by using SAE-AIR-1845 equation (A18):

$$S_{aw} = \frac{S_a \cdot (v_T - w)}{(v_T - 8)} \qquad \text{Eq. 2-39}$$

where

S_{aw} horizontal distance (feet) corrected for headwind,

S_a horizontal distance (feet) for the acceleration segment, uncorrected,

v_T average true airspeed (knots) on the segment:

$$\mathrm{v_T} = \frac{1}{2} \cdot (\mathrm{v}_{T1} + v_{\mathrm{T2}})$$ Eq. 2-40

w headwind (knots).

2.3.9 Accel-Percent Segment

For an acceleration percent (accel-percent) segment, the initial altitude A_1, initial true airspeed v_{T1}, and initial thrust $(F_n/\delta)_1$ are given from the previous segment. The final calibrated airspeed v_2 and the energy-share percentage value A_p are user inputs. The final altitude, final true airspeed, final thrust, and horizontal flying distance are calculated.

Acceleration percent (accel-percent) segments are calculated in a similar manner to acceleration segments (see section 2.3.8 above). The key difference is that accel-percent segments utilize an input energy-share percentage value while acceleration segments use an input average climb rate. The energy-share percentage value defines the division of aircraft thrust between use for climbing vs. use for accelerating. The climb gradient in Eq. 2-37 is replaced with a climb gradient calculated using the input acceleration percent value. At an acceleration percent value of 100% all thrust is dedicated to increasing airspeed and the climb rate will be zero. As A_p is decreased to 0% more thrust is dedicated to climbing and less to acceleration. Acceleration for climbing is calculated as follows:

$$G = G_m \cdot (1 - A_p)$$ Eq. 2-41

where

- G acceleration available for climbing, also called the climb gradient,
- G_m maximum available acceleration, see Eq. 2-35 and
- A_p percentage of thrust applied to acceleration.

Thus Eq. 2-41 is used instead of Eq. 2-37; otherwise the process is identical to the acceleration segment.

2.3.10 Descent Segment

For a descent segment, the initial altitude, true airspeed, and thrust are given from the previous segment. The final altitude A_2, final calibrated airspeed v_2, and descent angle γ are user inputs, with the final altitude and final calibrated airspeed being input on the following segment. The final true airspeed, final thrust, and horizontal distance are calculated.

In INM, the initial altitude and speed appear to be user inputs; however, a descent segment is not actually calculated until the next segment is processed. This procedure is necessary so that an approach profile can start with a descent segment.

The final true airspeed is:

$$v_{T2} = v_2 \cdot \sigma_2^{-½}$$ Eq. 2-42

where

- v_2 input final calibrated airspeed, and
- σ_2 density ratio at altitude A_2.

The final corrected net thrust per engine is calculated by using by using SAE-AIR-1845 equation (A15):

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{\left(\frac{W}{\delta_2}\right)\cdot\left[R_f - \frac{\sin(\gamma)}{1.03}\right]}{N} \quad \text{Eq. 2-43}$$

where

$(F_n/\delta)_2$ corrected net thrust per engine (lb) at altitude A_2,
W profile weight (lb),
δ_2 pressure ratio at altitude A_2,
R_f drag-over-lift coefficient that depends on flaps and gear setting,
γ average descent angle (a positive value), and
N number of engines.

The final corrected net thrust per engine is corrected for headwind by using SAE-AIR-1845 equation (A19):

$$\left(\frac{F_n}{\delta}\right)_{2w} = \left(\frac{F_n}{\delta}\right)_2 + \frac{1.03\cdot\left(\frac{W}{\delta_2}\right)\cdot\sin(\gamma)\cdot(w-8)}{(N\cdot v_2)} \quad \text{Eq. 2-44}$$

where

$(F_n/\delta)_{2w}$ corrected net thrust per engine (lb) for headwind w,
$(F_n/\delta)_2$ corrected net thrust per engine (lb) at altitude A_2,
W profile weight (lb),
δ_2 pressure ratio at altitude A_2,
γ average descent angle (a positive value),
w headwind (knots),
N number of engines, and
v_2 calibrated airspeed (knots) at altitude A_2.

The horizontal distance is calculated by:

$$S_d = \frac{(A_1 - A_2)}{\tan(\gamma)} \quad \text{Eq. 2-45}$$

where

S_d horizontal distance (feet) for the descent segment,
A_1 initial altitude (feet) MSL,
A_2 final altitude (feet) MSL ($A_1 > A_2$), and
γ average descent angle (a positive value).

2.3.11 Descend-Decel Segment

For a descend-decel segment, the initial altitude, true airspeed, and thrust are given from the previous segment. The final altitude A_2, final calibrated airspeed v_2, and descent angle γ are user inputs, with the final altitude and final calibrated airspeed being input on the following segment. The final true airspeed, final thrust, and horizontal distance are calculated.

In INM, the initial altitude and speed appear to be user inputs; however, a descend-decel segment is not actually calculated until the next segment is processed. This procedure is necessary so that an approach profile can start with a descend-decel segment.

The process for calculating Descend_Decel segments in the INM is similar but not identical to the process described in Section B-10 of ECAC Doc 29.[2] The INM assumes that the procedural profile using the descend-decel segment was defined for ISA reference conditions at a sea-level airport. The deceleration that results over the segment given sea-level ISA conditions is assumed to remain constant even under non-sea level, non-ISA conditions, and other segment parameters are therefore modified for consistency under these conditions. Deceleration over the descend-decel segment for ISA conditions is calculated as:

$$a_{ISA} = \frac{\left(\left(v_{T2ISA}{}^{2} - \left(w^{2} \cdot \sin(\gamma)^{2}\right)\right)^{1/2} - w \cdot \cos(\gamma)\right)^{2} - \left(\left(v_{T1ISA}{}^{2} - \left(w^{2} \cdot \sin(\gamma)^{2}\right)\right)^{1/2} - w \cdot \cos(\gamma)\right)^{2}}{2 \cdot s_d}$$

Eq. 2-46

where

- a_{ISA} acceleration for ISA conditions (feet/s^2),
- v_{T1ISA} initial true airspeed (feet/s) for ISA conditions σ_{1ISA}:

$$v_{T1ISA} = \left(v_1 \cdot \sigma_{1ISA}^{-1/2}\right) \cdot \left(\frac{101.2686}{60}\right)$$ Eq. 2-47

- v_{T2ISA} final true airspeed (feet/s) for ISA conditions σ_{2ISA}:

$$v_{T2ISA} = \left(v_2 \cdot \sigma_{2ISA}^{-1/2}\right) \cdot \left(\frac{101.2686}{60}\right)$$ Eq. 2-48

- v_1 input initial calibrated airspeed (knots),
- v_2 input final calibrated airspeed (knots),
- σ_{1ISA} air density ratio at initial altitude A_1 (for ISA conditions),
- σ_{2ISA} air density ratio at final altitude A_2 (for ISA conditions),
- w headwind (ft/s),
- γ average descent angle (a positive value),
- S_d horizontal distance (feet) for the descent segment:

$$S_d = \frac{(A_2 - A_1)}{\sin(\gamma)}$$ Eq. 2-49

- A_1 initial altitude (feet) MSL, and
- A_2 final altitude (feet) MSL ($A_1 > A_2$).

For non-ISA conditions, the segment's ISA deceleration and the input descent angle are held constant and either the final true airspeed <u>or</u> the segment length (and therefore final altitude) are adjusted.

When the segment following the descend-decel segment is a level, level-decel, level-idle, or land segment the input final altitude is maintained and the final true airspeed is adjusted to account for non-ISA conditions. The new final true airspeed (feet/s) is calculated as:

$$v_{T2\,adjusted} = \left(\left(\left(\left(\left(v_{T1}^{\ 2} - \left(w^2 \cdot \sin(\gamma)^2 \right) \right)^{1/2} - w \cdot \cos(\gamma) \right)^2 + 2 \cdot s_d \cdot a_{ISA} \right)^{1/2} + w \cdot \cos(\gamma) \right)^2 + w^2 \cdot \sin(\gamma)^2 \right)^{1/2}$$

Eq. 2-50

where

$v_{T2adjusted}$	calculated final true airspeed for actual airport atmospheric conditions (feet/s), and
v_{T1}	input initial true airspeed for actual airport atmospheric conditions (feet/s).

When the segment following the descend-decel segment is a descend, descend-decel, or descend-idle segment the input final true airspeed is maintained and the segment length and final altitude are adjusted for non-ISA conditions. The new segment length is calculated as:

$$S_{ladjusted} = \frac{\left(\left(v_{T2}^{\ 2} - w^2 \cdot \sin(\gamma)^2 \right)^{1/2} - w \cdot \cos(\gamma) \right)^2 - \left(\left(v_{T1}^{\ 2} - w^2 \cdot \sin(\gamma)^2 \right)^{1/2} - w \cdot \cos(\gamma) \right)^2}{2 \cdot a_{ISA}}$$

Eq. 2-51

where

$s_{ladjusted}$	segment length adjusted for non-ISA conditions (feet),
v_{T1}	input initial true airspeed for actual airport atmospheric conditions (feet/s), and
v_{T2}	input final true airspeed for actual airport atmospheric conditions (feet/s),

The segment's new final altitude $A_{2adjusted}$ is calculated as:

$$A_{2adjusted} = A_1 - s_{ladjusted} \cdot \sin(\gamma)$$

Eq. 2-52

where

$A_{2adjusted}$	calculated final altitude (feet) MSL, and
A_1	input initial altitude (feet) MSL.

Descend-decel segment thrust values account for deceleration effects on thrust, unlike descent segments described in Section 2.3.10. Thrust is calculated with a force balance derived from SAE-AIR-1845 equation (A15) with an additional acceleration term:

$$\frac{F_n}{\delta} = \frac{W}{N \cdot \delta} \left(R \cdot \cos(\gamma) - \sin(\gamma) + \frac{a}{g} \right)$$

Eq. 2-53

where

F_n / δ corrected net thrust per engine,
W aircraft weight,
δ pressure ratio at segment's altitude,
N number of engines,
R drag over lift coefficient that depends on flaps and gear setting,
a aircraft acceleration along the velocity vector,
g acceleration due to gravity, and
γ descent angle (positive by convention).

2.3.12 Descend-Idle Segment

For a descend-idle segment, the initial altitude, true airspeed, and thrust are given from the previous segment. The final altitude A_2, final calibrated airspeed v_2, and descent angle γ are user inputs, with the final altitude and final calibrated airspeed being input on the following segment. The final true airspeed, final thrust, and horizontal distance are calculated.

In INM, the initial altitude and speed appear to be user inputs; however, a descend-idle segment is not actually calculated until the next segment is processed. This procedure is necessary so that an approach profile can start with a descend-idle segment.

Descend-idle segments are calculated in the same manner as descend-decel segments described in Section 2.3.11 with the exception of thrust. Idle thrust values for level-idle segments are calculated using SAE-AIR-1854 equation (A1) using idle thrust coefficients, which are unique to each aircraft type (see Eq. 2-8 in Section 2.3.4). The initial and final idle thrust values are calculated using the initial and final altitude and speed values as appropriate.

2.3.13 Level Segment

For a level segment, the initial altitude, true airspeed, and thrust are given from the previous segment. The final altitude A_2, final calibrated airspeed v_2, and distance flown S_v are user inputs (the final altitude and speed must be the same as the initial values). The final thrust is calculated.

If the initial thrust is not the same as the final thrust (for example, the previous segment was a climb segment), then a 1000-ft transition segment is created so that the major portion of the level segment is flown at constant thrust.

The corrected net thrust per engine is calculated by using by using SAE-AIR-1845 equation (A15) with zero descent angle:

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{\left(\frac{W}{\delta}\right) \cdot R_f}{N} \qquad \text{Eq. 2-54}$$

where

$(F_n/\delta)_2$ final corrected net thrust per engine (lb) at altitude $A_1 = A_2$,
W profile weight (lb),
δ pressure ratio at altitude $A_1 = A_2$,

R_f drag-over-lift coefficient that depends on flaps and gear setting, and
N number of engines.

2.3.14 Level-Decel Segment

For a level-decel segment the segment length, initial true airspeed, and segment altitude are user inputs. The initial true airspeed and segment altitude must match the final values from the previous segment. The final true airspeed is defined by the following segment, and the constant segment thrust is calculated.

The level-decel segment is calculated and then broken into two sub-segments. The first sub-segment is assigned a 1000-foot ground distance. The corrected net thrust at the beginning of this segment is equal to the final value from the previous segment, and the corrected net thrust at the end of 1000 feet is set equal to the level-decel thrust. (If the original horizontal distance is less than 2000 feet, one half of the segment distance is used to transition the thrust.) The final thrust on the second sub-segment is also set to the level-decel thrust. Thus, the second segment is flown at constant thrust.

Another 1000-foot sub-segment restores the thrust from the level-decel value to the appropriate initial thrust for the following segment, but this sub-segment is created in the following segment.

The INM assumes that the procedural profile using the level-decel segment was defined for ISA reference conditions at a sea-level airport. The deceleration that results over the segment given sea-level ISA conditions is assumed to remain constant even under non-sea level, non-ISA conditions, and other segment parameters are therefore modified for consistency under these conditions. Deceleration over the level-decel segment for ISA conditions is calculated as:

$$a_{ISA} = \frac{\left(\left(\frac{v_2}{\sigma_{ISA}^{1/2}} - w\right) \cdot \frac{101.2686}{60}\right)^2 - \left(\left(\frac{v_1}{\sigma_{ISA}^{1/2}} - w\right) \cdot \frac{101.2686}{60}\right)^2}{2 \cdot s_d} \qquad \text{Eq. 2-55}$$

where

a_{ISA} acceleration for ISA conditions (feet/s^2),
v_1 input initial calibrated airspeed (knots),
v_2 input final calibrated airspeed (knots),
σ_{ISA} air density ratio at segment altitude (for ISA conditions),
w headwind (feet/s), and
S_d input horizontal distance (feet) for the segment.

For non-ISA conditions, the segment's ISA deceleration is held constant and the segment length is adjusted. The new segment length (horizontal distance) is calculated as:

$$s_{dadjusted} = \frac{\left(\left(\frac{v_2}{\sigma_{actual}^{1/2}} - w\right)\cdot\frac{101.2686}{60}\right)^2 - \left(\left(\frac{v_1}{\sigma_{actual}^{1/2}} - w\right)\cdot\frac{101.2686}{60}\right)^2}{2\cdot a_{ISA}} \qquad \text{Eq. 2-56}$$

where

$s_{adjusted}$ segment length (feet),
v_1 input initial calibrated airspeed (knots),
v_2 input final calibrated airspeed (knots),
σ_{actual} air density ratio at segment altitude (for actual airport conditions),
w headwind (feet/s), and
a_{ISA} acceleration for ISA conditions (feet/s^2).

The level-decel segment thrust is calculated with SAE-AIR-1845 equation (A15) with an additional acceleration term and zero climb angle:

$$\frac{F_n}{\delta} = \frac{\left(\frac{W}{\delta}\right)\cdot\left(R_f + \frac{a}{g}\right)}{N} \qquad \text{Eq. 2-57}$$

where

F_n / δ corrected net thrust per engine,
W aircraft weight,
δ pressure ratio at segment's altitude,
N number of engines,
R drag over lift coefficient that depends on flaps and gear setting,
a aircraft acceleration along the velocity vector, and
g acceleration due to gravity.

2.3.15 Level-Idle Segment

For a level-idle segment the segment length, initial true airspeed, and segment altitude are user inputs. The initial true airspeed and segment altitude must match the final values from the previous segment. The final altitude is set equal to the initial value, the final true airspeed is set equal to the initial true airspeed of the following segment, and the segment's idle thrust values are calculated.

The level-idle segment is calculated and then it is broken into two sub-segments. The first sub-segment is assigned a 1000-foot ground distance. The corrected net thrust at the beginning of this segment is equal to the final value from the previous segment, and the corrected net thrust at the end of 1000 feet is set equal to the calculated initial idle thrust value. (If the original horizontal distance is less than 2000 feet, one half of the segment distance is used to transition the thrust.) The final thrust on the second sub-segment is set to the calculated final idle thrust value.

Another 1000-foot sub-segment restores the thrust from the final idle thrust value to the appropriate initial thrust for the following segment, but this sub-segment is created in the following segment.

As for level-decel segments, the INM assumes that the procedural profile using the level-idle segment was defined for ISA reference conditions at a sea-level airport. The deceleration that results over the segment given sea-level ISA conditions is assumed to remain constant even under non-sea level, non-ISA conditions, and other segment parameters are therefore modified for consistency under these conditions. The segment length for level-idle segments flown under non-ISA conditions is calculated using Eq. 2-56 and 2-57 from Section 2.3.14.

Idle thrust values for level-idle segments are calculated using SAE-AIR-1854 equation (A1) using idle thrust coefficients, which are unique to each aircraft type (see Eq. 2-8 in Section 2.3.4). The initial and final idle thrust values are calculated using the constant segment altitude and the initial and final speed values as appropriate.

2.3.16 Cruise-Climb Segment

For a cruise-climb segment, the initial altitude, true airspeed, and thrust are given from the previous segment. The final altitude A_2, final calibrated airspeed v_2, and climb angle γ are user inputs (the initial and final calibrated airspeeds must be the same). The final true airspeed, final thrust, and horizontal distance are calculated. Cruise-climb thrust is less than "maximum-takeoff" or "maximum-climb" departure thrust.

The final corrected net thrust per engine is calculated by using by using SAE-AIR-1845 equation (A15) with an additive term for climb thrust:

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{\left(\frac{W}{\delta_2}\right)\cdot\left[R_f + \frac{\sin(\gamma)}{0.95}\right]}{N} \qquad \text{Eq. 2-58}$$

where

- $(F_n/\delta)_2$ corrected net thrust per engine (lb) at altitude A_2,
- W profile weight (lb),
- δ_2 pressure ratio at altitude A_2,
- R_f drag-over-lift coefficient that depends on flaps and gear setting,
- γ average climb angle (a positive value), and
- N number of engines.

The horizontal distance is calculated by:

$$S_{cc} = \frac{(A_2 - A_1)}{\tan(\gamma)} \qquad \text{Eq. 2-59}$$

where

- S_{cc} horizontal distance (feet) for the cruise-climb segment, and
- A_1 initial altitude (feet) MSL, and
- A_2 final altitude (feet) MSL ($A_1 < A_2$).

2.3.17 Landing Segment

For a landing segment, the initial and final altitudes are given (the airport elevation), the initial (landing) speed is calculated, the final roll-out true speed is calculated from user-input calibrated speed v_2, the initial (landing) thrust is calculated, the final thrust is calculated from a user-input percentage value P, and the ground-roll distance S_b is user input.

The landing calibrated airspeed is calculated by using SAE-AIR-1845 equation (A13):

$$v_1 = D_f \cdot W^{½} \qquad \text{Eq. 2-60}$$

where

- v_1 calibrated airspeed (knots) just before landing,
- D_f landing coefficient that depends on the flaps and gear setting, and
- W approach profile weight (lb); weight is assumed to remain constant for the entire approach profile.

The initial and final true speeds are calculated by:

$$v_{T1} = v_1 \cdot \sigma^{-½} \qquad \text{Eq. 2-61}$$

$$v_{T2} = v_2 \cdot \sigma^{-½} \qquad \text{Eq. 2-62}$$

where

- σ density ratio at airport altitude.

The initial thrust $(F_n/\delta)_1$ is calculated using the descent thrust equation with the landing descent angle, landing calibrated airspeed v_1, and airport elevation (see Section 2.3.9).

The user-input percentage of thrust may also be used to calculate the final thrust for the landing segment represents the level of reverse thrust, if supplied by the user. The final thrust $(F_n/\delta)_2$ is calculated by:

$$\left(\frac{F_n}{\delta}\right)_2 = F_S \cdot \left(\frac{P}{100}\right) \qquad \text{Eq. 2-63}$$

where

- $(F_n/\delta)_2$ corrected net thrust per engine (lb) at end of landing roll-out,
- F_S static corrected net thrust per engine (an input parameter), and
- P percentage of thrust (an input parameter).

If the aircraft NPD curves are in percent, the value of "thrust" that is actually assigned to the flight segment is the percentage value P; it is used to directly access the noise tables.

2.3.18 Decelerate Segment

For a deceleration segment, the initial and final altitudes are given (the airport elevation), the initial speed is given from the previous step, and the final speed is calculated from user-input calibrated speed and density ratio. The initial thrust is given from the previous step, the final thrust is calculated from user-input percentage of thrust (see Section 2.3.17), and the ground-roll distance is user input.

2.4 Helicopter Flight Profiles

INM supports only one kind of flight profile input data for helicopters: an ordered set of procedure steps. Compared to fixed-wing aircraft, helicopter procedure steps are more similar to fixed-wing profile points than fixed-wing procedure steps. Like fixed-wing profile points, helicopter procedure steps explicitly define the flight profile, do not involve any flight performance calculations within the INM, and are not modified by the INM to account for non-standard atmospheric conditions. Unlike fixed-wing profile points, helicopter procedure steps are modal; they are defined as a set of procedure steps that each represents a helicopter flight operational mode.

The NPD data for helicopters used by the INM references operational modes and not thrust values. Each helicopter operational mode has its own NPD curve that defines the source noise for that mode. There is only one NPD curve per mode, therefore there is no interpolation or extrapolation across helicopter NPD curves in the INM. Thrust is not included in helicopter flight profiles.

2.4.1 Helicopter Procedure Steps

Helicopter flight profiles can only be specified in terms of procedure steps. INM processes the steps one at a time to calculate profile points, putting them in a format that differs slightly from the fixed-wing aircraft profile point format described in Section 2.3.1.

An ordered set of helicopter procedure steps specifies a two-dimensional trajectory. For each point, the following data are given:

d	horizontal coordinate (feet) relative to an origin,
z	altitude of the helicopter above the helipad (feet AFE),
v_T	helicopter true airspeed at the point (knots),
Mode	helicopter operational mode, and
t_{seg}	time spent at a location for static operational modes (sec).

The origin is where the d-coordinate is equal to zero, and it depends on the kind of flight operation:

An approach origin is at the touchdown point, and d-values are negative during descent.
A departure origin is at the starting point on a helipad, and d-values are positive.
A taxi origin is at the starting point on a helipad, and d-values are positive all the way to the end-point on the same or different helipad.
An overflight origin is at the first point, and d-values are positive.

For all types of operations, d-values increase as a helicopter flies along its profile.

Profile speed is the speed at the profile point; it is the magnitude of the helicopter velocity vector.

It is the same as true airspeed with no wind, and the sections below refer to profile speed as true airspeed (TAS). Profile speed is approximately equal to ground speed, except when climbing or descending at steep angles.

The helicopter operational mode for each profile segment is used to specify which helicopter NPD curve to use for that segment. Each helicopter operational mode has a single corresponding NPD curve.

Helicopter procedure steps explicitly define a helicopter's flight profile. There are no thrust, altitude, or speed calculations for helicopter flight profiles as there are for fixed-wing aircraft. The four types of helicopter flight operations (APP, DEP, TAX, OVF) are created by using 14 types of procedure steps:

1. Start Altitude: This step is used to start a profile at a given altitude and speed. The starting altitude and speed are inputs.
2. Level Fly: This step is used to maintain altitude and speed for a given distance. The track distance covered by the step is the only input. Altitude and speed are defined by the previous step.
3. App Const Speed: This step is used to descend at constant speed to a given altitude over a given distance. The track distance covered by the step and the final altitude are inputs. The initial altitude and speed are defined by the previous step.
4. App Desc Decel: This step is used to descend and decelerate to a final altitude and speed over a given distance. The track distance covered by the step, the final altitude, and the final speed are inputs. The initial altitude and speed are defined by the previous step.
5. App Horiz Decel: This step is used to decelerate to a final speed at constant altitude over a given distance. The track distance covered by the step and the final speed are inputs. The altitude and initial speed are defined by the previous step.
6. App Vertical: This step is used to maintain horizontal position while descending to a final altitude over a given duration. The duration of the step and the final altitude are inputs. The horizontal position of the step is calculated from the previous step and the horizontal speed is zero.
7. Hover: This step is used to maintain altitude and horizontal position for a given duration. The duration of the step is the only input. The altitude is defined by the previous step, the horizontal position of the step is calculated from the previous step, and the horizontal speed is zero.
8. Ground Idle: This step is used to maintain ground idle for a given duration. The duration of the step is the only input. The altitude is zero, the horizontal position of the step is calculated from the previous step, and the horizontal speed is zero.
9. Flight Idle: This step is used to maintain flight idle for a given duration. The duration of the step is the only input. The altitude is zero, the horizontal position of the step is calculated from the previous step, and the horizontal speed is zero.
10. Dep Vertical: This step is used to maintain horizontal position while ascending to a final altitude over a given duration. The duration of the step and the final altitude are inputs. The horizontal position of the step is calculated from the previous step and the horizontal speed is zero.

11. Dep Horiz Accel: This step is used to accelerate to a final speed over a given distance. The track distance covered by the step and the final speed are inputs. The altitude and initial speed are defined by the previous step.
12. Dep Climb Accel: This step is used to climb and accelerate to a final altitude and speed over a given distance. The track distance covered by the step, the final altitude, and the final speed are inputs. The initial altitude and speed are defined by the previous step.
13. Dep Const Speed: This step is used to climb at constant speed to a given altitude over a given distance. The track distance covered by the step and the final altitude are inputs. The initial altitude and speed are defined by the previous step.
14. Taxi: This step is used to taxi at a given constant speed. The speed is the only input. The track distance is calculated based on the assigned taxi ground track, and the altitude is defined by the previous step. INM allows helicopters defined as having wheels to taxi at zero altitude. Helicopters defined as not having wheels must taxi at an altitude greater than zero.

Some helicopter procedure steps correlate with different helicopter flight operational modes (and therefore different NPD and directivity data) depending on their altitude. When constructing flight paths with the Hover, Dep Vertical, and App Vertical procedure steps, the INM calculates a ground effect altitude as follows:

$$A_{GE} = 1.5 \cdot (D_{MR}) \qquad \text{Eq. 2-64}$$

where

A_{GE} ground effect altitude (feet above field elevation), and
D_{MR} main rotor diameter (eeft, an input parameter),

If the procedure step stays below the ground effect altitude, the procedure step correlates with the corresponding In Ground Effect flight operational mode. If the step stays at or above the ground effect altitude the procedure correlates with the corresponding Out of Ground Effect flight operational mode. If a given Dep Vertical or App Vertical procedure step crosses the ground effect altitude, the INM automatically divides the step into two at the ground effect altitude and assigns flight operational modes to the two steps as appropriate.

INM does not correct for non-standard temperature and pressure when generating helicopter flight profiles. This means that the input values of altitude, speed, and duration are used exactly as specified regardless of the atmosphere defined.

2.5 Flight Path Calculation

An INM flight path is an ordered set of flight path segments. Each segment contains the following data:

x_1, y_1, z_1 starting coordinates for the segment (feet, feet, feet),
u_x, u_y, u_z unit vector directed along the segment,
L length of the segment (feet),
v_{T1} speed (knots) at the starting point, relative to x,y,z coordinates,

Δv	change in speed (knots) along the segment:
	$\Delta v = v_{T2} - v_{T1}$ Eq. 2-65
$(F_n/\delta)_1$	corrected net thrust per engine (lb, %, or other) at the starting point, and
ΔF	change in corrected net thrust per engine (lb, %, or other) along the segment:
	$\Delta F = \left(\frac{F_n}{\delta}\right)_2 - \left(\frac{F_n}{\delta}\right)_1$ Eq. 2-66

The starting velocity vector (v_{T1} **u**) is directed along the segment, and the aircraft is assumed to continue to fly along the segment as speed and thrust change. Segment true airspeed and length are used in the noise module to calculate the segment flying-time duration that a ground-based observer would experience.

Corrected net thrust per engine is in units of pounds, percent of static thrust, or other units, depending on the units defining the NPD curves.

Three-dimensional flight path segments are constructed by using ground track data and flight profile data, as presented in the sections below.

2.5.1 Ground Track Processing

INM supports two kinds of ground tracks: (1) an ordered set of x,y points, and (2) an ordered set of vectoring commands (for example, fly straight 5.5 nmi, turn left 90° using radius 2.0 nmi).

INM transforms the vectoring commands into a set of x,y points. To do this, INM converts circular segments into multiple straight lines, processes approach tracks so that they line up with the runway, adds leader lines to approach tracks, and adds follower lines to departure tracks.

The details of circular arc conversion are presented in Section 2.5.2 below.

When processing an approach vector track, INM starts the track at the origin and heads north. After all of the x,y points are calculated, the entire set of track points is rotated and translated to line-up with the approach end of the runway. INM makes the last track point coincide with the displaced approach threshold point on the runway. Then, a 200-nmi leader line is added to the beginning of the approach track (a new first point is added), so that the ground track is always longer than a profile.

When processing a departure vector track, INM makes the first track point coincide with the displaced takeoff threshold point on the runway. A 200-nmi follower line is added to the end of a departure or overflight track, so that the ground track is always longer than a profile. Touch-and-go ground tracks are not extended.

2.5.2 Circular Arc Conversion

INM approximates a circular-arc ground track with two or more straight-line segments. The method of Reference 26 is used. First, the number of sub-arcs contained in the circular arc is computed:

$$N = \text{int}\left(1 + \frac{A}{40}\right) \qquad \text{Eq. 2-67}$$

where

N number of sub-arcs,
A given circular arc (degrees), and
int(x) function that returns the integer part of x.

Then, the angular size of each sub-arc is computed:

$$\alpha = \frac{A}{N} \qquad \text{Eq. 2-68}$$

For each sub-arc, three x,y points are computed. These three points define two line segments. The first point is at the start of the sub-arc, and the third point is at the end of the sub-arc. The second point is half-way along the sub-arc, but not located on it. The distance from the center of the sub-arc to the second point, instead of being the arc radius, is computed by:

$$r_2 = r \cdot \left[\cos\left(\frac{1}{2} \cdot \alpha\right) + \left(\frac{1}{4} \cdot \alpha^2 - \sin^2\left(\frac{1}{2} \cdot \alpha\right)\right)^{½} \right] \qquad \text{Eq. 2-69}$$

where

r_2 distance from the center of the sub-arc to the second point,
r radius of the sub-arc, and
α magnitude of the sub-arc (radians).

This method ensures that a line segment replaces not more than 20 degrees of turn angle. Also, the sum of the lengths of the line segments equals the distance along the arc, so that the flying time along the line segments is the same as the time that would be flown along the circular arc.

2.5.3 3-D Flight Path Construction

A three-dimensional flight path is constructed by merging a two-dimensional profile (a set of distance vs. altitude points) with a two-dimensional ground track (a set of x,y points). Wherever there is a track point, a z-value is computed by interpolating between two points on the profile. Wherever there is a profile point, x,y values are computed on the ground-track segment under the profile point. The result of this construction is an ordered set of x,y,z points and associated speed and thrust data that describe the flight path.

When a track point lies between two profile points, a linear interpolation method is used to calculate the altitude, speed, and thrust at that point:

$$z = z_1 + f \cdot (z_2 - z_1) \qquad \text{Eq. 2-70}$$

$$v_T = v_{T1} + f \cdot (v_{T2} - v_{T1}) \qquad \text{Eq. 2-71}$$

$$\left(\frac{F_n}{\delta}\right) = \left(\frac{F_n}{\delta}\right)_1 + f \cdot \left[\left(\frac{F_n}{\delta}\right)_2 - \left(\frac{F_n}{\delta}\right)_1\right] \qquad \text{Eq. 2-72}$$

where

- z — altitude at the interpolated point (ft AFE),
- f — fraction of the distance from profile point 1 to the interpolated point divided by the distance from profile point 1 to point 2,
- z_1, z_2 — initial and final profile altitudes (ft AFE),
- v_T — speed at the interpolated point (knots),
- v_{T1}, v_{T2} — initial and final profile point speeds (knots),
- F_n/δ — corrected net thrust per engine (lbs) at the interpolated point, and
- $(F_n/\delta)_1$, $(F_n/\delta)_2$ — initial and final profile point corrected net thrust per engine (lbs).

2.5.4 Displaced Thresholds and Threshold Crossing Heights

A departure flight path starts at a given distance from the departure end of the runway:

$$D = D_{dep} + \Delta_{trk} \qquad \text{Eq. 2-73}$$

where

- D — start-roll distance (feet) from the end of the runway,
- D_{dep} — displaced departure threshold (feet) for the runway (user input), and
- Δ_{trk} — delta distance (feet) for the departure ground track (user input).

An approach or touch-and-go flight touches down on the runway a given distance from the approach end of the runway:

$$D = D_{app} + \Delta_{trk} + \frac{h_{tc} \cdot |d_{-1}|}{z_{-1}} \qquad \text{Eq. 2-74}$$

where

- D — touch-down distance (feet) from the end of the runway,
- D_{app} — displaced approach threshold (feet) for the runway (user input),
- Δ_{trk} — delta distance (feet) for the approach ground track (user input),
- h_{tc} — threshold crossing height (feet) for the runway (user input),
- d_{-1} — coordinate value (feet) of the profile point immediately before the touch-down point (it is a negative number), and
- z_{-1} — altitude (feet AFE) of the profile point immediately before the touch-down point (the touch-down point has coordinates: $d_o = 0$, $z_o = 0$).

2.5.5 Touch-and-Go and Circuit Flight Path Methods

INM uses special processing to construct touch-and-go and circuit flight paths.

A user-defined touch-and-go profile starts in level flight at airport pattern altitude, descends, touches down on the runway, rolls out, takes off, climbs, and ends somewhere after leveling off at pattern altitude. After associating a touch-and-go profile with a touch-and-go track, but before calculating flight path points, INM reorders and modifies the set of profile points so that the profile starts and ends at the touchdown point. While reordering the points, INM inserts an extra level segment in the downwind portion of the profile (between the last departure point and first approach point), so that the profile distance is the same as the track distance. Also, a final touchdown point is added at the end. When finished, the new profile starts at touchdown, ends at touchdown, and has horizontal coordinate distance equal to the touch-and-go ground track distance.

A user-defined circuit profile starts on the runway as a standard departure, takes off, climbs to pattern altitude, levels out, descends from pattern altitude, lands, and decelerates to taxi speed. After associating a circuit profile with a touch-and-go track (there are no circuit tracks), INM inserts an extra level segment in the downwind portion of the profile, so that the profile distance is the same as the track distance. The place where the extra segment is inserted is determined by the "level-stretch" procedure step, which is provided by the user.

After modifying a touch-and-go or circuit profile, INM merges the new profile points and the ground track points to compute a three-dimensional flight path.

2.5.6 Segments Too Short and Too Long

After INM constructs the ordered set of flight path points, they are processed to remove points that are too close together. If two (x,y,z) points are closer than 10 feet, and if the speed and thrust data are the same, one of the points is removed from the set of points.

The last step in constructing a flight path is to insert points into segments that are too long. A path segment is subdivided if its length multiplied by the change in speed is greater than 100000 foot-knots. The number of sub-segments is calculated by:

$$N = \text{int}\left(1 + \left[\frac{(v_{T2} - v_{T1}) \cdot L}{100000}\right]^{½}\right) \qquad \text{Eq. 2-75}$$

where

N	number of equal-distance sub-segments,
int(x)	function that returns the integer part of a number x,
v_{T1}	initial speed (knot),
v_{T2}	final speed (knot), and
L	length of the segment (feet).

If the flight path segment is subdivided, the speed and thrust values at the end points of the equal-distance sub-segments are linearly interpolated by using the initial and final end-point values.

2.6 Bank Angle Calculation

INM bank angle calculation methods are based on the guidance provided in the European Civil

Aviation Conference (ECAC) Doc 29[2] (B-8):

$$\varepsilon = \tan^{-1}\left(\frac{2.85 \cdot {v_g}^2}{r \cdot g}\right) \qquad \text{Eq. 2-76}$$

where

- ε bank angle (positive in a left turn and negative in a right turn),
- v_g ground speed (knots),
- r turn radius (feet), and
- g acceleration due to gravity (feet/s^2).

Two important assumptions inherent in the equation are: 1) that the aircraft is in a coordinated turn where the velocity vector is always aligned with the aircraft roll axis, and 2) that speed and acceleration in the vertical plane is insignificant. The flight procedures typically used in close proximity to airports do not result in large speed and acceleration values in the vertical plane.

Another important consideration is that bank depends on both the flight profile (because speed appears in the equation) and the flight track (because turn radius appears in the equation). The turn radius ➹ is obtained from the flight track. INM supports two types of flight tracks: points-type tracks and vector-type tracks. Vector-type tracks have a user-defined turn radius for each turn segment, so the radius at any point on the track is a known quantity. Turn radius can be obtained from points-type tracks, but the calculations are sensitive to fluctuations in the track data and ambiguity around where turns begin and end. The INM method for calculating turn radius from a points-type track is described in the next section.

2.6.1 Calculating Turn Radius From a Points-Type Track

Deriving a turn radius from "clean" points-type track data is straightforward, but complications arise when there are fluctuations in the data or points are spaced unevenly. The radius calculation method in INM Version 7.0 makes tradeoffs between ease-of-use, assumptions about track data quality, and calculation complexity.

INM uses a radius calculation method that was designed to meet three objectives:

1. Automated: user interaction should not be required.
2. Flexible: the method must accommodate points-type tracks from a variety of sources, including radar data, user inputs through the INM interface, and computer-generated points.
3. Realistic: "Clean" input tracks should result in realistic radius calculations, and "bad" data with gaps or noise should result in feasible bank output, with warnings.

These objectives are met through a three step process. First, track points are interpolated to a regular point spacing. Second, turn radius and bank are calculated, smoothed, and filtered. Third, path points are interpolated back to the original point spacing.

The first interpolation step is designed to reduce fluctuations in the track data, fill in gaps, and provide evenly-spaced points for smoothing. The track is interpolated at 0.5 nautical mile intervals with cubic splines. A cubic spline is analogous to stretching a flexible piece of plastic so that it contacts all the track points. The interpolated track is smooth and continuous in the first derivative, and continuous in the second derivative, which eliminates sharp corners in the flight track that would be impossible for an aircraft to follow. Curvature derivatives are undefined at the track endpoints, so the second derivatives are set to zero, which is called the "natural" endpoint condition.

The next step is to calculate turn radius at each point by considering three consecutive track points at a time. The turn radius is equal to the radius of a circle passing through the three points. The circle radius r is calculated as follows:

$$r = \frac{a \cdot b \cdot c}{4 \cdot K} \qquad \text{Eq. 2-77}$$

where

a, b, c distances between three consecutive points in the track, and
K area of a triangle formed by the points.

The calculated radius is assigned to the middle point, and the process is repeated for each set of three consecutive track points. The first and last points have an undefined radius, so the bank at these points is set to zero.

2.6.2 Bank Smoothing and Filtering

Once the turn radius is determined then the bank is easily calculated with speed and the gravitational acceleration. However, the turn radius calculation is sensitive to fluctuations in the aircraft position and speed, which will cause the calculated bank to have unrealistic spikes. INM attempts to remove fluctuations in the bank angle through exponential smoothing. Exponential smoothing is similar to a moving average except that points are weighted exponentially. The smoothed value is calculated recursively as follows:

$$\varepsilon_{si} = (1-b) \cdot \varepsilon_i + b \cdot \varepsilon_{si-1} \qquad \text{Eq. 2-78}$$

where

ε_{si} smoothed bank value,
b smoothing parameter,
ε_i unsmoothed bank value, and
ε_{si-1} previous smoothed value.

This formulation requires data that is evenly spaced, a condition that was enforced with the first interpolation step. The smoothing parameter b can have a range of values between 0 and 1. At $b = 0$ there is no smoothing, and at $b = 1$ all of the smoothed values are equal to the initial value. Between b values of 0 and 1, there are varying degrees of smoothing.

Ideally the smoothing parameter b will be high enough to remove noise, yet low enough to retain banking during turns. The parameter is selected automatically in INM by using a variant of the signal to noise ratio on the calculated bank. The fluctuation magnitude N is defined as:

$$N = \frac{\text{median}(|\text{diff}(\varepsilon)|)}{\text{stdev}(\varepsilon)} \qquad \text{Eq. 2-79}$$

where

stdev standard deviation, and
diff point-by-point difference:

$$\text{diff}(\varepsilon_i) = \varepsilon_{i+1} - \varepsilon_i \qquad \text{Eq. 2-80}$$

Once noise is calculated, the smoothing parameter is set to the smaller of two values:

$$b = \min(0.25 \cdot N, 0.5) \qquad \text{Eq. 2-81}$$

This step limits the smoothing value to be between 0 and 0.5 no matter how high the fluctuation magnitude is.

The smoothing process is repeated ten times, forward and backward. The backward step removes biases introduced in the forward step. Repeated smoothing with a lower **Z** value tends to reject high-frequency fluctuations more effectively than smoothing once with a higher **Z** value.

After smoothing, the bank angles are filtered to ensure that data are compatible with typical flight operations. If the bank changes sign twice within a 30 second window then the bank is set to zero over the entire window. This step removes high-frequency oscillations caused by fluctuating data, while it tends to preserve actual aircraft banking.

At the beginning of the process the profile points were interpolated to have a consistent 0.5 nautical mile spacing. In the next step the bank angle is re-interpolated back to the original path points.

The final step is to cut off extreme bank values. If the bank angle exceeds a limit (+/– 30 degrees) the bank is set to the limit value and a single warning is written to the INM warning file. Warnings may indicate a flight path with unrealistic combinations of turn radii and airspeed. If the flight path uses a points-type track then fluctuations in the track data may result in unrealistic turn radii and extreme bank angles. Fluctuations may be eliminated by replacing the points-type track with a vector track.

2.7 Bank Angle Performance Effects

Aircraft banking affects flight performance because a portion of the aircraft's lift is directed horizontally instead of vertically. Aircraft performance is calculated under the assumption that the aircraft is not banking, so the calculated aircraft flight path must be adjusted to be consistent with banking.

2.7.1 Approach

To account for the effects of bank angle on approach flight paths, INM increases thrust so that forces (thrust, drag, lift, and weight) are in balance. The final thrust for each flight path segment Fn/d2 is recalculated using the following force balance equation:

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{W}{\delta \cdot N}\left(\frac{a}{g} + \frac{R_f \cdot u_h}{\cos(\varepsilon)} + u_v\right) \qquad \text{Eq. 2-82}$$

where

F_n / δ final corrected net thrust per engine (lb),
δ pressure ratio at aircraft altitude,
N number of engines,
W aircraft weight (lb),
a aircraft acceleration along the velocity vector (feet/s^2),
g acceleration due to gravity (feet/s^2),
R_f drag over lift coefficient that depends on flaps and gear setting,
u_v vertical component of the aircraft unit speed vector,
ε aircraft bank angle, and
u_h horizontal component of the unit speed vector, so

$$u_h = \left(1 - u_v^{\,2}\right)^{1/2}. \qquad \text{Eq. 2-83}$$

2.7.2 Departure

To account for the effects of bank angle on departure flight paths, INM reduces the climb angle and speed in order to balance the forces. Thrust and acceleration are not altered. However, reduced speed results in a reduced bank angle because bank is a function of speed. This circular relationship is resolved with an iterative solution to the following equation:

$$\frac{R \cdot \cos(\gamma_2)}{\cos(\varepsilon_1)} + \sin(\gamma_2) = R \cdot \cos(\gamma_1) + \sin(\gamma_1) \qquad \text{Eq. 2-84}$$

where

ε_1 aircraft bank angle at start of segment after smoothing and filtering,
γ_1 climb angle at start of segment, and
γ_2 climb angle at end of segment.

Note that $\sin(\gamma_2)$ can be rewritten in terms of $\cos(\gamma_2)$ with the following substitution:

$$\sin(\gamma_2) = \left(1 - \cos^2(\gamma_2)\right)^{1/2} \qquad \text{Eq. 2-85}$$

After the substitution only $\cos(\gamma_2)$ is unknown. The value of γ_2 is iterated by requiring that it is less than or equal to γ_1:

$$\gamma_2 = \begin{cases} \gamma_1 & \text{if } \gamma_2 > \gamma_1 \\ \gamma_2 & \text{otherwise} \end{cases} \qquad \text{Eq. 2-86}$$

Since γ_2 must be less than or equal to γ_1 then the original segment length L must decrease or remain unchanged. The new segment length L_{new} is calculated as follows:

$$L_{new} = L \cdot \frac{\cos(\gamma_1)}{\cos(\gamma_2)} \qquad \text{Eq. 2-87}$$

Acceleration is held constant, so the new segment length must coincide with a change in endpoint speed to maintain consistency:

$$v_2 = \left(v_1^{\ 2} + 2 \cdot a \cdot L_{new}\right)^{1/2}$$ Eq. 2-88

where

- a — aircraft acceleration along the velocity vector,
- v_1 — aircraft true airspeed at start of segment, and
- v_2 — aircraft true airspeed at end of segment.

The segment speed along the horizontal plane is then

$$v_g = \left(\cos(\gamma_2)\right)\left(v_1 + v_2\right)/2$$ Eq. 2-89

The segment speed can be used with Equation 2-77 to calculate a new bank angle at the end of the segment ε_2.

Iteration continues until the thrust error falls within an acceptable threshold, which is 100 lbs in INM. Thrust error is the difference between the pre-adjustment thrust and the recalculated thrust derived from the adjusted bank and speed values. Thrust error is calculated as follows:

$$F_{error} = W \cdot \left(\frac{a}{g} + \frac{R \cdot \cos(\gamma_2)}{\cos(\varepsilon_2)} + \sin(\gamma_2) \right) - F_{segment}$$ Eq. 2-90

where

- a — aircraft acceleration along the velocity vector,
- g — acceleration due to gravity,
- F_{error} — uncorrected thrust error for all engines, and
- $F_{segment}$ — uncorrected average thrust over the segment for all engines.

The segment average thrust is calculated with the uncorrected total thrust for all engines at the start and end of the segment:

$$F_{segment} = \frac{N}{2} \cdot \left(\delta_1 \cdot \left(\frac{F_n}{\delta}\right)_1 + \delta_2 \cdot \left(\frac{F_n}{\delta}\right)_2 \right)$$ Eq. 2-91

where

- N — number of engines,
- δ_1, δ_2 — pressure ratios at beginning and end of the segment,
- $(F_n/\delta)_1$ — corrected net thrust per engine at beginning of the segment, and
- $(F_n/\delta)_2$ — corrected net thrust per engine at end of the segment.

3 ACOUSTIC COMPUTATION METHODOLOGY

Chapter 3 describes the acoustic computation methodology employed by INM. The starting point for these calculations is a noise database that provides aircraft source noise characteristics. The INM noise database includes noise-power-distance data (see Section 2.2.1) and aircraft spectral class data (see Section 2.2.2). The following sections describe the generation of noise-level and time-based metrics at a single observer, or at an evenly-spaced regular grid of observers, including the regular grid of observers that is used in the development of the recursively-subdivided irregular grid for noise contour analysis. Much of the discussion presented herein is based on information given in Reference 1.

Chapter 3 contains the following sections:

Section #	**Description**
Section 3.1	Gives an overview of the INM reference data.
Section 3.2	Describes the computation of the flight path segment geometric and physical parameters.
Section 3.3	Describes the flight path segment noise interpolation/extrapolation process.
Section 3.4	Describes general adjustments applicable to all aircraft.
Section 3.4.1	Describes the atmospheric absorption adjustment of NPD data, based on user-supplied local temperature and relative humidity.
Section 3.4.2	Describes a temperature/pressure dependent NPD acoustic impedance adjustment.
Section 3.4.3	Describes the computation of the flight-segment noise fraction adjustment for exposure-based noise level metrics.
Section 3.4.4	Describes the computation of the aircraft speed duration adjustment for exposure-based noise level metrics.
Section 3.4.5	Describes the computation of the lateral attenuation adjustment.
Section 3.4.6	Describes the computation of the line-of-sight blockage adjustment.
Section 3.5	Describes adjustments applicable only to fixed-wing aircraft.
Section 3.5.1	Describes the computation of the thrust reverser adjustment during the landing ground roll.
Section 3.5.2	Describes the ground-based directivity adjustment behind the start-of-takeoff roll, and the computations of metrics for runup operations.
Section 3.6	Describes adjustments applicable only to helicopters.
Section 3.6.1	Describes the source noise adjustment for in-flight helicopter operations.
Section 3.6.2	Describes the Lateral Directivity adjustment for in-flight helicopter operations.

Section #	Description
Section 3.6.3	Describes the idle and hover directivity adjustments for static helicopter operations.
Section 3.6.4	Describes the duration adjustment for static helicopter operations.
Section 3.7	Describes the computation of exposure-based noise level metrics.
Section 3.7.1	Describes the computation of system/study level adjustments used to compute the exposure-based noise level metrics
Section 3.7.2	Describes how the flight-segment computations of Sections 3.2 through 3.5 are used to compute the exposure-based noise level metrics for fixed-wing aircraft.
Section 3.7.3	Describes the computation of the exposure-based noise level metrics for fixed-wing aircraft during runup operations.
Section 3.7.4	Describes how the flight-segment computations of Sections 3.2 through 3.4 and 3.6 are used to compute the exposure-based noise level metrics for helicopters.
Section 3.7.5	Describes the computation of the exposure-based noise level metrics for helicopters during static operations.
Section 3.8	Describes the computation of maximum noise level metrics.
Section 3.9	Describes the computation of time-based metrics.

Figure 3-1 graphically summarizes the acoustic computation process employed in INM Version 7.0.

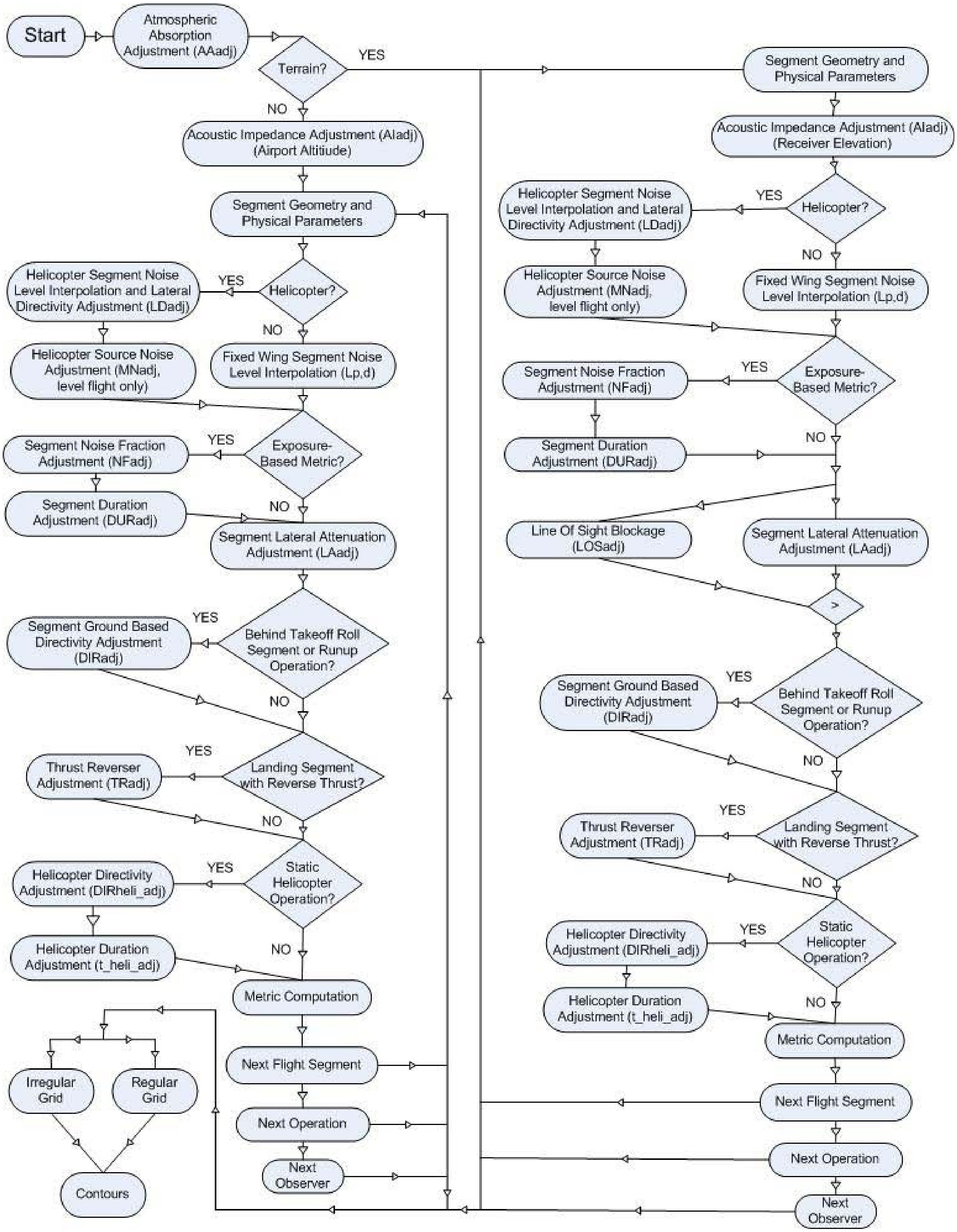

Figure 3-1: INM Version 7.0 Acoustic Computation Process

3.1 INM Reference Data

As a prerequisite to noise level computations, INM computes several geometric and physical parameters associated with an aircraft flight path. Section 3.2 describes the computation of these parameters.

INM contains an acoustic database of noise-power-distance values for fixed-wing aircraft and noise-operational mode-distance values for helicopters (both referred to as NPDs), augmented by a database of spectral characteristics. The sets of three NPD curves for dynamic helicopter operations are used to model the asymmetrical helicopter directivity, in conjunction with the Lateral Directivity Adjustment (see Section 3.6.2). Helicopter static operations are modeled with a single set of NPD curves, and directivity is accounted for with a Static Directivity Adjustment presented in Section 3.6.3.

INM provides separate NPD/Spectral class data sets for approach, departure, level flight and afterburner conditions, to model additional changes in aircraft state not captured by power setting alone.

The input data for all acoustic calculations in the INM include both the reference NPD data sets (Section 2.2.1) and Spectral Class data sets (Section 2.2.2).

3.2 Flight Path Segment Parameters

As a prerequisite to noise level computations, INM computes several geometric and physical parameters associated with an aircraft flight path. This section describes the computation of these parameters.

Computation of the following flight-segment geometric parameters is presented in Section 3.2.1: (1) the closest point of approach on the flight-path segment, or the extended flight-path segment, to the observer; and (2) the slant range from the observer location to the closest point of approach.

Computation of the following flight-segment geometric and physical parameters is presented in Section 3.2.2: (1) the speed along the flight-path segment; (2) the altitude associated with the flight-path segment; (3) the over-ground, sideline distance from the observer location to the ground-projection of the closest point of approach; and (4) the engine power associated with the flight-path segment.

Figure 3-2 through Figure 3-3 present, respectively, the observer/flight-segment geometry for the three general INM cases: (1) the observer is behind the flight-path segment; (2) the observer is astride the flight-path segment; and (3) the observer is ahead of the flight-path segment.

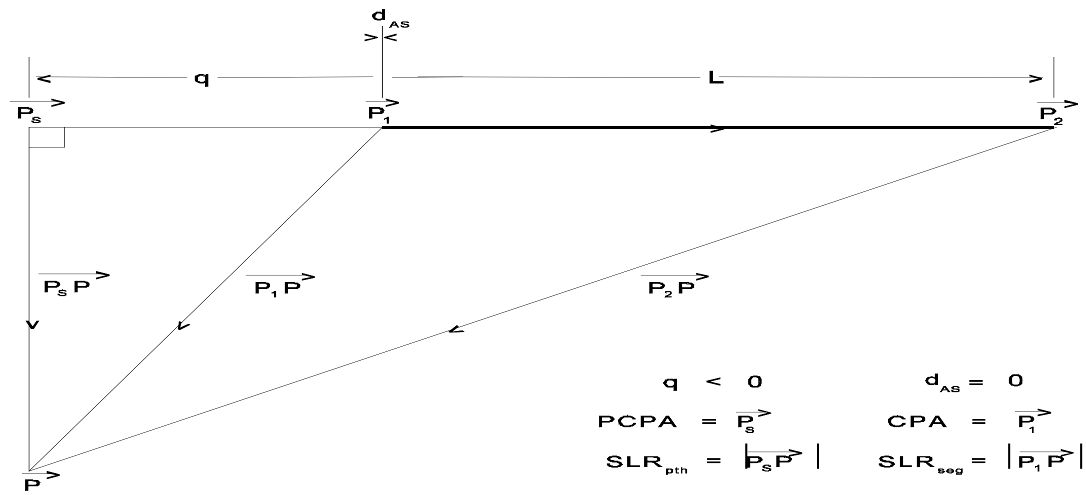

Figure 3-2: Flight–Segment Geometry when an Observer is Behind a Segment

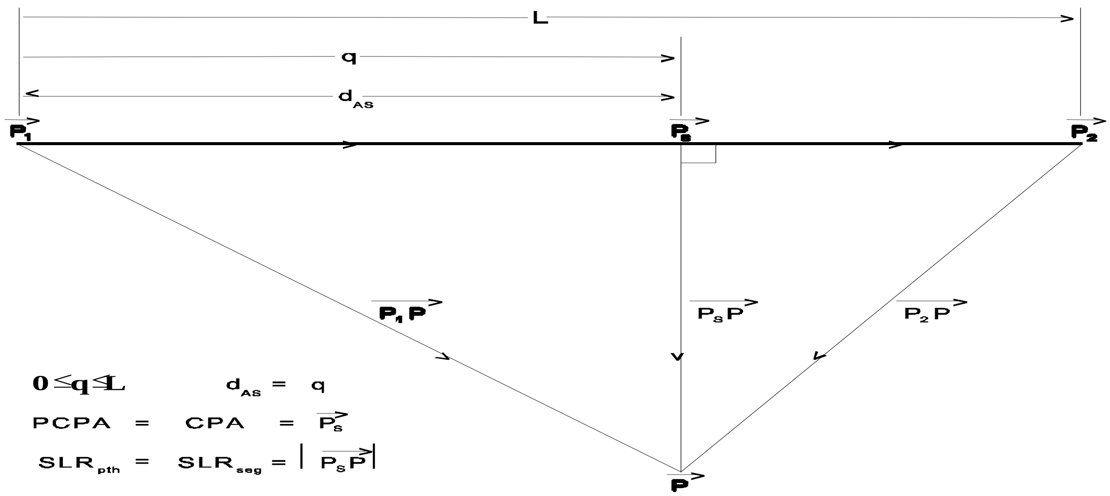

Figure 3-3: Flight–Segment Geometry when an Observer is Astride a Segment

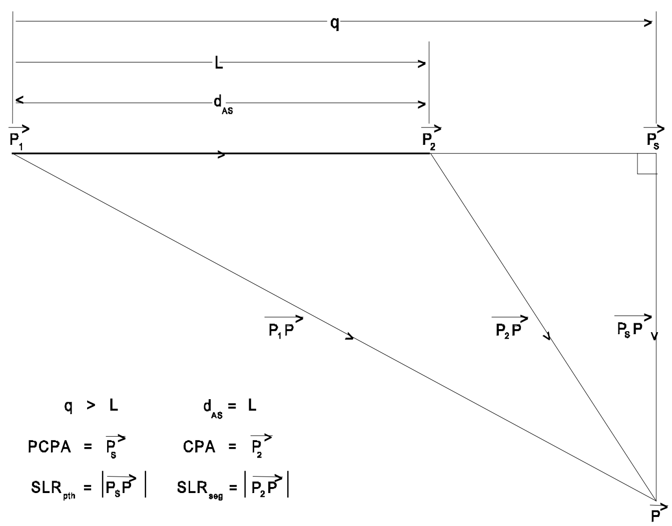

Figure 3-4: Flight-Segment Geometry when an Observer is Ahead of a Segment

The variables shown in these figures are defined as follows:

$\mathbf{P}$ observer point.
$\mathbf{P}_1$ start-point of the flight-path segment.
$\mathbf{P}_2$ end-point of the flight-path segment.

$\mathbf{P}_S$ PCPA, the point on the flight-path segment, or the extended flight-path segment, which is the perpendicular closest point of approach to the observer, as defined in detail in Section 3.2.1, below. The specific definition depends on the position of the observer relative to the flight-path segment.

$\mathbf{P}_1\mathbf{P}_2$ vector from the start of the flight-path segment to the end of the flight-path segment. It has a minimum length of 10 feet.

$\mathbf{P}_1\mathbf{P}$ vector from the start of the flight-path segment to the observer. It has a minimum length of 1 foot.

$\mathbf{P}_2\mathbf{P}$ vector from the end of the flight-path segment to the observer. It has a minimum length of 1 foot.

$\mathbf{P}_S\mathbf{P}$ perpendicular vector from the observer to PCPA on the flight-path segment, or the extended flight-path segment, as defined in detail in Section 3.2.1. It has a minimum length of 1 foot.

SLR_{pth} $|\mathbf{P}_S\mathbf{P}|$, the length of the perpendicular vector from the observer to PCPA on the flight-path segment, or the extended flight-path segment, as defined in detail in Section 3.2.1. It has a minimum value of 1 foot.

L length of the flight-path segment. It has a minimum value of 10 feet.

CPA point on the flight-path segment, not the extended flight-path segment, which is the closest point of approach to the observer, as defined in detail in Section 3.2.1, below. The specific definition depends on the position of the observer relative to the flight-path segment.

SLR_{seg} length of the vector from the observer to CPA on the flight-path segment, not the extended flight-path segment, as defined in detail in Section 3.2.1. It has a minimum value of 1 foot.

q relative distance along the flight-path segment, or the extended flight-path segment, from $\mathbf{P}_1$ to $\mathbf{P}_S$ (feet). The value of q is used to determine the position of the observer relative to the flight-path segment, as shown in Table 3-1.

d_{AS} distance along the flight-path segment from the start of the segment at $\mathbf{P}_1$, to CPA. Depending on the value of q, i.e., the relative geometry between the observer and the flight-path segment, d_{AS} takes on the values shown in Table 3-1.

Table 3-1: Position of the Observer Relative to the Flight-Path Segment

Value of q	Value of d_{AS}	Position of observer relative to flight path segment
$q < 0$	0	Observer is behind segment
$0 \le q \le L$	q	Observer is astride segment
$q > L$	L	Observer is ahead of segment

3.2.1 Closest Point of Approach and Slant Range

The closest point of approach and slant range parameters are fundamental parameters to INM computations. The slant range is used for noise-level interpolation of the NPD data (see Section 3.3). In addition, the computation of the closest point of approach and slant range parameters is a prerequisite to the noise fraction algorithm used for exposure-based metrics (see Section 3.4.3) and for lateral attenuation (see Section 3.4.5).

The slant range from the observer location to the closest point of approach on the flight path, SLR_{pth}, is defined as the distance from the perpendicular closest point of approach (PCPA), on the flight-path segment, or the extended flight-path segment, to the observer. SLR_{pth} is used for exposure-based metrics, because NPDs represent aircraft data on infinitely long flight paths, and the time-based nature of the exposure-based metrics makes the difference between finite flight-path segments (as modeled in INM) and infinite flight paths significant. To obtain the noise exposure level due to an aircraft proceeding along a finite flight-path segment in INM, the exposure-based noise-level data must be adjusted by the noise fraction adjustment, which accounts for the geometry difference between SLR_{pth} and SLR_{seg}. The specific definition of PCPA depends upon the position of the observer location relative to the flight-path segment. If the observer is behind or ahead of the flight-path segment, then PCPA is the intersection point of the perpendicular from the observer to the extended segment. If the observer is astride the flight-path segment, then PCPA is the intersection point of the perpendicular from the observer to the segment.

The exceptions to the above definition for slant range occur: (1) when the observer is behind a takeoff ground-roll segment (see Section 3.5.2); (2) for runup operations; and (3) when performing computations involving L_{ASmx}, L_{PNTSmx}, or time-based metrics. In these cases, the slant range, designated SLR_{seg}, is defined as the distance from the observer location to the closest point of approach on the flight-path segment (CPA), not the extended flight-path segment. The specific definition of CPA depends on the position of the observer location relative to the flight-path segment. If the observer is behind the flight-path segment, CPA is the start point of the segment. If the observer is astride the flight-path segment, CPA is equivalent to PCPA. If the observer is ahead of the flight-path segment, CPA is the end point of the flight-path segment.

3.2.2 Speed, Altitude, Distance, and Power

Computations of the following four parameters, associated with each flight-path segment, are described: (1) the speed at CPA; (2) the altitude at CPA; (3) the horizontal sideline distance from the observer location to the vertical projection of CPA; and (4) the engine power setting at CPA. These computation methodologies are identical for fixed wing aircraft and helicopters, except for the computation of engine power setting. Engine power setting is fixed for helicopters in INM. Therefore, the following engine power setting computation methodology is only applicable to fixed wing aircraft.

The aircraft speed, AS_{seg}, at CPA is computed via linear interpolation as follows:

$$AS_{eg} = AS_{P1} + \left[\frac{d_{AS}}{L}\right] \cdot \Delta AS \qquad \text{Eq. 3-1}$$

where

- AS_{P1} speed at the start of the flight-path segment (knots),
- d_{AS} defined in Section 3.2,
- L defined in Section 3.2, and
- ΔAS change in speed along the flight-path segment (knots).

AS_{seg} is used to compute the duration adjustment for exposure-based noise-level metrics as presented in Section 3.4.4.

The altitude, d_{seg}, in feet at CPA is computed via linear interpolation:

$$d_{seg} = [P_1]_z + d_{AS}\left[\frac{(P_1P_2)_z}{L}\right] + h_{terr} - h_{aprt} \qquad \text{Eq. 3-2}$$

where

- $[\mathbf{P}_1]_z$ altitude at the start of the flight path segment, given by the z-component of the vector from the origin of coordinates to the start of the flight-path segment (feet above airport elevation),
- d_{AS} defined in Section 3.2,
- $(\mathbf{P}_1\mathbf{P}_2)_z$ change in altitude along the flight-path segment (feet),
- L defined in Section 3.2,
- h_{terr} terrain elevation (feet MSL); when the terrain option is not invoked, $h_{terr} = h_{aprt}$, and
- h_{aprt} airport elevation (feet MSL).

The sideline distance from the flight-path segment to the observer, l_{seg}, defined as the distance in the horizontal plane from the observer location on the ground to the vertical projection of CPA, is computed as follows:

$$l_{seg} = (SLR_{seg}{}^2 - d_{seg}{}^2)^{½} \qquad \text{Eq. 3-3}$$

where

- SLR_{seg} defined in Section 3.2, and
- d_{seg} as computed above.

The sideline distance, l_{seg}, is used to compute the ground-to-ground component of the lateral attenuation adjustment as presented in Section 3.4.5.

For fixed wing aircraft, the engine power setting*, P_{seg}, at CPA is computed via linear interpolation:

$$P_{seg} = P_{P1} + \left[\frac{d_{AS}}{L}\right] \cdot \Delta P \qquad \text{Eq. 3-4}$$

where

- P_{P1} engine power at the start of the flight-path segment,
- d_{AS} defined in Section 3.2,
- L defined in Section 3.2, and
- ΔP change in power along the flight-path segment.

P_{seg} is used in performing noise level interpolation as presented in Section 3.3†.

3.3 Noise Level Interpolation ($L_{P,d}$)

The NPD data are used to either interpolate or extrapolate an associated noise-level value. The interpolation/extrapolation is a piece-wise linear process between the engine power setting and the base-10 logarithm of the distance. An expanded process is utilized for helicopter noise interpolation/extrapolation (Section 3.3.3).

Interpolation or extrapolation of NPD data for departure operations is performed using the NPD curves designated as departure curves. Similarly, interpolation or extrapolation of NPD data for approach operations, with one exception, is performed using the NPD curves designated as approach curves. The one exception occurs for the thrust reverse segment after aircraft touchdown. For this segment interpolation/extrapolation is performed using the departure NPD curves because of the higher noise levels associated with both departure and reverse thrust.

For each aircraft flight operation, NPD data are available for the four fundamental noise-level metrics, L_{AE}, L_{EPN}, L_{ASmx}, and L_{PNTSmx}. The appropriate metric is selected for interpolation or extrapolation based upon the user-specified noise metric, or family of metrics to be computed at the observer. The specific distance and power value used in the interpolation/extrapolation process is dependent on the type of base metric selected. Section 3.2.1 and 3.2.2 discuss the distance and power values for exposure-based noise-level metrics and maximum noise-level metrics, respectively.

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* Engine power setting, also known as thrust-setting, is expressed on a per engine basis in a variety of units, including pounds, percent, engine-pressure-ratio (EPR), as well as other units. The specific unit designation can be found in the `THRSET_TYP` field in the *NOIS_GRP.DBF* database file.

† For helicopters, the engine power setting is an arbitrarily assigned number in INM, because the helicopter NPDs are dependant on operational mode, instead of thrust setting. Therefore, the helicopter engine power setting is determined by $P_{seg} = P_{P1}$.

Following is a generalized description of the noise interpolation for an engine power P* and distance d. For this interpolation, the engine power is bounded by NPD curves with engine power P_1 and P_2. Within these NPD curves, the distance d is bounded by the NPD distances of d_1 and d_2. For extrapolation, P_1 and P_2 and d_1 and d_2 are chosen to be the core database values "closest" to the desired power P or distance d.

The noise level in decibels at engine power, P_1, and distance, d, is given by:

$$L_{P1,d} = L_{P1,d1} + \frac{(L_{P1,d2} - L_{P1,d1}) \cdot (\log_{10}[d] - \log_{10}[d_1])}{(\log_{10}[d_2] - \log_{10}[d_1])} \qquad \text{Eq. 3-5}$$

where

- P_1, P_2 engine power values for which noise data are available in the NPD database,
- d_1, d_2 distance values for which noise data are available in the NPD database,
- $L_{P1,d1}$ noise level at power P_1 and distance d_1 (dB),
- $L_{P2,d1}$ noise level at power P_2 and distance d_1 (dB),
- $L_{P1,d2}$ noise level at power P_1 and distance d_2 (dB), and
- $L_{P2,d2}$ noise level at power P_2 and distance d_2 (dB).

The noise level in decibels at engine power P_2 and distance d is given by:

$$L_{P2,d} = L_{P2,d1} + \frac{(L_{P2,d2} - L_{P2,d1}) \cdot (\log_{10}[d] - \log_{10}[d_1])}{(\log_{10}[d_2] - \log_{10}[d_1])} \qquad \text{Eq. 3-6}$$

Finally, the interpolated/extrapolated noise level in decibels at engine power P and distance d is given by:

$$L_{P,d} = L_{P1,d} + \frac{(L_{P2,d} - L_{P1,d}) \cdot (P - P_1)}{(P_2 - P_1)} \qquad \text{Eq. 3-7}$$

The above methodology is utilized when: (1) the engine power and/or distance associated with the observer/segment pair lies between existing values in the NPD data (i.e., interpolation); (2) the power and/or distance associated with the observer/segment pair is larger than existing values in the NPD data (i.e., extrapolation); or (3) the power associated with the observer/segment pair is smaller than existing values in the NPD data (i.e., extrapolation). When noise levels are extrapolated to power settings below those represented by the NPD curves, the extrapolation is limited to 5 dB below the lowest noise curve.

When the distance associated with the observer/segment pair is smaller than the smallest distance in the NPD data (i.e., 200 feet) a special case applies. This special case is presented separately for exposure-based noise-level metrics (Section 3.3.1), maximum noise-level metrics (Section 3.3.2) and noise levels generated by helicopters (Section 3.3.3).

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* Several of the NOISEMAP aircraft, which were included in the INM database beginning with Version 5.1, contain NPD data for afterburner operations (NOISEMAP equivalent of "FIXED" interpolation). These data are identified in the `CURVE_TYPE` field in the *NPD_CURV.DBF* database file with an "X" for Afterburner, as compared to an "A" for Approach or "D" for Depart. If a particular flight path segment is identified as an afterburner segment, interpolation or extrapolation is only performed with regard to distance, not power.

3.3.1 Exposure-Based Noise Level Metrics

The general noise interpolation/extrapolation process described in Section 3.3 is applicable for the four fundamental noise-level metrics, L_{AE}, L_{EPN}, L_{ASmx}, and L_{PNTSmx}. However, the specific engine power and distance value used in the interpolation/extrapolation process is different for exposure-based noise-level metrics as compared with maximum noise-level metrics.

If the end points of a flight-path segment are defined by **P**$_1$ at the start of the segment, and **P**$_2$ at the end of the segment, then the exposure-based noise level, either L_{AE} or L_{EPN} interpolated or extrapolated for an observer/segment pair, is given by:

$$L_{P,d} = \begin{cases} L_{P_{seg},d=SLR_{pth}} & \text{observer behind or ahead of segment} \\ L_{P_{seg},d=SLR_{seg}} & \text{observer astride segment} \end{cases} \qquad \text{Eq. 3-8}$$

where

$L_{Pseg,d=SLRpth}$ Interpolated noise level (dB) based upon engine power associated with the flight-path segment, P_{seg}, as defined in Section 3.2.2, and the distance to PCPA on the extended flight-path segment, as defined in Section 3.2.1, and

$L_{Pseg,d=SLRseg}$ Interpolated noise level (dB) based upon engine power associated with the flight path segment, P_{seg}, and the distance to CPA=PCPA on the flight-path segment.

For the special case in which SLR_{pth} or SLR_{seg} is smaller than 200 feet, i.e., the smallest value in the distance portion of the NPD data, cylindrical divergence (i.e., line-source) is assumed and a $10 \log_{10}[d_1/d_2]$ relationship is used for the L_{AE}-based and L_{EPN}-based noise-level metrics. For example, if L_{AE} at 200 feet and for a given power setting in the NPD data is 95.6 dB, the extrapolated L_{AE} at 100 feet and at the same power setting is $(95.6 + 10 \log_{10}[200/100]) = 98.6$ dB.

3.3.2 Maximum Noise Level Metrics

The general noise interpolation/extrapolation process described in Section 3.3 is applicable for the four fundamental noise-level metrics, L_{AE}, L_{EPN}, L_{ASmx}, and L_{PNTSmx}. However, the specific distance and power value used in the interpolation/extrapolation process is different for maximum noise-level metrics as compared with exposure-based metrics.

If the end points of a flight-path segment are defined by **P**$_1$ at the start of the segment, and **P**$_2$ at the end of the segment, then the maximum noise level, either L_{ASmx} or L_{PNTSmx}, as appropriate, interpolated/extrapolated for an observer/segment pair, is given by:

$$L_{P,d} = \begin{cases} Max[L_{P,d,START}, L_{P,d,END}] & \text{observer behind / ahead of segment} \\ Max[L_{P,d,START}, L_{P,d,PCPA}, L_{P,d,END}] & \text{observer astride segment} \end{cases}$$

Eq. 3-9

where

Max[ ] function that returns the maximum of two or three noise level values,

$L_{P,d,START}$	interpolated noise level (dB) based upon the distance and engine power values associated with the start of the flight-path segment,
$L_{P,d,END}$	interpolated noise level (dB) based upon the distance and engine power values associated with the end of the flight-path segment, and
$L_{P,d,PCPA}$	interpolated noise level (dB) based upon the distance and engine power values associated with PCPA = CPA on the flight path segment.

As with exposure-based metrics, a special case applies for maximum noise level metrics when the distance is smaller than 200 feet. For the L_{ASmx}-based and L_{PNTSmx}-based noise metrics, spherical divergence (i.e., a point-source) is assumed and a 20 $\log_{10}[d_1/d_2]$ relationship is used. For example, if L_{ASmx} at 200 feet and for given power setting in the NPD database is 95.6 dB, then the extrapolated L_{ASmx} at 100 feet at the same power setting is 95.6 + 20 $\log_{10}[200/100]$ = 101.6 dB.

3.3.3 Noise Level Interpolation/Extrapolation for Helicopters

Interpolation or extrapolation of Helicopter NPD data involves more steps than the general NPD interpolation and extrapolation process described in Section 3.3. Besides the three standard dynamic operational modes (approach, departure and level flyover), there are also helicopter noise data for four stationary modes (ground idle, flight idle, hover-in-ground-effect, and hover-out-of-ground-effect).

For the four stationary operational modes associated with helicopters interpolation and extrapolation on the Helicopter NPD curves are performed in the same manner as standard aircraft interpolation and extrapolation presented in Section 3.3.

However, interpolation and extrapolation for the three dynamic operational modes are handled a little differently, because each operational mode data set consists of three noise curves. These noise curves take into account in-flight directivity, and are labeled Left, Center and Right. For these dynamic operational modes, interpolation and extrapolation between power and distance values is handled according to Section 3.3, and interpolation and extrapolation between the Left, Center and Right NPD curves are handled using the Lateral Directivity Adjustment (see Section 3.6.2).

3.4 General INM Adjustments

The sound level adjustments presented in Section 3.4 are applicable to all aircraft in INM. These adjustments include atmospheric absorption (AA_{ADJ}), acoustic impedance (AI_{ADJ}), noise fraction (NF_{ADJ}), duration (DUR_{ADJ}), lateral attenuation (LA_{ADJ}) and line-of-sight blockage (LOS_{ADJ}).

3.4.1 Atmospheric Absorption Adjustment (AA_{ADJ})

The introduction of a spectral database into INM allows a user to take into account atmospheric absorption due to the effects of temperature and relative humidity on an airport-specific basis. Sound levels tend to be lower in low humidity environments as compared to high humidity ones due to the increased atmospheric absorption associated with the lower humidity.[7]

The spectral data in INM has been corrected to reference day conditions, using the SAE-AIR-1845 [1] standard atmosphere, at a distance of 1000 feet (305 meters). The following steps, which are consistent with the simplified procedure of FAR Part 36 [11], are used to correct the data to the user-specified temperature and relative humidity:

1. The aircraft spectrum is A-weighted (or C-weighted, as appropriate*) and corrected back to the source (from the 1000 foot reference), effectively removing the SAE-AIR-1845 atmosphere. This is the weighted source spectrum.
2. The weighted source spectrum is then corrected to the ten standard INM distances assuming two conditions: the INM standard atmosphere based on SAE-AIR-1845 [1] and a user-supplied atmosphere generated with SAE-ARP-866A [7]. These are $\text{spectrum}_{1845,\,d}$ and $\text{spectrum}_{866A,\,d}$ respectively.
3. The 24 one-third octave band values of each spectrum are logarithmically summed at each INM NPD distance, yielding a distance-specific, atmosphere-specific sound pressure level ($L_{1845,\,d}$ and $L_{866A,\,d}$). These levels are then arithmetically subtracted for each INM distance ($L_{1845,\,d} - L_{866A,\,d}$). This distance-specific delta represents the difference between the metric propagated through the SAE-AIR-1845 atmosphere and the metric propagated through the user-supplied atmosphere generated with SAE-ARP-866A at each distance.
4. The distance-specific delta is the atmospheric absorption adjustment (AA_{ADJ}), which takes into account the user-defined temperature and humidity. It is applied to the appropriate NPD values ($NPD_d + (L_{1845,\,d} - L_{866A,\,d})$) at the corresponding INM distance.

An example of the atmospheric absorption adjustment derivation is presented in Appendix F.

The atmospheric absorption correction for the C-weighted family of noise metrics is calculated similar to the process outlined above using C-weighting in place of A-weighting. The atmospheric absorption adjustment for tone-corrected perceived noise metrics is based on A-weighted spectral data. This process is considered to be a reasonable approximation for these metrics.

3.4.2 Acoustic Impedance Adjustment (AI_{ADJ})

Before the interpolated/extrapolated noise level data, $L_{P,d}$, is utilized for computations, an acoustic impedance adjustment, designated by the symbol AI_{ADJ}, is applied. Acoustic impedance is related to the propagation of sound waves in an acoustic medium, and is defined as the product of the density of air and the speed of sound. It is a function of temperature, atmospheric pressure, and indirectly altitude.

The noise-levels in the INM NPD database are corrected to reference-day conditions: temperature 77 °F, pressure 29.92 inches of mercury, and altitude mean sea level.[11] The noise levels can be adjusted to airport temperature and pressure by:[13,14,27,28]

* The weighting on the spectral class is unimportant, as long as it is consistent with the desired metric resulting from the calculations.

$$AI_{ADJ} = 10 \cdot \log_{10}\left[\frac{\rho \cdot c}{409.81}\right] \qquad \text{Eq. 3-10}$$

$$\rho \cdot c = 416.86 \cdot \left(\frac{\delta}{\theta^{½}}\right) \qquad \text{Eq. 3-11}$$

where

- AI_{ADJ} acoustic impedance adjustment to be added to noise level data in the INM NPD data base (dB),
- ρc specific acoustic impedance at observer altitude and pressure (newton-seconds/m^3),
- θ ratio of absolute temperature at the observer to standard-day absolute temperature at sea level, and
- δ ratio of atmospheric pressure at the observer to standard-day pressure at sea level.

See Appendix B for a derivation of the AI_{ADJ} equation.

When the terrain elevation enhancement is invoked, AI_{ADJ} is computed and applied to the NPD data on an observer-by-observer basis, according to the observer altitude, temperature, and pressure. Otherwise, the airport elevation and the observer altitude are equivalent, and a single value of AI_{ADJ} is computed and applied, regardless of the observation point.

When terrain elevation is not invoked, and when airport temperature, pressure, and altitude are equal to 77°F, 29.92 in-Hg, and 0 feet MSL, respectively, then AI_{ADJ} is zero.

3.4.3 Noise Fraction Adjustment for Exposure Metrics (NFADJ)

The exposure-based noise level data interpolated/extrapolated from the INM NPD data, $L_{P,d}$, represents the noise exposure level associated with a flight path of infinite length. However, the aircraft flight path in INM Version 7.0 is described by a set of finite-length segments, each contributing varying amounts of exposure to the overall noise metric computed at an observer.

The noise fraction algorithm, used exclusively for computation of the exposure-based metrics (L_{AE}, L_{dn}, L_{den}, L_{Aeq24h}, L_d, L_n, L_{CE}, L_{EPN}, L_{NEF}, L_{WECPN}, and ΔL), and indirectly for computation of the time-based metrics (TA_{LA}, TA_{LC}, TA_{PNT}, TAud, $\%TA_{LA}$, $\%TA_{LC}$, $\%TA_{PNT}$, and %TAud), computes the fraction of noise exposure associated with a finite-length flight path segment. This fraction of noise exposure is computed relative to the noise associated with a flight path of infinite length. It is based upon a fourth-power, 90-degree dipole model of sound radiation[26,29,30] and its derivation is presented in Appendix C.

Computation of the noise fraction is necessary because the L_{AE}, L_{CE}, and L_{EPN}-based noise levels in the NPD database are computed assuming that an aircraft proceeds along a straight flight path, parallel to the ground, and of infinite length. To obtain the noise exposure level or time-above at an observer location due to an aircraft proceeding along a finite flight-path segment, the exposure-based noise-level data, interpolated/extrapolated from the INM NPD data, must be adjusted by a fractional component, which is associated with the geometry of the observer/flight-segment pair.

3.4.3.1 Noise Fraction Adjustment for Flight Segments

For an arbitrary segment, the fourth-power time-history model computes noise exposure fraction, F_{12}, as follows:

$$F_{12} = \left(\frac{1}{\pi}\right) \cdot \left[\frac{\alpha_2}{(1+\alpha_2^{\ 2})} + \tan^{-1}(\alpha_2) - \frac{\alpha_1}{(1+\alpha_1^{\ 2})} - \tan^{-1}(\alpha_1)\right] \qquad \text{Eq. 3-12}$$

where

$$\alpha_1 = \frac{-q_1}{s_L}, \qquad \text{Eq. 3-13}$$

$$\alpha_2 = \frac{(-q_1 + L)}{s_L}, \qquad \text{Eq. 3-14}$$

$$s_L = s_0 \cdot 10^{\frac{[L_{E,P,d} - L_{Smx,P,d}]}{10}}, \qquad \text{Eq. 3-15}$$

- q_1 relative distance (feet) from segment start point to point $\mathbf{P}_S$,
- L length of segment (feet),
- s_o 171.92 feet (52.4 m) for L_{AE} and L_{CE}, or 1719.2 feet (524.0 m) for L_{EPN},
- $L_{E.P,d}$ unadjusted interpolated NPD noise exposure level (dB) at 160 knots (L_{AE}, L_{CE}, L_{EPN}), and
- $L_{Smx.P,d}$ unadjusted interpolated NPD maximum noise level (dB) (L_{ASmx}, L_{CSmx}, L_{PNTSmx}).

Both $L_{E.P,d}$ and $L_{Smx.P,d}$ are interpolated from NPD data at a given engine power setting and at a distance SLR_{pth}, which is the distance from the observer to the perpendicular closest point of approach (PCPA) on the extended segment.

The noise fraction is then converted to a dB adjustment:

$$NF_{ADJ} = 10 \cdot \log_{10}[F_{12}] \qquad \text{Eq. 3-16}$$

3.4.3.2 Noise Fraction Adjustment for Behind Start-of-Takeoff Roll

For an observer behind the start-of-takeoff ground roll, a special case of the noise fraction equation applies. This special case noise fraction, denoted by the symbol F_{12}', ensures consistency of computed exposure levels that are on a line at azimuth angle of 90° measured from the nose of the aircraft at start of takeoff roll.

$$F_{12}' = \left(\frac{1}{\pi}\right) \cdot \left[\frac{\alpha_2}{(1+\alpha_2^{\ 2})} + \tan^{-1}(\alpha_2)\right] \cdot 10^{\frac{DIR_{ADJ}}{10}} \qquad \text{Eq. 3-17}$$

where

$$\alpha_2 = \frac{L}{s_L} \qquad \text{Eq. 3-18}$$

L and s_L are defined in the above section and DIR_{ADJ} is the ground based directivity adjustment (see Section 3.5.2).

The noise fraction for the special case of observers behind the start-of-takeoff roll is then converted to a dB adjustment:

$$NF_{ADJ} = 10 \cdot \log_{10}[F_{12}'] \qquad \text{Eq. 3-19}$$

A similar equation is used for observers in front of the end point of the last approach segment.

3.4.4 Duration Adjustment for Exposure-Based Metrics (DUR_{ADJ})

For exposure-based metrics, consistent with SAE-AIR-1845 [1], NPDs are derived for a reference speed of 160 knots. For aircraft speeds other than 160 knots, the duration adjustment is applied to account for the effect of time-varying aircraft speed, both acceleration and deceleration. It is not applied to maximum noise level metrics since they are mostly independent of speed. In addition, since runup operations are stationary operations and they do not have associated speeds, the duration adjustment is not applied.

For fixed-wing aircraft, the L_{AE} and L_{EPN} values in the NPD database are referenced to an aircraft speed of 160 knots. For other aircraft speeds, the aircraft speed adjustment in decibels, DUR_{ADJ}, is given by:

$$DUR_{ADJ} = 10\log_{10}\left[\frac{AS_{ref}}{AS_{seg}}\right] \qquad \text{Eq. 3-20}$$

where

AS_{ref} references aircraft speed (160 knots for fixed-wing aircraft),
AS_{seg} aircraft speed at the closest point of approach (CPA) for the segment, as presented in Section 3.2.2.

Helicopters in the INM database are referenced to NPD-specific reference speeds based on measurement-specific information when the data were collected. These helicopter-specific reference speeds are applied to Equation 3-20, when calculating the aircraft speed adjustment, DUR_{ADJ}, for helicopters.

3.4.5 Lateral Attenuation Adjustment (LA_{ADJ})

The difference in level between the sound directly under the aircraft's flight path and at a location to the side of the aircraft at the time of closest approach is termed "lateral attenuation." The lateral attenuation adjustment takes into account the following effects on aircraft sound due to over-ground propagation:* (1) ground reflection effects; (2) refraction effects; and (3) airplane shielding effects, as well as other ground and engine/aircraft installation effects. It is computed as a function of two empirical parameters, the sideline distance from the flight-path segment to the observer, l_{seg}, given in Section 3.2.2, and the elevation angle, β, formed by SLR_{seg} and the horizontal plane of the observer location (see Figure 3-5). The ground beneath the observer is

* The lateral attenuation adjustment in INM was derived from field measurements made over grass-covered, acoustically soft terrain. Consequently, when source-to-receiver propagation occurs primarily over an acoustically hard surface (e.g., water), and the hard surface dominates the study environment, it is possible that INM could under predict the actual noise level.

defined by a flat plane, regardless of whether the terrain enhancement is invoked or not.

The specific algorithms used for computing lateral attenuation in INM Version 7.0 depend on whether the model type associated with a particular aircraft is type INM or type NOISEMAP. Aircraft types are identified in the `MODEL_TYPE` field of the INM Version 7.0 *NOIS_GRP.DBF* database file, with an "N" for NOISEMAP, and an "I" for INM.

3.4.5.1 INM Aircraft

Since the release of INM Version 6.0, the lateral attenuation adjustment for INM has undergone numerous updates. In INM Version 6.0, the lateral attenuation adjustment was defined by SAE-AIR-1751[31], which did not differentiate aircraft types. In anticipation of an update to SAE-AIR-1751 that would differentiate between aircraft types, the lateral attenuation adjustment was updated in INM Version 6.1. The source noise data was reorganized to differentiate between fuselage-mounted, wing-mounted, and propeller aircraft categories, and the existing SAE-AIR-1751 framework within INM was adapted to more closely correlate with measurements that have been collected both in the United States and internationally. Instead of applying lateral attenuation across all aircraft types for elevation angle 0-60 degrees, INM Version 6.1 applied lateral attenuation for wing-mounted jets and propeller aircraft only up to elevation angles of 30 degrees. This algorithm change increased the predicted noise impact for these aircraft. In 2006, SAE-AIR-5662 "Method for Predicting Lateral Attenuation of Airplane Noise[6]" was published to supersede SAE-AIR-1751, with further updated methodology. The methodology in SAE-AIR-5662 was implemented in INM Version 7.0.

In INM Version 7.0, computation of the lateral attenuation adjustment for "INM" aircraft depends upon the following parameters:

1. The sideline distance from the flight-path segment to the observer, l_{seg}, given in Section 3.2.2;
2. The elevation angle, β, formed by SLR_{seg} and the horizontal plane of the observer location, given by the following equation:

$$\beta = \sin^{-1}\left(\frac{d_{seg}}{SLR_{seg}}\right) \quad \text{Eq. 3-21}$$

   where

$$SLR_{seg} = \left(d_{seg}^2 + l_{seg}^2\right)^{1/2} \quad \text{Eq. 3-22}$$

3. The aircraft bank angle, ε, given in Section 2.6; and
4. The depression angle, φ, which is defined by β and ε in the following equation:

$$\varphi = \varepsilon + \beta \quad \text{Eq. 3-23}$$

These parameters are presented in Figure 3-5 and Figure 3-6.

These parameters are applied to the following equations for calculating lateral attenuation for "INM" aircraft that take into account engine-installation effects, $E_{ENGINE}(\varphi)$, attenuation due to ground effects, $G(l_{seg})$, and attenuation due to refraction-scattering effects, $\Lambda(\beta)$. These effects are calculated differently for each aircraft engine-installation (wing-mounted, fuselage-mounted or propeller-driven engines) and for each of the following different sets of aircraft position criteria relative to the receiver:

1. Aircraft is on the ground or the elevation angle associated with the aircraft/receiver pair is less than 0 degrees;
2. Aircraft is airborne, the elevation angle is greater than 0 degrees, and the lateral (or sideline) distance is greater than 3000 feet (914 meters); or
3. Aircraft is airborne, the elevation angle is greater than 0 degrees, and the lateral distance is less than or equal to 3000 feet (914 meters).[6]

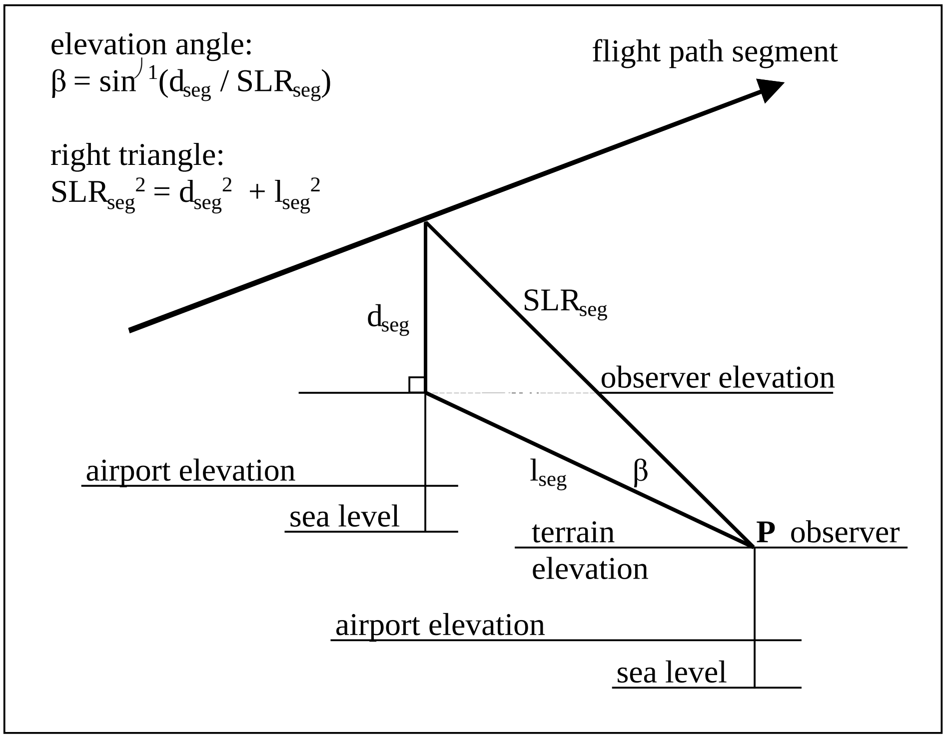

Figure 3-5: Lateral Attenuation Geometry

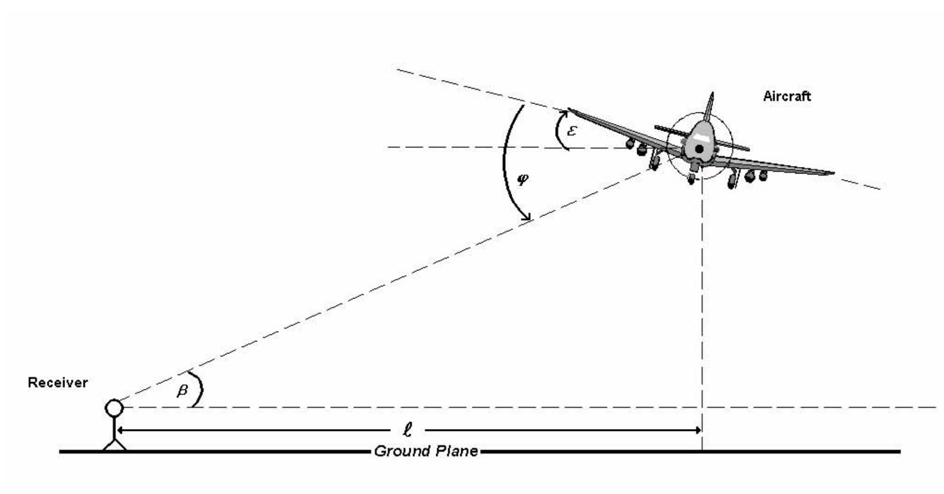

Figure 3-6: Illustration of bank angle ε, elevation angle β, depression angle φ, and lateral distance ℓ*

* Source: SAE-AIR-5662 "Method for Predicting Lateral Attenuation of Airplane Noise[6]."

The engine-installation effect component of the lateral attenuation adjustment, $E_{ENGINE}(\varphi)$, is computed with the following equations, which are dependent on engine mounting location (fuselage or wing) and depression angle.

The engine installation effect (in decibels) for an airplane with fuselage-mounted jets engines is:

$$E_{FUS}(\varphi) = 10 \cdot \log_{10}\left([0.1225 \cdot \cos^2(\varphi) + \sin^2(\varphi)]^{0.329}\right) \qquad for\ -180^o \le \varphi \le 180^o$$

Eq. 3-24

where

φ depression angle (degrees).

The engine installation effect (dB) for an airplane with wing-mounted jets engines is:

$$E_{WING}(\varphi) = \begin{cases} 10 \cdot \log_{10}\left(\dfrac{[0.0039 \cdot \cos^2(\varphi) + \sin^2(\varphi)]^{0.062}}{[0.8786 \cdot \sin^2(2 \cdot \varphi) + \cos^2(2 \cdot \varphi)]}\right) & for\ 0^o \le \varphi \le 180^o \\ -1.49 & for\ 0^o > \varphi > -180^o \end{cases}$$

Eq. 3-25

The engine installation effect (dB) for an airplane with propeller-driven engines is:

$$E_{PROP}(\varphi) = 0.00$$

Eq. 3-26

Since helicopter directional effects are represented by the left-center-right NPD curves (see Section 2.2.1) and the directivity adjustments (see Section 3.6), their engine installation effects are already taken into account and therefore are represented by:

$$E_{HELI}(\varphi) = E_{PROP}(\varphi) = 0.00$$

Eq. 3-27

The engine installation effects for jet-powered airplanes are illustrated in Figure 3-7.

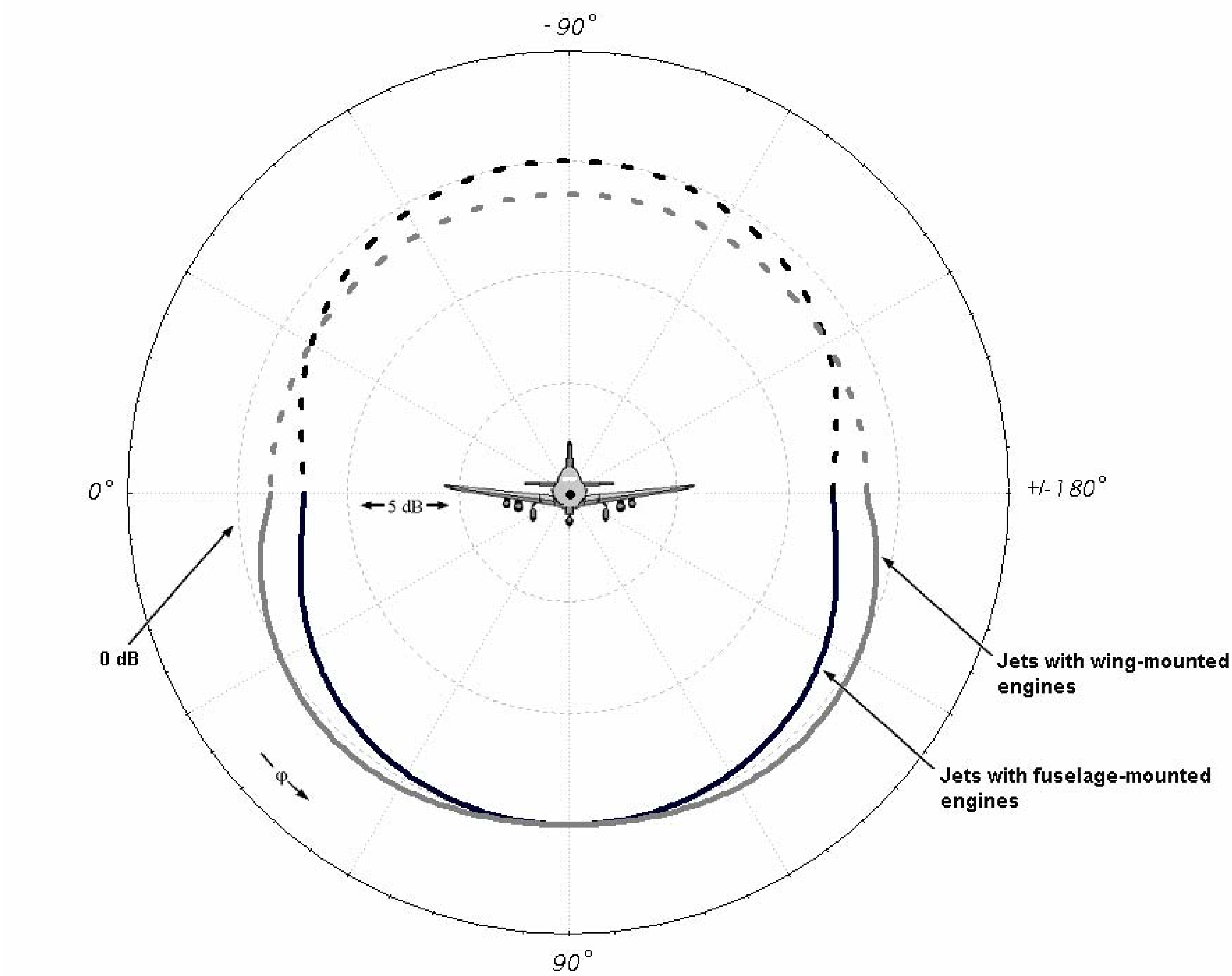

Figure 3-7: Illustration of Engine-Installation Effects for Jet-Powered Airplanes*

The ground effect, or ground-to-ground, component of the lateral attenuation adjustment, $G(l_{seg})$, is computed as follows:

$$G(l_{seg}) = \begin{cases} 11.83 \cdot \left[1 - e^{-0.00274 \cdot l_{seg}}\right] & for\ 0 < 1_{seg} \leq 914\,m\,(3000\ ft) \\ 10.86 & for\ 1_{seg} > 914\,m\,(3000\ ft) \end{cases} \quad \text{Eq. 3-28}$$

where

l_{seg} sideline distance (meters) in the horizontal plane from the observer to the projection of CPA.

* Source: SAE-AIR-5662 "Method for Predicting Lateral Attenuation of Airplane Noise[6]."

The ground-to-ground component of the lateral attenuation adjustment is illustrated in Figure 3-8.

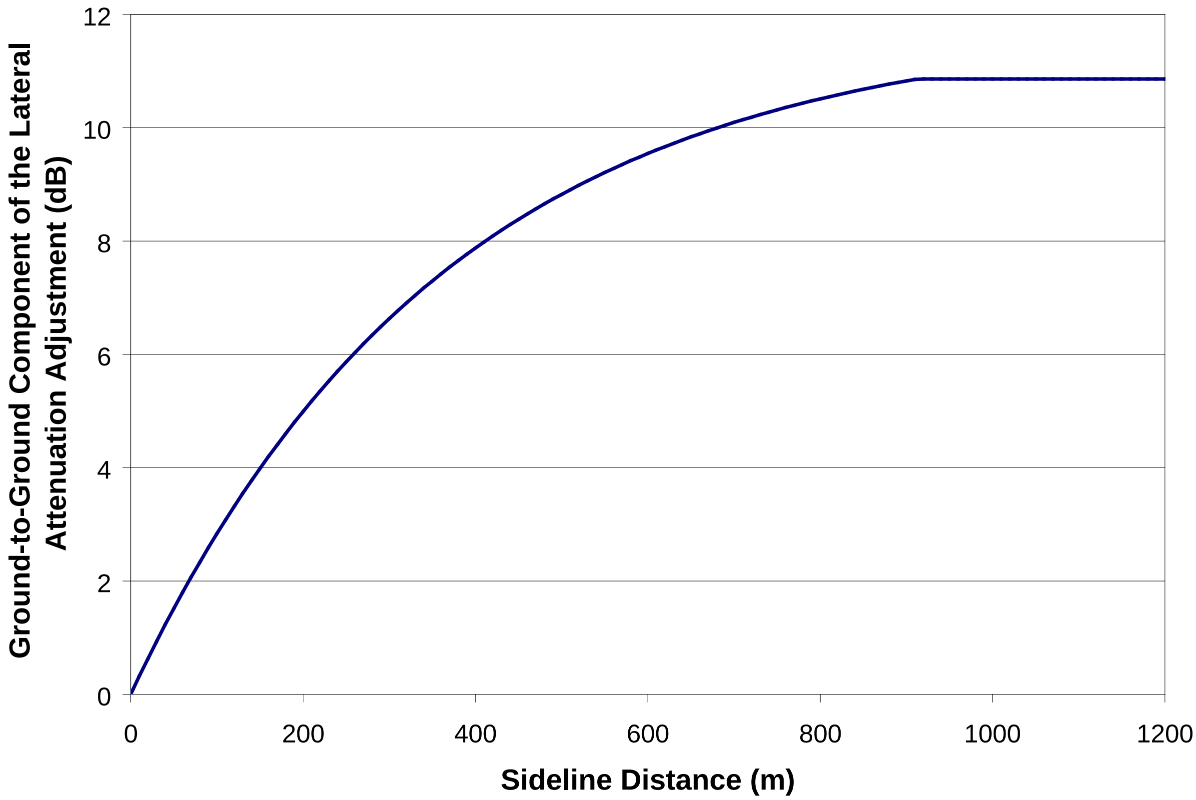

Figure 3-8: Illustration of Ground-to-Ground Component of Lateral Attenuation

The refraction-scattering, or air-to-ground, component of the lateral attenuation adjustment, $\Lambda(\beta)$, is computed as follows:

$$\Lambda(\beta) = \begin{cases} 10.86 & \text{for } \beta \le 0^\circ \\ 1.137 - 0.0229 \cdot \beta + 9.72 \cdot e^{-0.142 \cdot \beta} & \text{for } 0^\circ < \beta \le 50^\circ \\ 0.0 & \text{for } 50^\circ < \beta \le 90^\circ \end{cases} \qquad \text{Eq. 3-29}$$

where

β elevation angle (degrees); if $\beta \le 0°$ or the aircraft is on the ground, β is reset to 0°.

The air-to-ground component of the lateral attenuation adjustment is illustrated in Figure 3-9.

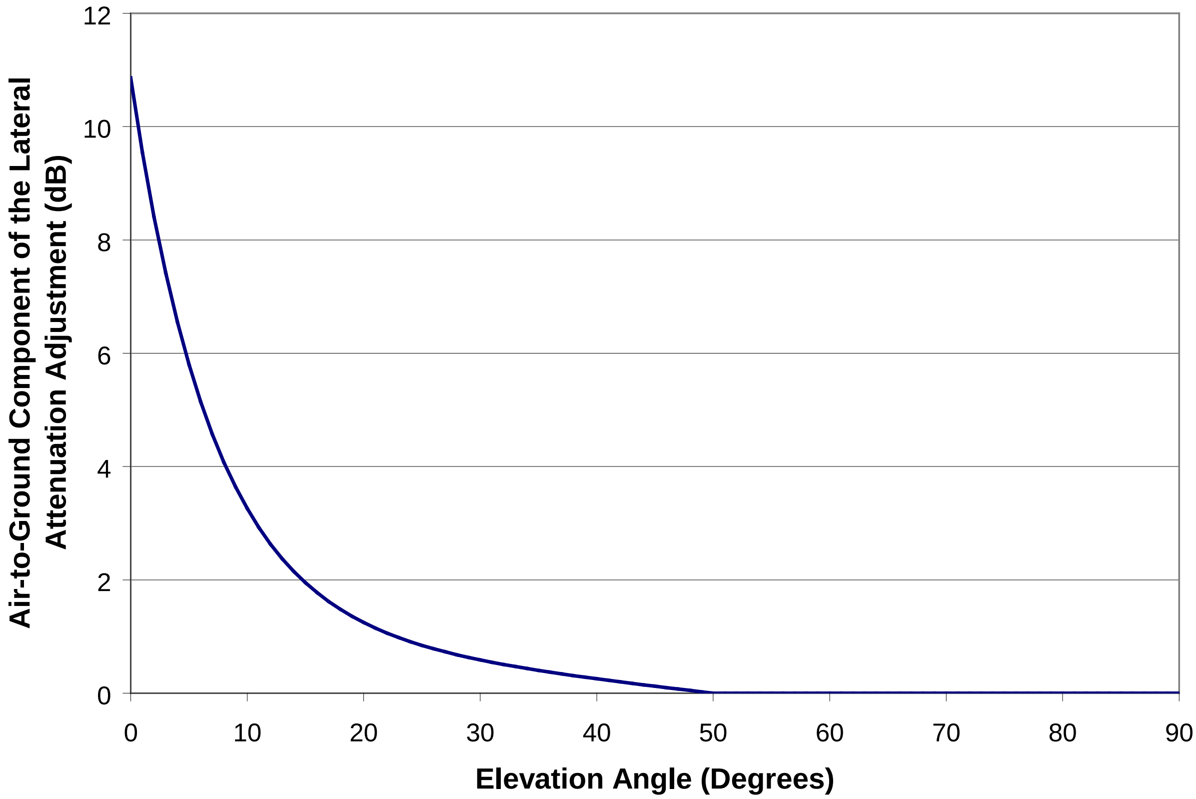

Figure 3-9: Illustration of Air-to-Ground Component of Lateral Attenuation

The overall lateral attenuation adjustment, LA_{ADJ} (in decibels)*, which takes into account the engine-installation effect component, $E_{ENGINE}(\varphi)$, the ground-to-ground component, $G(l_{seg})$, and the air-to-ground component, $\Lambda(\beta)$, is then computed as follows:

$$LA_{ADJ(INM)} = -\left[E_{ENGINE}(\varphi) - \frac{G(l_{seg}) \cdot \Lambda(\beta)}{10.86} \right] \qquad \text{Eq. 3-30}$$

It is important to note that the depression angle in Fig. 3-6 is general enough to include the bank angle. Therefore the bank angle effect on lateral attenuation is already considered. If bank angle is not zero, the lateral attenuation will be non-symmetric from one side of the aircraft to another.

3.4.5.2 NOISEMAP Aircraft

The INM database includes all of the aircraft from the United States Air Force NOISEMAP suite of programs[18], as of March 2001. If the model type in the NPD database is categorized as "NOISEMAP", computation of the lateral attenuation adjustment depends upon the elevation

* For "INM" Aircraft in INM 7.0, the sign of $LA_{ADJ\,(INM)}$ is made negative (see Eq. 3-30), in order to fit INM calculation conventions.

angle, β. If the elevation angle is less than 2 degrees, the adjustment has a ground-to-ground component only. If the elevation angle is greater than or equal to 2 degrees, it has both a ground-to-ground and an air-to-ground component. In the latter case, the two components are computed separately and then combined.

The ground-to-ground component of the lateral attenuation adjustment (in decibels) is computed as follows:*

$$G(l_{seg}) = \begin{cases} 15.09 \cdot \left[1 - e^{-0.00274 \cdot l_{seg}}\right] & for\, 0 < l_{seg} \le 401m\,(1316\,ft) \\ 10.06 & for\, l_{seg} > 401m\,(1316\,ft) \end{cases} \qquad \text{Eq. 3-31}$$

where

l_{seg} sideline distance (meters) in the horizontal plane from the observer to the projection of CPA.

The ground-to-ground component of the lateral attenuation adjustment for NOISEMAP aircraft is illustrated in Figure 3-10.

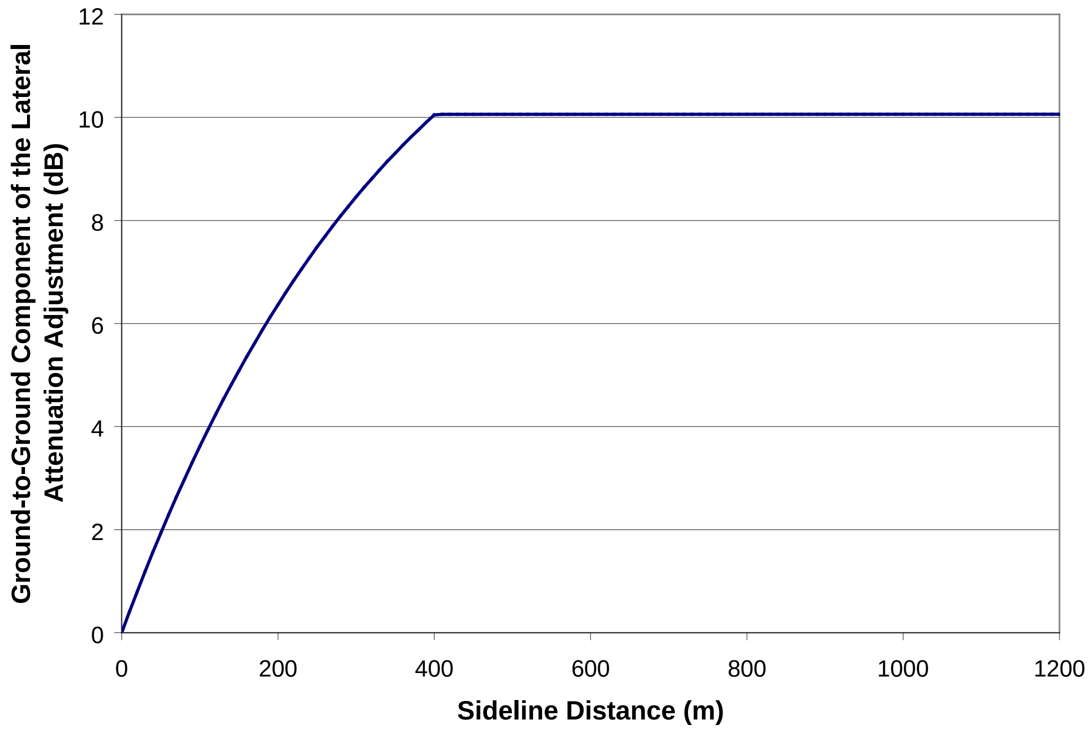

Figure 3-10: Illustration of Ground-to-Ground Component of Lateral Attenuation for NOISEMAP Aircraft

The air-to-ground component of the lateral attenuation adjustment (in decibels) is computed as

* The ground-to-ground component of the lateral attenuation adjustment actually computed by the NOISEMAP program depends on the one-third octave-band frequency characteristics of the noise source. Due to this fact, small differences are expected when comparing INM and NOISEMAP results directly, especially in the immediate vicinity of the airport runways.

follows:

$$\Lambda(\beta) = \begin{cases} \left(\frac{21.056}{\beta}\right) - 0.468 & for\ 2^o \leq \beta \leq 45^o \\ 0 & for\ 45^o < \beta \leq 90^o \end{cases}$$ Eq. 3-32

where

β elevation angle (degrees); if β < 0, β is reset to 0°.

The air-to-ground component of the lateral attenuation adjustment for NOISEMAP aircraft is illustrated in Figure 3-11.

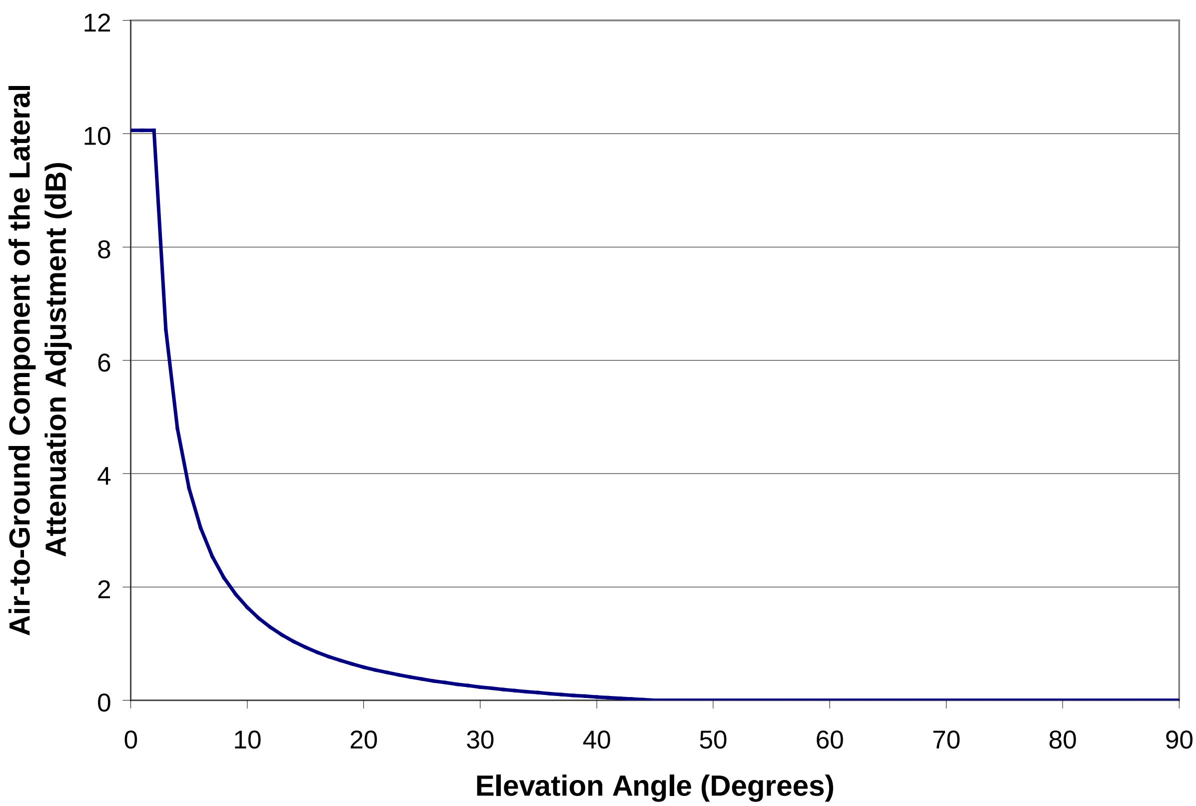

Figure 3-11: Illustration of Air-to-Ground Component of Lateral Attenuation for NOISEMAP Aircraft

The overall lateral attenuation adjustment, LA_{ADJ} (in decibels), which takes into account both the ground-to-ground component, $G(l_{seg})$, and the air-to-ground component, Λ(β), for 2° ≤ β, is then computed as follows:

$$LA_{ADJ(NOISEMAP)} = \frac{G(l_{seg}) \cdot \Lambda(\beta)}{10.06}$$ Eq. 3-33

3.4.6 Line-of-Sight Blockage Adjustment (LOS_{ADJ})

The line-of-sight blockage adjustment, LOS_{ADJ}, accounts for the attenuation due to line-of-sight (LOS) blockage from terrain features. The LOS blockage calculation 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. This methodology has been extensively used and validated by the Federal Highway Administration and others[32].

Figure 3-12 illustrates LOS blockage due to a terrain feature.

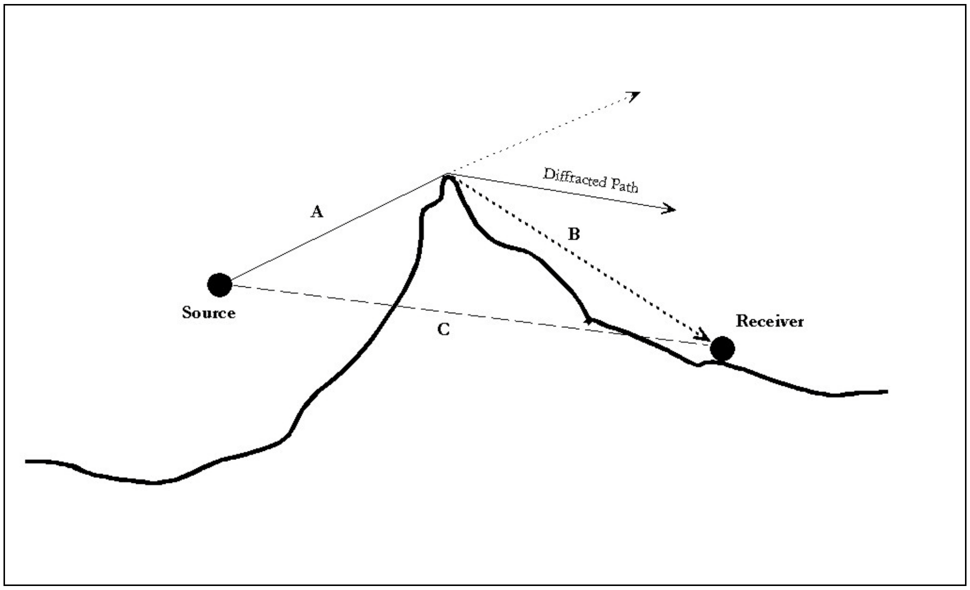

Figure 3-12: Line-of-Sight (LOS) Blockage Concept

Path length difference in INM is determined along the path defined by a particular source-barrier-receiver geometry, and is calculated and the following equation (see Figure 3-12):

$$\delta_0 = (A + B) - C \qquad \text{Eq. 3-34}$$

where

A	length of path from the noise source to the diffraction point (or barrier),
B	length of path from the diffraction point to the receiver, and
C	length of direct path from the noise source to the receiver.

The path length difference is used to compute:

1. Fresnel Number (N_0), which is a dimensionless value used in predicting the attenuation provided by a noise barrier positioned between a source and a receiver; which in turn is used to compute
2. Barrier Effect, which is the sound level attenuation on a one-third octave-band basis at a receiver due to line-of-sight blockage; which in turn is used to compute
3. Line-of-sight blockage adjustment (LOS_{ADJ}).

An example illustrating the relationship between path length difference and barrier attenuation is presented in Appendix F.

The adjustment for line-of-sight blockage (LOS_{ADJ}) is based on the theoretical barrier effect (assuming a barrier of infinite length), which is calculated with the following equation:

$$Barrier\ Effect = \begin{cases} 5 + 20 \cdot \log_{10}\left(\dfrac{\left(2 \cdot \pi \cdot |N_0|\right)^{1/2}}{\tan\left(\left(2 \cdot \pi \cdot |N_0|\right)^{1/2}\right)} \right) & N_0 < 0 \\ 5 + 20 \cdot \log_{10}\left(\dfrac{\left(2 \cdot \pi \cdot |N_0|\right)^{1/2}}{\tanh\left(\left(2 \cdot \pi \cdot |N_0|\right)^{1/2}\right)} \right) & N_0 > 0 \end{cases} \qquad \text{Eq. 3-35}$$

where

N_0 Fresnel Number determined along the path defined by a particular source-barrier-receiver geometry*, which is computed as follows:

$$N_0 = \pm 2 \cdot \left(\frac{\delta_0}{\lambda} \right) = \pm 2 \cdot \left(\frac{f \cdot \delta_0}{c} \right) \qquad \text{Eq. 3-36}$$

where

± positive in the case where the line of sight between the source and receiver is lower than the diffraction point, and negative when the line of sight is higher than the diffraction point,

δ_0 path length difference determined along the path defined by a particular source-barrier-receiver geometry (see Eq. 3-34),

λ wavelength of the sound radiated by the source,

f frequency of the sound radiated by the source, and

c speed of sound.

LOS_{ADJ} is computed by (1) calculating the Barrier Effect for each of the one-third octave-band center frequencies, (2) summing the acoustic energy in each one-third octave-band, and (3) converting that sum to decibels.

$$LOS_{ADJ} = 10 \cdot \log_{10}\left(\sum_{i=17}^{40} 10^{\frac{Barrier\ Effects_i}{10}} \right) \qquad \text{Eq. 3-37}$$

where

$Barrier\ Effect_i$ sound level attenuation at a receiver due to line-of-sight blockage for the i-th one-third octave-band (ranging from one-third octave-bands 17 through 40).

It is important to note that, if line-of-sight blockage is invoked as a run option, LOS_{ADJ} is compared to lateral attenuation adjustment (LA_{ADJ}, see Section 3.4.5) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations.

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* In INM, N_0 is limited to –0.1916 on the low end. Furthermore, the Barrier Effects are set to 23.1 for values of N_0 greater than 10.

For each segment-receiver-based noise calculation, either LOS_{ADJ} or LA_{ADJ} are implemented, but not both. This allows for a seamless transition between LOS_{ADJ} or LA_{ADJ}, although it does not handle their interaction. As stated in the Federal Interagency Committee on Aviation Noise (FICAN) report “Assessment of Tools for Modeling Aircraft Noise in the National Parks”[17], this approach has been validated for distances up to 1000 feet, beyond which a practical limit between 18 and 25 dB of attenuation can be expected due to refraction and scattering effects[33]. Therefore, an 18 dB attenuation cap is implemented for LOS_{ADJ} in the INM, as a practical upper limit on barrier attenuation.

3.5 Fixed-Wing Aircraft Adjustments

The sound level adjustments presented in this section are applicable only to fixed-wing aircraft in INM Version 7.0. These adjustments include thrust reverser (TR_{ADJ}) and ground-based directivity (DIR_{ADJ}). Sound level adjustments applicable only to helicopters are presented in Section 3.6.

3.5.1 Thrust Reverser Adjustment (TR_{ADJ})

For the special case of computing noise during thrust reverser deployment as part of the landing ground roll, an empirically-derived thrust reverser adjustment is employed in INM Version 7.0. In previous versions of INM, thrust reverser was applied to all STANDARD approach profiles in INM as 60% of the max rated thrust for jets and 40% for props over a distance of 90% of the total roll-out distance after touchdown. In addition, thrust reverser thrust levels referenced Departure NPDs, instead of Approach NPDs. These thrust values during ground roll in INM were used to ensure good agreement between measured and modeled noise, but were not considered representative of actual thrust levels during thrust reverser deployment. Since there is a need to utilize realistic fuel burn values for integrated noise and emission modeling in AEDT and those fuel burn values are to be based on realistic thrust levels, the thrust reverser assumptions were updated in INM Version 7.0. The updated thrust reverser noise assumptions in INM Version 7.0 better represent reverse thrust levels in typical aircraft operations, while maintaining agreement between measured and modeled noise generated during landing ground roll.

As highlighted in Section 1, INM Version 7.0 is compliant with ECAC Doc 29 [2]. Doc 29 specifies a more complex implementation of reverse thrust than existed in previous versions of INM, citing a typical reverse thrust power level of 20% of static thrust coupled with an additional noise-power-distance adjustment (in decibels) that varies according to distance traveled from touchdown. Even though this implementation is more representative of actual thrust reverser deployment, the Doc 29 development team noted, that there is still need to investigate the issue.

The thrust reverser adjustment methodology used in INM Version 7.0 is presented in “Thrust Reverser Analysis for Implementation in the Aviation Environmental Design Tool (AEDT),[34]” which is based on the Doc 29 approach in conjunction with supplemental analysis of empirical thrust reverser deployment data for a variety of aircraft[35,36,37,38]. These analyses were coordinated directly with the lead author of Doc 29 and are being considered for possible future enhancement of that document. INM models peak thrust reverser engine power levels at 10% of max rated thrust for widebody aircraft, and 40% of max rated thrust for narrowbody aircraft, decreasing linearly to 10% of max rated thrust over a distance of 90% of the total roll-out distance after touchdown, all of which reference Approach NPDs*. To account for the change in engine power settings during thrust reverser deployment between previous versions of INM and INM Version 7.0, without altering the resulting sound levels, the thrust reverser adjustment is applied as a NPD dB adjustment that varies according to distance traveled from touchdown on the landing ground roll.

The thrust reverser adjustment for a given segment is calculated with the following equation:

$$TR_{ADJ} = \begin{cases} L_{old\_seg} - L_{narrow\_seg} & \text{for narrowbody aircraft} \\ L_{old\_seg} - L_{wide\_seg} & \text{for widebody aircraft} \\ 0 & \text{for propeller and military aircraft} \end{cases} \qquad \text{Eq. 3-38}$$

where

- L_{old_seg}† noise level at P_{old_seg} based on Departure NPDs when $P_{old\_seg} \geq P_{final}$, noise level at P_{old_seg} based on Approach NPDs when $P_{old\_seg} < P_{final}$,
- L_{narrow_seg} noise level at P_{narrow_seg} based on Approach NPDs, and
- L_{wide_seg} noise level at P_{wide_seg} based on Approach NPDs.

The engine power level during reverse thrust for a given segment is derived according to:

$$P_{old\_seg} = \left[\frac{d_{rev\_seg}}{d_{rev}} \cdot \left(P_{60\%} - P_{10\%} \right) \right] + P_{10\%} \qquad \text{Eq. 3-39}$$

$$P_{narrow\_seg} = \left[\frac{d_{rev\_seg}}{d_{rev}} \cdot \left(P_{40\%} - P_{10\%} \right) \right] + P_{10\%} \qquad \text{Eq. 3-40}$$

$$P_{wide\_seg} = \left[\frac{d_{rev\_seg}}{d_{rev}} \cdot \left(P_{10\%} - P_{10\%} \right) \right] + P_{10\%} = P_{10\%} \qquad \text{Eq. 3-41}$$

where

- $P_{60\%}$ 60% Max Thrust, which is the previous reverse thrust implementation,
- $P_{40\%}$ 40% Max Thrust, which is the new reverse thrust implementation for narrow-body aircraft,
- $P_{10\%}$ 10% Max Thrust, which is the new reverse thrust implementation for wide-body aircraft,
- d_{rev} the distance along the runway from the point of thrust reverser deployment to the end of the landing ground roll, where:

$$d_{rev} = -0.9 \cdot s_{stop} \quad , \qquad \text{Eq. 3-42}$$

- s_{stop} the location on the runway where the landing ground roll ends,
- d_{rev_seg} the distance along the runway from the aircraft position to the end of the landing ground roll, where:

$$d_{rev\_seg} = -\left(300 + s_{stop} - d\right) \quad . \qquad \text{Eq. 3-43}$$

---

* There is no thrust reverser adjustment for propeller-driven aircraft in INM 7.0.
† L_{old_seg} is the sound level during reverse thrust operations used prior to INM 7.0.

Engine power, aircraft speed and reverse thrust levels for a standard landing ground roll are presented in Figure 3-13.

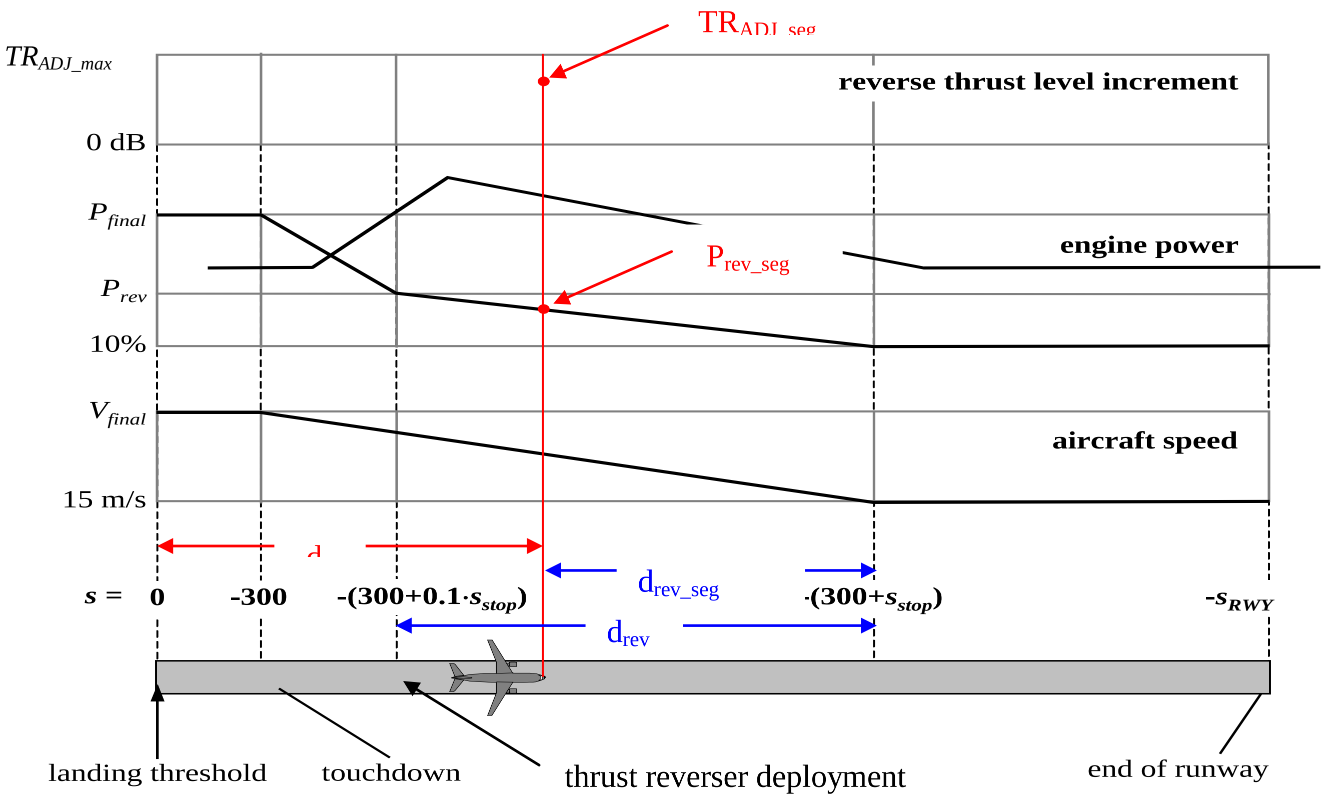

Figure 3-13: Modeling of thrust reverser deployment during landing ground roll

The thrust reverser adjustment in INM Version 7.0 better represents thrust reverser engine power levels used in the derivation of noise levels than previous versions of INM. Additional data collection and research efforts are on-going and may result in future refinements.

3.5.2 Ground-Based Directivity Adjustment (DIR_{ADJ})

For the special case of computing noise behind the start-of-takeoff ground roll, as well as for computing metrics associated with runup operations, a field-measurement-based directivity adjustment is employed. This directivity adjustment is expressed as a function of azimuth angle, θ, defined as the angle formed by the direction of the nose of the aircraft and the line connecting the aircraft to the observer.[26]

To account for the effect of slight variations in the heading of the aircraft just prior to takeoff ground roll, among other effects, a directivity smoothing adjustment, computed as a function of slant range from the observer location to the aircraft, is also applied.

The azimuth angle, θ (in degrees), used in computing the directivity adjustment is given by:

$$\theta = \cos^{-1}\left(\frac{q}{r_1}\right) \qquad \text{Eq. 3-44}$$

where

q relative distance between points $\mathbf{P}_1$, and $\mathbf{P}_S$ (feet). By definition, the value of q is negative (see Figure 3-2 through Figure 3-4), and

r_1 SLR_{seg}, the slant range from the observer to the start of takeoff roll (feet).

Since the value of q is negative, and the value of SLR_{seg} is positive, the value of θ is greater than 90° when the observer is behind start of takeoff.

The directivity adjustment, DIR_{ADJ} (in decibels), is computed as a function of azimuth angle. For θ between 90° and 148.4°,

$$DIR_{ADJ} = 51.44 - (1.553 \cdot \theta) + (0.015147 \cdot \theta^2) - (0.000047173 \cdot \theta^3) \qquad \text{Eq. 3-45}$$

For θ between 148.4° and 180°,

$$DIR_{ADJ} = 339.18 - (2.5802 \cdot \theta) - (0.0045545 \cdot \theta^2) + (0.000044193 \cdot \theta^3) \qquad \text{Eq. 3-46}$$

Equations 3-45 and 3-46 are plotted in Figure 3-14. The directivity adjustment is symmetric along the longitudinal axis of the aircraft in INM.

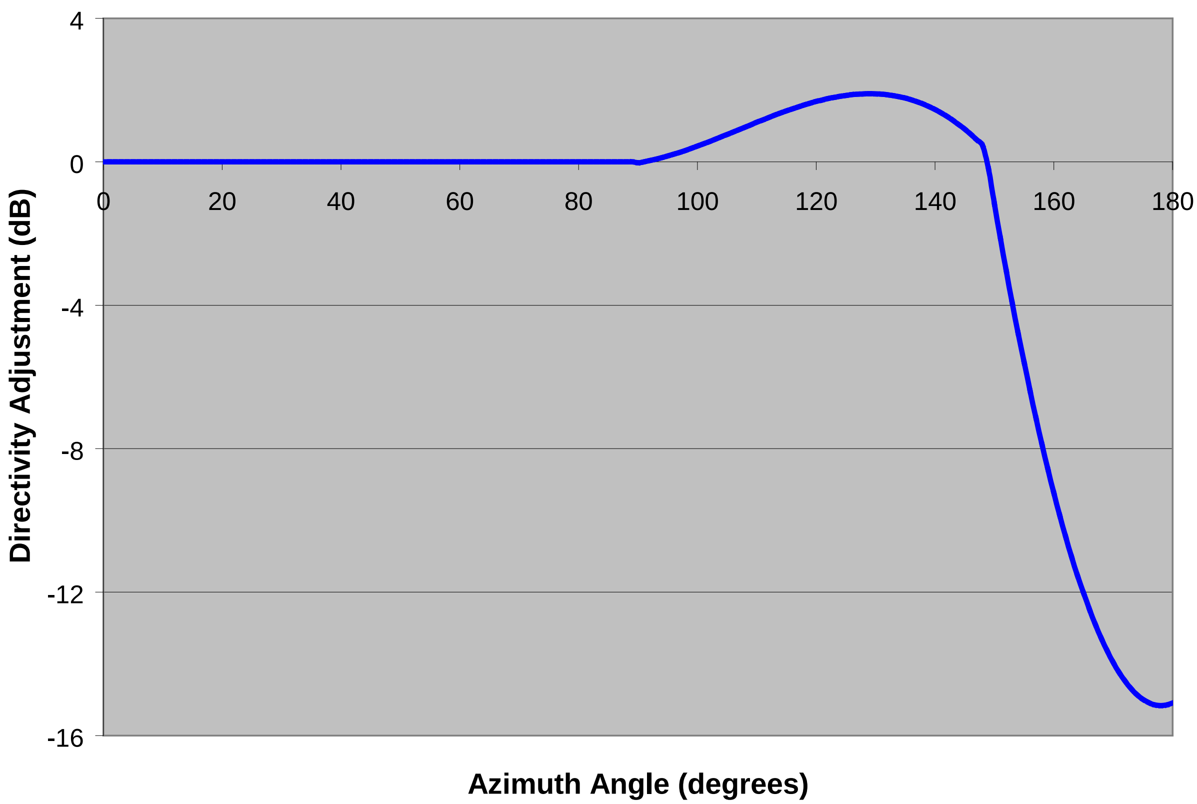

Figure 3-14: Ground-Based Directivity Adjustment

The directivity adjustment, DIR_{ADJ}, is modified by a smoothing equation that is computed as a function of slant range from the observer location to start of takeoff, SLR_{seg}. The smoothing function is activated when SLR_{seg} is greater than 2500 feet. The function, which reduces the directivity by a factor of one-half per doubling of distance, is given by:

$$DIR_{ADJ} = DIR_{ADJ} \cdot \left(\frac{2500}{SLR_{seg}} \right) \qquad \text{Eq. 3-47}$$

for $SLR_{seg} > 2500$ feet.

3.6 Helicopter Adjustments

The sound level adjustments presented in this section are applicable only to helicopters. These adjustments include source noise due to advancing tip Mach Number (MN_{ADJ}), Lateral Directivity (LD_{ADJ}), static directivity (DIR_{HELI_ADJ}), and static operation duration (DUR_{HELI_ADJ}). These adjustments are based on the corresponding adjustment implemented in the Heliport Noise Model.

3.6.1 Source Noise Adjustment Due to Advancing Tip Mach Number (MN_{ADJ}, Level Flyover only)

The helicopter-specific source noise adjustment due to advancing tip mach number account for airspeed, temperature and/or rotor RPM which deviate from helicopter-specific reference values. A detailed description of advancing tip mach number is presented in FAR Part 36 Appendix H[11]. The adjustment is calculated using stored constants from a polynomial regression using the following equation:

$$MN_{ADJ} = B_0 + B_1 \cdot \left(M_{ADV_T} - M_{ADV_R} \right) + B_2 \cdot \left(M_{ADV_T} - M_{ADV_R} \right)^2 \qquad \text{Eq. 3-48}$$

where

B_0, B_1, B_2 helicopter specific coefficients, and
M_{ADV} advancing tip Mach Number, as defined by:

$$M_{ADV} = \frac{\left(1.688 \cdot V\right) + \left(\frac{\pi \cdot D \cdot RPM}{60} \right)}{C} \qquad \text{Eq. 3-49}$$

where

V airspeed (feet/s),
V_T operational airspeed (feet/s),
V_R reference airspeed for the noise curve (feet/s),
D blade diameter (ft),
RPM blade rotations per minute, and
C speed of sound in air (feet/s), as defined by:

$$C = 49.018 \cdot (459.63 + T)^{1/2} \qquad \text{Eq. 3-50}$$

where

T temperature (F).

An example of the derivation of advancing tip mach number adjustment from measured data may be found in the 1993 report "Noise Measurement Flight Test of Five Light Helicopters.[39]"

3.6.2 Lateral Directivity Adjustment (LD_{ADJ})

Helicopters are significantly more directive noise sources than fixed-wing aircraft. Helicopter in-flight directivity is implemented by using three sets of NPDs; left, center and right (see Sections 3.1 and 3.3.3). The left and right data are representative of the acoustic characteristics at a horizontal (to the side) elevation angle of 45°; the center data are representative of the characteristics directly below the helicopter, or at 90°. In cases where the elevation angle is between -45° and 45°, a linear interpolation is performed on the observed elevation angle between the center NPD value and the left or right 45° NPD value for all distances, which is reflected in the Lateral Directivity Adjustment (LD_{ADJ}). The Lateral Directivity Adjustment is calculated according to the following equation:

$$LD_{ADJ} = \left(L_{Left\ or\ Right} - L_{Center}\right) \cdot \left(\frac{|\beta| - 90}{45 - 90}\right) \qquad \text{Eq. 3-51}$$

where

L_{Left}, L_{Center}, L_{Right}

Left, Center or Right NPD data, and

β observed elevation angle between 90 and 45 degrees on either side of the helicopter (see Figure 3-15).

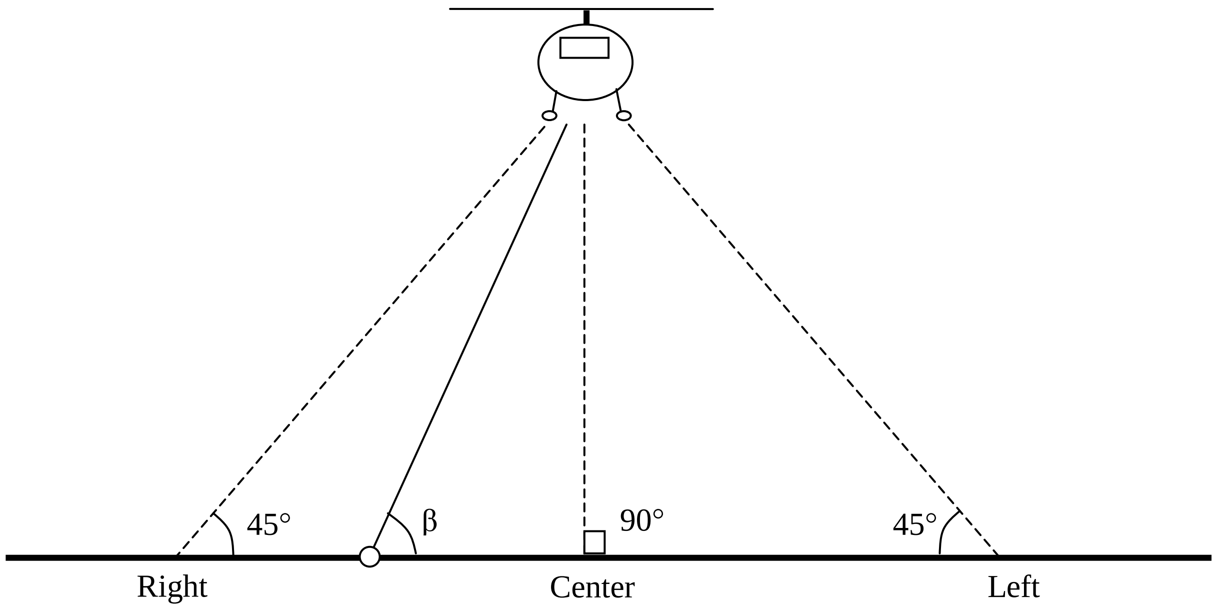

Figure 3-15: Elevation Angle for Helicopter Lateral Directivity Adjustment

For observed elevation angle less than 45 degrees on either side of the helicopter, no lateral directivity adjustment is applied, and the corresponding left or right NPD is used to determine the helicopter noise level. An example of the helicopter lateral directivity adjustment implementation is presented in Figure 3-16.

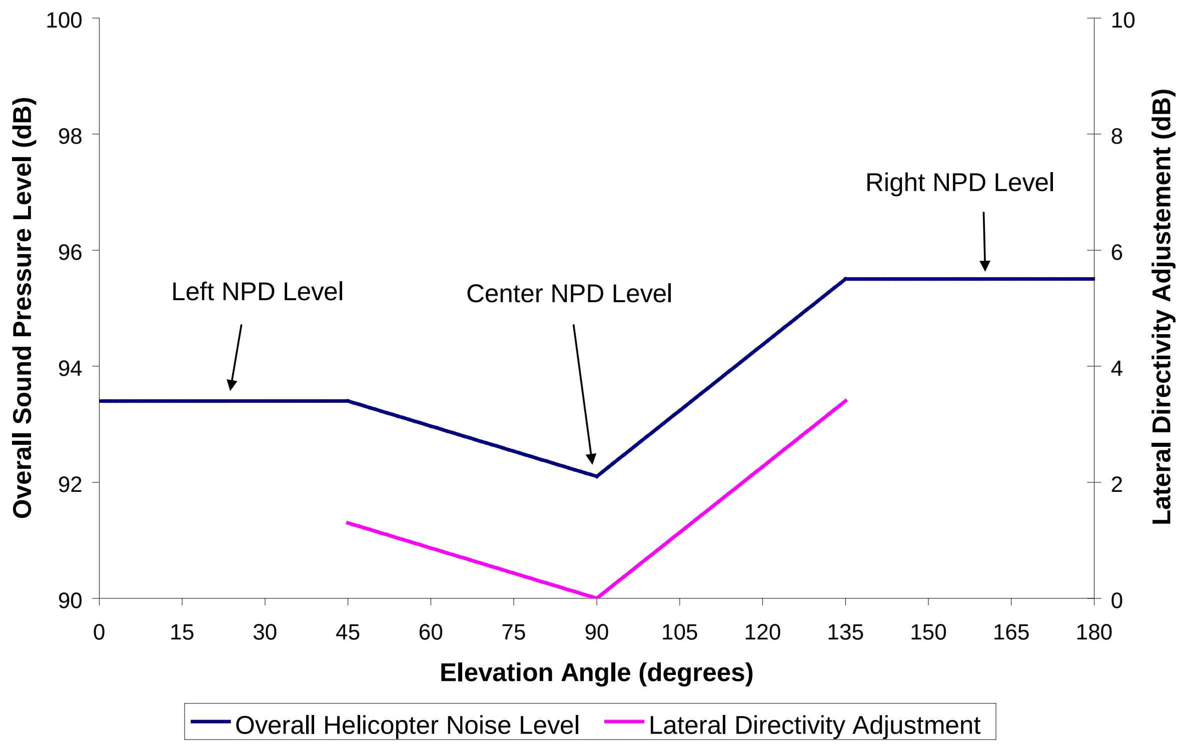

Figure 3-16: Example Helicopter Sound Pressure Levels According to Elevation Angle (including Helicopter Lateral Directivity Adjustment)

3.6.3 Static Directivity Adjustment (DIR_{HELI_ADJ})

The static directivity adjustment accounts for changes to the sound level as a function of the helicopter azimuth angle, which is measured clockwise from the nose. These adjustments are based on empirical data, and account for relative differences in sound level at different angles around the helicopter. $DIR_{HELI,ADJ}$ is only applied during static helicopter operations (Flight Idle, Ground Idle, HIGE and HOGE), as described in Section 3.3.3.. Depending on data availability, different adjustments may be available for each of the four types of static helicopter operations (Flight Idle, Ground Idle, HIGE and HOGE).

3.6.4 Static Operation Duration Adjustment (t_{HELI_static})

Helicopters can perform static operations along a flight track, and as such the duration of time spent on a segment during a static operation can not be determined as a function of aircraft speed and segment length. Instead, the duration of a static event becomes a multiplier to the overall acoustical energy, and is applied as the static operation duration adjustment once all the other general and helicopter adjustments have been applied (see Section 3.7.5).

3.7 Computation of Exposure-Based Noise Level Metrics

This section presents the computation of exposure-based noise level metrics for both fixed wing aircraft flight operations (Section 3.7.2), including runup operations (Section 3.7.3), and helicopter flight operations (Section 3.7.4), including static operations (Section 3.7.5). To obtain the total noise exposure at an observer location, the contributions from fixed wing flight operations and runup operations, and helicopter flight and static operations are combined.

For the computation of exposure-based metrics at multiple observers in a regular grid, including the base regular grid used in a contour analysis, the methodology described in Sections 3.2 through 3.7 is repeated iteratively. If terrain processing is not invoked, the step of computing the acoustic impedance adjustment (Section 3.4.2) and the line-of-sight blockage adjustment (Section 3.4.6) for each observer iteration are skipped. It is not necessary to repeat these steps if the terrain is inactive because the observer's elevation, temperature, and pressure are the same as at the airport, and the effects of terrain blockage are ignored. Furthermore, if the INM study only contains fixed wing aircraft, then the helicopter-specific adjustments (Section 3.6) are skipped. Likewise, the fixed wing aircraft-specific adjustments (Section 3.5) are skipped for studies only containing helicopters.

3.7.1 System Adjustments

Prior to the calculation of noise metrics for flight and runup/static operations, described in Sections 3.7.2 through 3.7.5, INM applies study-wide adjustments to the interpolated NPD data. These adjustments include atmospheric absorption (AA_{ADJ}, Section 3.4.1) and acoustic impedance (AI_{ADJ}, Section 3.4.2). When terrain processing is utilized, only the atmospheric absorption adjustment is applied study-wide.

Study-wide atmospheric absorption (AA_{ADJ}) and acoustic impedance (AI_{ADJ}) adjustments

Prior to application of the segment adjustments highlighted in Sections 3.4.3 through 3.6.4, study-wide atmospheric absorption and acoustic impedance adjustments are applied to the NPD values that are used for noise level interpolation (Section 3.3). In effect, noise level interpolation is undertaken utilizing adjusted NPD curves per the following:

$$L_{E,p,d-ADJ} = L_{E,P,d} + [AA_{ADJ} + AI_{ADJ}]_{study-wide} \quad \text{Eq. 3-52}$$

$$L_{Smx,P,d-ADJ} = L_{Smx,P,d} + [AA_{ADJ} + AI_{ADJ}]_{study-wide} \quad \text{Eq. 3-53}$$

Study-wide atmospheric absorption (AA_{ADJ}) and observer-based acoustic impedance (AI_{ADJ}) adjustments

For studies that utilize terrain processing, the acoustic impedance adjustment is applied separately for each observer, using the terrain elevation at the observer’s location instead of the airport elevation. For studies with terrain processing, noise level interpolation is undertaken by first adjusting NPD curves using study-wide atmospheric absorption, and then the observer location-specific acoustic impedance adjustment is added to the sound levels after noise level interpolation:

$$L_{E,p,d-ADJ} = L_{E,P,d} + [AA_{ADJ}]_{study-wide} + [AI_{ADJ}]_{per-observer} \quad \text{Eq. 3-54}$$

$$L_{Smx,P,d-ADJ} = L_{Smx,P,d} + [AA_{ADJ}]_{study-wide} + [AI_{ADJ}]_{per-observer} \quad \text{Eq. 3-55}$$

3.7.2 Fixed Wing Aircraft Flight Operations

For the exposure-based noise metrics, the sound exposure ratio due to a single flight-path segment of a flight operation for a fixed wing aircraft, denoted by the symbol E_{seg}, is computed as follows:

$$E_{seg} = 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} + DUR_{ADJ} - LA_{ADJ} + TR_{ADJ} + DIR_{ADJ}]}{10}} \quad \text{Eq. 3-56}$$

where

$L_{E.P,d-ADJ}$ L_{AE}, L_{CE}, or L_{EPN}, in dB, resulting from the noise interpolation process using NPD data (Section 3.3) and atmospheric absorption, acoustic impedance and line-of-sight blockage adjustments (Section 3.7.1),
NF_{ADJ} noise fraction adjustment, in dB (see Section 3.4.3),
DUR_{ADJ} aircraft speed duration adjustment, in dB (see Section 3.4.4),
LA_{ADJ} lateral attenuation adjustment, in dB (see Section 3.4.4),
TR_{ADJ} thrust reverser adjustment, in dB, which is applied only if the flight-path segment is part of the landing ground roll during thrust reverser deployment (see Section 3.5.1), and
DIR_{ADJ} directivity adjustment, in dB, which is applied only if the flight-path segment is part of takeoff ground roll (see Section 3.5.2).

As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}, see Section 3.4.6) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (in place of LA_{ADJ}). If line-of-sight blockage is invoked, Equation 3-56 can be rewritten as:

$$E_{seg} = 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} + DUR_{ADJ} - Max[LA_{ADJ}, LOS_{ADJ}] + TR_{ADJ} + DIR_{ADJ}]}{10}} \quad \text{Eq. 3-57}$$

where

LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 3.4.6).

Each flight in the study case has associated with it a given number of operations for the day, evening, and night-time periods. Also, depending upon the user-specified metric, each time period may have a weighting factor, i.e., a noise penalty, associated with it. The weighting factors for the standard exposure-based metrics, along with their associated time-averaging constants N_T, which are presented later in this section, are summarized in Table 3-2.

INM users also have the option to define their own weighting factors and averaging constants through the use of a user-specified exposure-based metric.

The number of operations associated with each time period, coupled with the weighting factors, is used to compute the weighted sound exposure ratio, denoted by the symbol $E_{wt.seg}$, for a single flight-path segment and operation.

$$E_{wt,seg} = [W_{day} \cdot N_{day} + W_{eve} \cdot N_{eve} + W_{ngt} \cdot N_{ngt}] \cdot E_{seg} \qquad \text{Eq. 3-58}$$

where

- N_{day} number of user-specified operations between 0700 and 1900 hours local time,
- N_{eve} number of user-specified operations between 1900 and 2200 hours local time,
- N_{ngt} number of user-specified operations between 2200 and 0700 hours local time,
- W_{day} day-time weighting factor, either standard or user-defined (see Table 3-2 for the standard weighting factors associated with a particular exposure-based noise level metric),
- W_{eve} evening weighting factor, either standard or user-defined,
- W_{ngt} night-time weighting factor, either standard or user-defined, and
- E_{seg} sound exposure ratio at an observer location due to a single flight-path segment of a flight operation.

Table 3-2: Weighting Factors and Time-Averaging Constants for the Standard Exposure-Based Metrics

Metric	W_{day}	W_{eve}	W_{ngt}	N_T	$10 \log_{10}[N_T]$ (dB)
L_{AE}	1	1	1	1	0
L_{dn}	1	1	10	86400	49.37
L_{den}	1	3*	10	86400	49.37
L_{Aeq24h}	1	1	1	86400	49.37
L_d	1	1	0	54000	47.32
L_n	0	0	1	32400	45.11
L_{CE}	1	1	1	1	0
L_{EPN}	1	1	1	1	0
L_{NEF}	1	1	16.67	630957345	88.0†
L_{WECPN}	1	3*	10	8640‡	39.37

The weighted sound exposure ratio for each segment, $E_{wt.seg(i)}$, is computed iteratively and preserved.

The weighted sound exposure ratio due to an entire flight operation is obtained by summing the ratios associated with each segment in the flight path. The weighted sound exposure ratio for a flight operation, $E_{wt.flt}$, is computed as follows:

$$E_{wt,flt} = \sum_{i=1}^{n_{seg}} E_{wt,seg(i)} \qquad \text{Eq. 3-59}$$

where

n_{seg} number of segments in the three-dimensional flight path.

* 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.

† The 88.0 dB value is an arbitrarily chosen scaling constant inherent in the definition of the L_{NEF} metric. A 24-hour period is used to compute the metric.

‡ The 8640 value is the number of 10-second intervals in a 24-hour period. Unlike L_{AE} and L_{CE}, which are normalized to a duration of t_o = 1 second, L_{EPN} is normalized to a duration of t_o = 10 seconds.

The weighted sound exposure ratio for all flight operations in the entire study case is obtained by summing the ratios associated with each flight operation. The weighted sound exposure ratio for all flight operations in the study case, $E_{wt.arpt}$, is computed as follows:

$$E_{wt,arpt} = \sum_{k=1}^{n_{flt}} E_{wt,flt(k)} \qquad \text{Eq. 3-60}$$

where

n_{fl} number of flight operations in the study case.

The mean-square sound-pressure ratio associated with a specific exposure-based noise level metric is computed by dividing the weighted sound exposure ratio for the related base metric, $E_{wt.aprt}$, by a time-averaging constant N_T, either standard or user-specified. The time-averaging constants for the standard exposure-based metrics were summarized in Table 3-2. Note that three of the exposure-base metrics (L_{AE}, L_{CE}, and L_{EPN}) are true sound exposure levels, and they are not divided by a time-averaging constant (or, equivalently, they are divided by 1).

The average or equivalent mean-square sound-pressure ratio, P, associated with an exposure-based metric, is given by:

$$P_{wt,arpt} = \frac{E_{wt,arpt}}{N_T} \qquad \text{Eq. 3-61}$$

The final step in the process is to convert $P_{wt.arpt}$ to its equivalent dB value. The dB value for a user-specified, exposure-based metric due to all flight operations in an airport case is computed as follows:

$$L_{E,wt,arpt} = 10 \cdot \log_{10}[P_{wt,arpt}] \qquad \text{Eq. 3-62}$$

$L_{E.wt.arpt}$ is a standard exposure-based noise level metric or a user-specified exposure-based metric, depending upon the specific weighting factors and time-averaging constants selected.

In addition to the above calculations, the single-event, un-weighted sound exposure level, $L_{E.flt}$, for each flight operation is computed iteratively and saved for use in the time-above calculation (see Section 3.9.1).

$$L_{E,flt} = 10 \cdot \log_{10}\left[\sum_{i=1}^{n_{seg}} E_{seg(i)}\right] \qquad \text{Eq. 3-63}$$

3.7.3 Fixed Wing Aircraft Runup Operations

For the exposure-based noise metrics, the mean-square sound-pressure ratio due to a single runup operation for a fixed wing aircraft, denoted by the symbol P_{runup}, is computed as follows:

$$P_{runup} = 10^{\frac{[L_{Smx,P,d-ADJ} - LA_{ADJ} + DIR_{ADJ}]}{10}} \quad \text{Eq. 3-64}$$

where

$L_{Smx.,P,d-ADJ}$	L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from noise interpolation (Sections 3.3) and adjustment process (Section 3.7.1),
DIR_{ADJ}	directivity adjustment, in dB (Section 3.5.2), and
LA_{ADJ}	lateral attenuation adjustment, in dB (see Section 3.4.5).

As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (Max[LA_{ADJ}, LOS_{ADJ}] in place of LA_{ADJ}).

As is the case with flight operations, each runup in the study case has associated with it a given number of operations for the day, evening, and night-time periods. Depending upon the user-specified metric, each time period may have a weighting factor associated with it. The main difference in computing an exposure-based metric for a flight operation, as compared with a runup operation, is that the runup also has a time duration associated with it.

The number of operations associated with each time period, coupled with the weighting factors and the runup duration, are used to compute the weighted sound exposure ratio, $E_{wt.runup}$, for a single runup operation:

$$E_{wt,runup} = \left[W_{day} \cdot N_{day} + W_{eve} \cdot N_{eve} + W_{ngt} \cdot N_{ngt}\right] \cdot \left(\frac{t_{runup}}{t_0}\right) \cdot P_{runup} \quad \text{Eq. 3-65}$$

where

t_{runup}	runup duration (seconds),
t_o	1 second for L_{ASmx}, or 10 seconds for L_{PNTSmx},

and all other variables are defined in Section 3.7.2.

All subsequent steps required for computing exposure-based noise levels for runup operations are identical to those described in Section 3.7.2 for a flight operation. Specifically, the weighted sound exposure ratio for each runup operation is computed iteratively and preserved. Each ratio is then arithmetically summed for all runup operations in the airport case, a time averaging constant is applied and the ratio is converted to a decibel value.

3.7.4 Helicopter Flight Operations

For the exposure-based noise metrics, the sound exposure ratio due to a single flight-path segment of a flight operation for a helicopter, denoted by the symbol E_{seg_HELI}, is computed as follows:

$$E_{seg\_HELI} = 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} + DUR_{ADJ} - LA_{ADJ} + MN_{ADJ} + LD_{ADJ}]}{10}} \qquad \text{Eq. 3-66}$$

where

- $L_{E.P,d\text{-}ADJ}$ L_{AE}, L_{CE}, or L_{EPN}, in dB, resulting from the noise interpolation process using NPD data (Section 3.3) and atmospheric absorption, acoustic impedance and line-of-sight blockage adjustments (see Section 3.7.1),
- NF_{ADJ} noise fraction adjustment, in dB (see Section 3.4.3),
- DUR_{ADJ} aircraft speed duration adjustment, in dB (see Section 3.4.4),
- LA_{ADJ} lateral attenuation adjustment, in dB (see Section 3.4.5),
- MN_{ADJ} helicopter source noise adjustment, in dB (see Section 3.6.1), and
- LD_{ADJ} lateral directivity adjustment for helicopters, in dB (see Section 3.6.2).

As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (Max[LA_{ADJ}, LOS_{ADJ}] in place of LA_{ADJ}).

All subsequent steps required for computing exposure-based noise levels for helicopter flight operations are identical to those described in Section 3.7.2 for fixed wing aircraft flight operations.

3.7.5 Helicopter Static Operations

For the exposure-based noise metrics, the sound exposure ratio due to a static operation for a helicopter, denoted by the symbol $E_{seg\_HELI\_static}$, is computed as follows:

$$E_{seg\_HELI\_static} = t_{HELI\_static} \cdot 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} - LA_{ADJ} + DIR_{HELI\_ADJ}]}{10}} \qquad \text{Eq. 3-67}$$

where

- $L_{E.P,d\text{-}ADJ}$ L_{AE}, L_{CE}, or L_{EPN}, in dB, resulting from the noise interpolation process using NPD data (Section 3.3) and atmospheric absorption, acoustic impedance and line-of-sight blockage adjustments (Section 3.7.1),
- DIR_{HELI_ADJ} helicopter directivity adjustment for static operations, in dB (Section 3.6.3),
- t_{HELI_static} helicopter duration adjustment for static operations, in seconds (Section 3.6.4),

and all other variables are defined in Section 3.7.2 and 3.7.4. As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (Max[LA_{ADJ}, LOS_{ADJ}] in place of LA_{ADJ}).

All subsequent steps required for computing exposure-based noise levels for helicopter static operations are identical to those described in Section 3.7.2 for fixed wing aircraft flight operation.

3.8 Computation of Maximum Noise Level Metrics

This section presents separately the computation of maximum noise level metrics for flight operations (Section 3.8.1), including runup operations (Section 3.8.2), and helicopter flight operations (Section 3.8.3), including static operations (Section 3.8.4). To obtain the maximum noise level at an observer location, the contributions from fixed wing flight operations and runup operations, and helicopter flight and static operations are combined.

For the computation of maximum noise level metrics at multiple observers in a regular grid, including the base regular grid used in a contour analysis, the methodology described in Sections 3.2through 3.6, as well as that described in Section 3.7, is repeated iteratively. If terrain processing is not invoked, the step of computing the acoustic impedance adjustment (Section 3.4.2) and the line-of-sight blockage adjustment (Section 3.4.6) for each observer iteration are skipped. It is not necessary to repeat these steps if the terrain is inactive because the observer's elevation, temperature, and pressure are the same as at the airport, and the effects of terrain blockage are ignored. Furthermore, if the INM study only contains fixed wing aircraft, then the helicopter-specific adjustments (Section 3.6) are skipped. Likewise, the fixed wing aircraft-specific adjustments (Section 3.5) are skipped for studies only containing helicopters.

3.8.1 Fixed Wing Aircraft Flight Operations

The maximum noise level due to a single flight-path segment for a fixed wing aircraft, $L_{Smx.seg}$, is computed as follows:

$$L_{Smx,seg} = L_{Smx,P,d} + AA_{ADJ} + AI_{ADJ} - LA_{ADJ} + TR_{ADJ} + DIR_{ADJ} \quad \text{Eq. 3-68}$$

where

- $L_{Smx.P,d}$ unadjusted, L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process (see Section 3.3), where the maximum noise level is computed at each segment end and the closest point of approach (CPA), and the maximum of the three levels is used,
- AA_{ADJ} atmospheric absorption adjustment, in dB (see Section 3.4.1),
- AI_{ADJ} acoustic impedance adjustment, in dB (see Section 3.4.2),
- LA_{ADJ} lateral attenuation adjustment, in dB (see Section 3.4.5),
- TR_{ADJ} thrust reverser adjustment, in dB, which is applied only if the flight-path segment is part of the landing ground roll during thrust reverser deployment (see Section 3.5.1), and
- DIR_{ADJ} directivity adjustment, in dB, which is applied only if the flight-path segment is part of takeoff ground roll (see Section 3.5.2).

As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (Max[LA_{ADJ}, LOS_{ADJ}] in place of LA_{ADJ}). Therefore, if line-of-sight blockage is invoked, Equation 3-68 can be rewritten as:

$$L_{Smx,seg} = L_{Smx,P,d} + AA_{ADJ} + AI_{ADJ} - Max\left[LA_{ADJ}, LOS_{ADJ}\right] + TR_{ADJ} + DIR_{ADJ} \qquad \text{Eq. 3-69}$$

where

LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 3.4.6).

The maximum noise level associated with each flight-path segment in a flight operation, $L_{Smx.seg(i)}$, is computed iteratively and preserved.

The maximum noise level associated with each flight operation, $L_{Smx.flt}$, is then determined by performing a flight-segment by flight-segment comparison of $L_{Smx.seg}$ values, and preserving the largest value associated with each flight. $L_{Smx.flt}$ is computed as follows:

$$L_{Smx,flt} = \underset{i=1}{\overset{n_{seg}}{Max}}\left[L_{Smx,seg(i)}\right] \qquad \text{Eq. 3-70}$$

where

n_{seg} number of segments in the three-dimensional flight path.

The maximum noise level associated with each flight operation in the airport case, $L_{Smx.flt(k)}$, is computed iteratively and saved.

The $L_{Smx.flt(k)}$ values are grouped according to the time period within which they occur, day, evening, or night.

The maximum noise level associated with each time period, t, is computed as follows:

$$L_{Smx(t)} = \underset{k=1}{\overset{n_{flt(t)}}{Max}}\left[L_{Smx,flt(k)}\right] \qquad \text{Eq. 3-71}$$

where

$n_{flt(t)}$ number of flight operations in the study case for a given time period, t.

Given three $L_{Smx(t)}$ values, one for each time period, day, evening and night, the user is given the option to select a time period, either day, evening, or night, or any combination thereof, for which the maximum noise level is to be determined.

$$L_{Smx} = Max\left[L_{Smx(day)} \cdot W_{day}, L_{Smx(eve)} \cdot W_{eve}, L_{Smx(ngt)} \cdot W_{ngt}\right] \qquad \text{Eq. 3-72}$$

where

Max[ ] function that returns the maximum of three noise level values,

$L_{Smx(day)}$ maximum noise level for the time period between 0700 and 1900 hours local time,

$L_{Smx(eve)}$	maximum noise level for the time period between 1900 and 2200 hours local time,
$L_{Smx(ngt)}$	noise level for the time period between 2200 and 0700 hours local time,
W_{day}	day-time weighting factor, either zero or one, depending on whether that time period should be considered by the Max function,
W_{eve}	evening weighting factor, either zero or one, and
W_{ngt}	night-time weighting factor, either zero or one.

L_{Smx} is equivalent to either the maximum A-weighted sound level, with slow-scale exponential weighting characteristics (L_{ASmx}), the maximum C-weighted sound level, with slow-scale exponential weighting characteristics (L_{CSmx}), or the tone-corrected maximum perceived noise level, with slow-scale exponential weighting characteristics (L_{PNTSmx}). L_{Smx} is expressed in dB.

3.8.2 Fixed Wing Aircraft Runup Operations

The maximum noise level due to a single runup operation for a fixed wing aircraft, denoted by the symbol $L_{Smx.runup}$, is computed as follows:

$$L_{Smx,runup} = L_{Smx,P,d} + AA_{ADJ} + AI_{ADJ} - LA_{ADJ} + DIR_{ADJ} \quad \text{Eq. 3-73}$$

where

DIR_{ADJ} directivity adjustment, in dB (Section 3.5.2),

and all other variables are defined in Section 3.8.1.

As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (Max[LA_{ADJ}, LOS_{ADJ}] in place of LA_{ADJ}).

As is the case with flight operations, the maximum noise level associated with each runup operation is computed iteratively and preserved.

All subsequent steps required for computing maximum noise levels for runup operations are the same as those described in Section 3.8.1 for fixed wing aircraft flight operations. Specifically, the $L_{Smx.runup}$ values are grouped according to the time period within which they occur, the maximum value for each time period is determined, and the specific time period or combination of periods is selected for determining the maximum level associated with runup operations.

3.8.3 Helicopter Flight Operations

As is the case with fixed wing aircraft (see Section 3.8.1), the maximum noise level due to a single flight-path segment for a helicopter, $L_{Smx.seg\_HELI}$, is computed as follows:

$$L_{Smx,seg\_HELI} = L_{Smx,P,d} + AA_{ADJ} + AI_{ADJ} - LA_{ADJ} + MN_{ADJ} + LD_{ADJ} \quad \text{Eq. 3-74}$$

where

$L_{Smx.P,d}$ unadjusted, L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process (see Section 3.3), where the maximum noise level is computed at each segment end and the closest point of approach (CPA), and the maximum of the three levels is used,

AA_{ADJ} atmospheric absorption adjustment, in dB (Section 3.4.1),

AI_{ADJ} acoustic impedance adjustment, in dB (Section 3.4.2),

LA_{ADJ} lateral attenuation adjustment, in dB (see Section 3.4.5),

MN_{ADJ} helicopter source noise adjustment, in dB (see Section 3.6.1), and

LD_{ADJ} lateral directivity adjustment for helicopters, in dB (see Section 3.6.2).

As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (Max[LA_{ADJ}, LOS_{ADJ}] in place of LA_{ADJ}).

All subsequent steps required for computing maximum noise levels for helicopter flight operations are the same as those described in Section 3.8.1 for fixed wing aircraft flight operations.

3.8.4 Helicopter Static Operations

The maximum noise level due to a static operation for a helicopter, denoted by the symbol $L_{Smx.HELI\_static}$, is computed as follows:

$$L_{Smx,HELI\_static} = L_{Smx,P,d} + AA_{ADJ} + AI_{ADJ} - LA_{ADJ} + DIR_{HELI\_ADJ} \quad \text{Eq. 3-75}$$

where

DIR_{HELI_ADJ} helicopter directivity adjustment for static operations, in dB (Section 3.6.3),

and all other variables are defined in Sections 3.8.1 and 3.8.3.

As noted in Section 3.4.6, if line-of-sight blockage is invoked as a run option, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}) on a segment-receiver calculation-by-calculation basis, and the larger of the two values is applied to the calculations (Max[LA_{ADJ}, LOS_{ADJ}] in place of LA_{ADJ}).

All subsequent steps required for computing maximum noise levels for helicopter static operations are the same as those described in Section 3.8.1 for fixed wing aircraft flight operations.

3.9 Computation of Time-based metrics

This section presents separately the computation of the time-based metrics for flight operations (Section 3.9.1), as well as for ground operations (Section 3.9.2); which include both runup operations for fixed wing aircraft and static operations for helicopters. To obtain time-based metrics at an observer location, the contribution from both flight operations and ground operations are combined. Although time audible takes into account adjusted noise levels for the flight and ground operations and a user-specified noise-level threshold like the other time-based metrics, the computation of time audible differs significantly from the other time-based metrics and is therefore presented separately (Section 3.9.3).

For the computation of time-based metrics at multiple observers in a regular grid, the methodology described in Sections 3.2 through 3.6, as well as that described in Section 3.7, is repeated iteratively. When computing time-based metrics at multiple grid points the user is given the option to define the threshold level for each unique point. All time-based metrics computations in INM are referenced to a noise level threshold: either a fixed threshold level or a file of threshold or ambient values that may vary in noise level according to receiver location. The only caveat is for time audible, which may only be computed with a user-specified ambient file including both noise levels and spectra according to receiver location.

If terrain processing is not invoked, the steps of computing the acoustic impedance adjustment (Section 3.4.2) and the line-of-sight blockage adjustment (Section 3.4.6) for each observer iteration are skipped. It is not necessary to repeat these steps if the terrain processing is not invoked because the observer's elevation, temperature, and pressure are the same as at the airport, and the effects of terrain blockage are ignored. Furthermore, if the INM study only contains fixed wing aircraft, then the helicopter-specific adjustments (Section 3.6) are skipped. Likewise, the fixed wing aircraft-specific adjustments (Section 3.5) are skipped for studies only containing helicopters.

An important assumption inherent in time-above and percent time-above computations, including time audible computations, is that operations do not overlap in time, i.e., user-specified operations occur in a serial fashion. However, if a study includes operations occurring simultaneously (e.g., modeling an airport with parallel runways), the computed time-above metric may be larger than what would be measured at the airport. In such instances, a user could define operations in terms of equivalent numbers of serial operations, as compared with average-annual day operations.

3.9.1 Flight Operations

The time-above metric (in minutes) due to a single flight operation is computed by the equation:

$$TA_{flt} = \left(\frac{4}{\pi}\right) \cdot t_0 \cdot \left[10^{\frac{\left[L_{E,flt} - L_{Smx,flt}\right]}{10}}\right] \cdot \left[10^{\frac{\left[L_{Smx,flt} - L_0\right]}{20}} - 1\right]^{½} \cdot \frac{1}{60} \qquad \text{Eq. 3-76}$$

where

t_o 1 second for L_{AE} and L_{CE}, or 10 seconds for L_{EPN},

$L_{E.flt}$ adjusted noise exposure level for the flight (dB), L_{AE}, L_{CE}, L_{EPN} (Section 3.7.2 for fixed wing aircraft and Section 3.7.4 for helicopters),

$L_{Smx.flt}$ adjusted maximum noise level for the flight (dB), L_{ASmx}, L_{CSmx}, L_{PNTSmx} ($L_{Smx.flt}$ must be larger than L_0), and

L_0 user-specified noise-level threshold (dB), expressed as A-weighted noise level, C-weighted noise level, or tone-corrected perceived noise level.

See Appendix C for a derivation of the time-above equation.

Each flight in the study case has associated with it a set number of operations for the day, evening, and night-time periods, along with weighting factors. In the case of the TA metric, the weighting factors act as binary switches, allowing the user to select/deselect specific time periods over which to compute TA. The number of operations associated with each time period, coupled with the weighting factors, are used to compute the weighted time-above value associated with a specific flight operation:

$$TA_{wt,flt} = \left[W_{day} \cdot N_{day} + W_{eve} \cdot N_{eve} + W_{ngt} \cdot N_{ngt}\right] \cdot TA_{flt} \qquad \text{Eq. 3-77}$$

where

N_{day} number of user-specified operations between 0700 and 1900 hours local time,

N_{eve} number of user-specified operations between 1900 and 2200 hours local time,

N_{ngt} number of user-specified operations between 2200 and 0700 hours local time,

W_{day} day-time weighting factor, either zero or one, depending on whether that time period should be considered,

W_{eve} evening weighting factor, either zero or one, and

W_{ngt} night-time weighting factor, either zero or one.

The weighted TA for each flight operation in the study case is computed iteratively and preserved.

The time-above metric for all flight operations in the entire study case is then obtained by summing the $TA_{wt.flt}$ values associated with each operation. The time above for all flight operations in the study case, $TA_{wt.aprt}$, is computed as follows:

$$TA_{wt,arpt} = \sum_{k=1}^{n_{flt}} TA_{wt,flt(k)} \qquad \text{Eq. 3-78}$$

where

n_{fl} number of flight operations in the airport case.

TA is equivalent to either the time above an A-weighted sound level (TA_{LA}), the time-above a C-weighted sound level (TA_{LC}), or the time above a tone-corrected perceived noise level (TA_{LPNT}), depending on the metric family selected, either the A-weighted, C-weighted, or the tone-corrected perceived. TA is expressed in minutes.

For percent time-above metrics (%TA_{LA}, %TA_{LC}, and %TA_{LPNT}), the total time in minutes is divided by the user-defined time period of interest (in minutes) and multiplied by 100 percent.

3.9.2 Ground Operations

The time-above metric due to a single ground operation (either a runup operation for fixed wing aircraft or a static operation for helicopters) is the portion of the ground operation time during which the user-specified noise level threshold is exceeded by the ground operation noise. The time-above for a ground operation is computed as follows:

$$TA_{ground} = \begin{cases} T_{ground} & when\ L_{Smx} > L_0 \\ 0 & when\ L_{Smx} \le L_0 \end{cases} \qquad \text{Eq. 3-79}$$

where

T_{ground} time-above duration (minutes) of the ground operation event,

L_{Smx} one of three types of adjusted maximum noise levels for a ground operation (Sections 3.8.1 and 3.8.2 for fixed wing aircraft and Section 3.8.4 for helicopters), and

L_0 time-above noise threshold level.

All subsequent steps required for computing time above for ground operations are identical to those described in Section 3.9.1 for a flight operation. Specifically, the weighted TA for each ground operation is computed iteratively and preserved. Each TA value is then arithmetically summed for all ground operations in the study case.

In the case of percent TA metrics the summed time is divided by the user-defined time period of interest (in minutes) and multiplied by 100 percent.

3.9.3 Time Audible Computations

The time audible metric (in minutes) due to a single aircraft operation is based on the computation of the total detectability level of that operation:

$$D'L_{total} = 10 \cdot \log_{10}\left[d'_{total}\right] \qquad \text{Eq. 3-80}$$

where

$D'L_{total}$ the total detectability level of an aircraft operation,

d'_{total} the square root of the sum of squares of detectability over all frequency bands, as given by:

$$d'_{total} = \left[\sum_{band=17}^{40}\left(d'_{band}\right)^2\right]^{1/2} \qquad \text{Eq. 3-81}$$

d'_{band} the detectability for each one-third octave frequency band:

$$d'_{band} = 10^{\frac{D'L_{band}}{10}} \quad \text{Eq. 3-82}$$

$D'L_{band}$ the detectability level for each one-third octave frequency band:

$$D'L_{band} = (L_{signal,band} - L_{noise,band}) + \{10 \cdot \log_{10}[\eta_{band}] + 0.5 \cdot 10 \cdot \log_{10}[bandwidth]\}$$

Eq. 3-83

$10\log[\eta_{band}]$	one-third octave band specific constant,
bandwidth	the bandwidth of the one-third octave band, and
$L_{noiseband}$	the addition of the un-weighted, measured one-third octave band ambient levels and the appropriate Equivalent Auditory System Noise (EASN)[40] level.

Specific constants utilized in the detectability equation are presented in Appendix E (see Table E-4-3 and Table E-4-4).

Once the total detectability level has been determined, it is compared to the following detectability criteria:

$$D'L_{total} \geq 7 \quad \text{the aircraft operation is detectable.}$$
$$D'L_{total} < 7 \quad \text{the aircraft operation is not detectable.} \quad \text{Eq. 3-84}$$

For each segment of the aircraft operation that is detectable, the time it takes aircraft to travel through that flight path segment is computed:

$$segtime = \left(\frac{seglength}{segspeed}\right) \cdot \#\ of\ operations \quad \text{Eq. 3-85}$$

where

seglength	length (in feet) of contributing flight path segment,
segspeed	average speed (in feet/s) during contributing flight path segment, and
segtime	time passed during contributing flight path segment (s).

Time audible is a cumulative metric, and as such it is the summation of all of the segtime values of an aircraft operation that are flagged as detectable. Therefore, time audible is computed according to:

$$TAud = TAud + segtime \quad \text{Eq. 3-86}$$

Once time audible has been computed iteratively with Eq. 3-86 for all detectable segments in the study case, the time audible (in minutes) for a time period will be:

$$TAud = \frac{TAud}{\left(\frac{60\,\text{seconds}}{\text{minute}}\right)} \qquad \text{Eq. 3-87}$$

For percent time audible, the total time in minutes is divided by the user-defined time period of interest (in minutes) and multiplied by 100 percent.

See Appendix E for a complete description of the time audible computation process.

4 RECURSIVELY-SUBDIVIDED IRREGULAR GRID DEVELOPMENT

As presented in Chapter 1, INM Version 7.0 computes noise-level or time-based metrics in the vicinity of an airport and presents the results in one of two formats: (1) noise-level or time-above values at observer positions; or (2) a plot of contours of user-specified noise levels or time-above values. The basic methodology presented in Chapter 3 describes the computation of noise metrics at a single point or for an evenly-spaced regular grid of points (or Fixed Grid). The development of the recursively-subdivided irregular grid of points (or Recursive Grid), which is only available for contour analysis, requires additional discussion.

When performing a contour analysis using a recursively-subdivided irregular grid, INM Version 7.0 computes noise-level or time-above values for each observer location in a regular base grid, using the methodology described in Chapter 3. The size of the base grid depends on a user-specified scenario analysis window. The number of points in the base grid is dynamically scaled up or down to provide a grid point spacing of one nautical mile or less. INM creates a recursively-subdivided irregular grid of observers inside the base grid. The density of points in the irregular grid depends on user-specified contour accuracy. Noise levels or time-above values are calculated at each grid point.

Noise-level or time-above contours are developed from the recursively-subdivided irregular grid noise data using a module derived from the United States Air Force NMPLOT Version 4.6 computer program.[41] NMPLOT constructs a contour by (1) computing the Delaunay Triangulation of the grid points, (2) finding a rough contour by drawing straight contour segments through each triangle in the triangulation, and (3) smoothing the rough contour by using cubic splines under tension.*

NMPLOT is an integral component of the NOISEMAP model that is used to predict noise in the vicinity of airports dominated by military operations.[18] To a certain extent, NMPLOT has become the standard contouring program in the transportation-related noise modeling industry. In addition to INM and NOISEMAP, NMPLOT is also used to compute sound level contours for the Federal Highway Administration's Traffic Noise Model (FHWA TNM®), which is used for predicting noise in the vicinity of highways and for designing highway noise barriers.[42]

4.1 Determination of Noise/Time Significant Flight Segments

After computing the regular base grid, the first step in the process of developing the recursively-subdivided grid is to determine which flight segments in a study case are noise- or time-significant at each observer location in the base grid. The purpose of determining significant flight segments is to help reduce the run-time associated with an INM contour computation.

* The NMPlot Version 4.6 User's Guide is available from Wasmer Consulting at http://www.wasmerconsulting.com.

In versions previous to INM Version 7.0, noise/time significance was performed on a per flight path basis. If an INM study case had 1000 flight paths, there might be 50000 flight path segments. Rather than evaluating 1000 flight paths for noise significant contributions, INM Version 7.0 evaluates the 50000 flight path segments. Even though there are overhead calculations associated with this new segment-based approach, a small increase in calculation precision and a modest decrease in overall runtime are obtained.

Two separate tests are performed by INM to determine if a flight segment is noise significant: (1) a relative noise-level/time test, and (2) a flight segment proximity test. These tests are performed at each observer location making up the base grid. The significance information is then used to guide the process of sub-dividing the base grid to improve contour precision.

4.1.1 Relative Noise-Level/Time Test

In the relative noise-level/time test, all flight segments are sorted, high-to-low, on the basis of their relative noise/time contribution to an observer in the base grid. If a user specifies that a contour analysis be computed, the sorted list takes into account the weighted segment associated with the specific metric. If a user specifies that a family of metrics (A-weighted, C-weighted, or tone-corrected perceived noise) contour analysis be computed, the sorted list cannot take into account weighted segments, since they are not yet known. Instead, three sorted lists are developed, one for each of the three time periods (day, evening, and night).

The total noise (or time) value at a base-grid observer location is computed by summing the sound exposure ratios (or time-above values) over all flight operations. A running total noise value is also computed from the sorted list of segments, beginning with the flight segment having the largest contribution to the noise, and proceeding through the ordered list. The running noise value is continually compared to the total noise value at a base-grid observer location. When the running value exceeds 97 percent of the total value, the running value is considered complete, and all subsequent flight segments in the sorted list are marked insignificant.

In the case of the exposure-based and time-based metrics, the 97 percent criterion guarantees that the significant-segment noise level is within 0.1 dB and that the time-above is within three percent of the total noise/time computed using all the flight segments.

For maximum noise-level metrics, the 97 percent criterion is not used, since the summation of maximum noise-level metrics is not meaningful. In the relative noise-level test for maximum noise-level metrics only one flight segment is considered significant, the one representing the maximum sound level at an observer location.

4.1.2 Segment Proximity Test

In addition to the relative noise-level/time test, a flight segment proximity test is performed on all segments that are marked noise-insignificant. This test uses acceptance criterion based on the diagonal distance between base grid points. For most metrics, this criterion is the diagonal distance, but several metrics also require a distance multiplier. These metrics are: TALA (three times the diagonal distance), TALC (four times the diagonal distance), PNLTM (two times the diagonal distance), and TAPNL (four times the diagonal distance). If any part of a flight segment is within this criterion based on diagonal distance of the base grid point being tested, then the flight segment is re-instated as being significant.

4.2 Grid Development

To generate a recursively-subdivided grid, INM first organizes the base grid into grid working areas, each containing nine observer locations (see Figure 4-1). The number of grid working areas depends on the size of the user-defined scenario analysis window. The base grid is dynamically scaled up or down to provide spacing between base grid points of approximately one nautical mile. For a scenario analysis window that is 16 x 16 nautical miles, there will be 64 working areas.

4.2.1 Low/High Contour Cutoff Splitting Test

A low/high cutoff contour test is performed on all working areas in the base grid for contour analyses. Similar to the two noise significance tests, the primary purpose of this test is to speed up the grid-development process.

If all nine noise-level or time-above values within a given working area are sufficiently below/above user-defined minimum/maximum contour levels, further computations are unnecessary, and splitting of the working area is not performed.

4.2.2 Tolerance and Refinement Splitting Tests

A tolerance/refinement splitting test is used to iteratively develop a recursively subdivided irregular grid. The splitting test compares known grid-point values in a nine-point working area to linearly interpolated values. If the interpolated values are within a user-specified tolerance of the known values, or if the user-specified refinement level has been reached, then no splitting is performed.

> The tolerance value is a user-specified value number greater than 0.1 dB or 0.1 minutes. The INM default tolerance value is 0.25 (dB or minutes).
>
> The refinement level is a user-specified integer between 4 and 18, where 4 represents one level of subdivision of the base grid, and each subsequent refinement level represents an additional level of subdivision. The INM default refinement level is 8, i.e., five levels of subdivision.

For a contour analysis, the comparison between known values and linearly interpolated values takes into account the weighted operations associated with the specific metric.

For the example nine-point working area shown in Figure 4-1 (points A through I), the splitting test proceeds by linearly interpolating values at B, D, E, F, H using the values at A, C, G, I. For example, the interpolated value at B is ½(A + C). Then, eight comparisons are made: calculated B versus interpolated B, calculated E versus interpolated E, etc. There are three horizontal, three vertical, and two diagonal comparisons. If any one of the eight comparisons produces an absolute difference between interpolated and computed values greater than the user-specified tolerance, then the rectangle formed by points A, C, G, and I is subdivided into four new nine-point working areas.

For example, new points (V, W, X, Y, Z) are created in the upper-left quadrant, forming a new nine-point working area. Point V is halfway between points A and B, point W is halfway between points A and D, etc. The noise-levels or time-above values at points V, W, X, Y and Z are then computed using the methodology of Chapter 3, taking into account only noise significant flight operations that are associated with the closest base grid points. For example, since point V is halfway in between points A and B, the noise-significant flights associated with both points are used in the computation.

The above computation iteratively continues until either the user-specified tolerance level or refinement level is achieved.

When the contour analysis is complete for all base grid working areas, point locations and associated noise-level or time-above values are saved in a pair of binary files, *GRID* and *CONTOUR*. These files are further processed to produce the *NMPLOT.GRD* binary file, which the NMPLOT module uses to generate the actual contours.

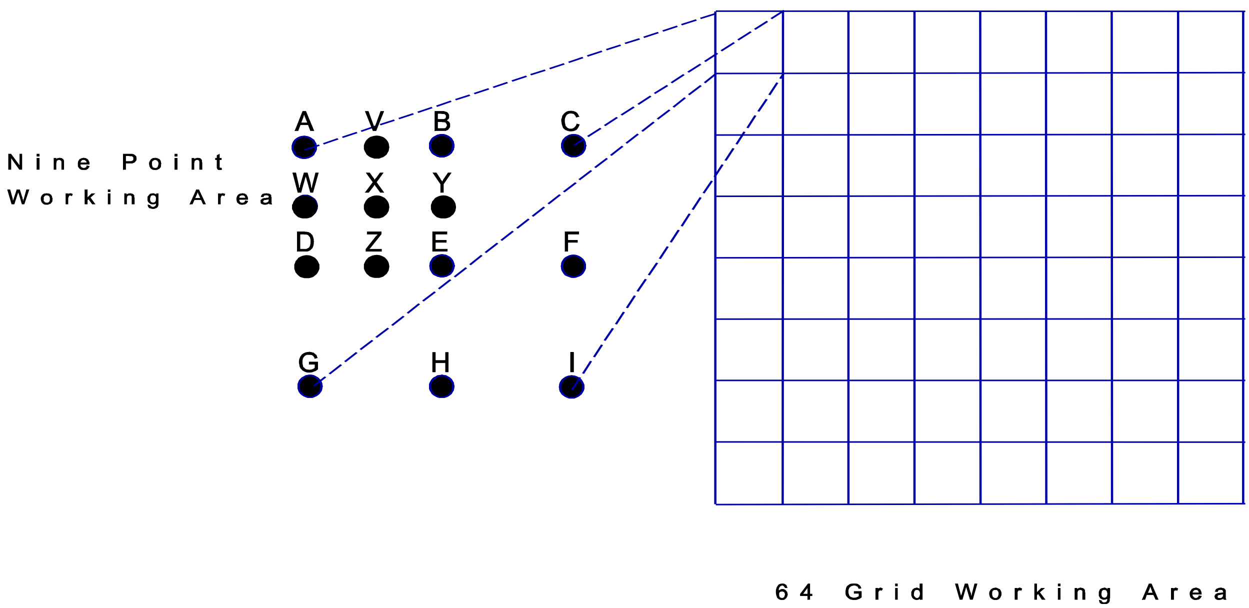

Figure 4-1: Example Grid Area Used for the Generation of Contours

APPENDIX A: EXAMPLE FLIGHT PATH FILE

The following example file shows data that are passed from the flight path calculation module to the noise calculation module. This is a text version of the INM Version 7.0 *FLIGHT.PTH* file. More detailed descriptions for the parameters that define the actual flight paths are presented in Table A-1 below.

```
INM 7.0
HEADER DATA
  case_id           = D:\INMSTUDY\v70\test411\CASE1
  aprt_lat          = 39.870431 deg
  aprt_long         = -75.245183 deg
  aprt_elev         = 2500.00 feet MSL
  aprt_temp         = 59.00 degF
  aprt_press        = 29.92 in-Hg
  aprt_humidity     = 70.0 %
  rs_refine         = 6
  rs_toler          = 1 dB or minutes
  min_level         = 55.0 dB or minutes
  max_level         = 85.0 dB or minutes
  run_type          = S (Single,AmbientScreening,Audibility)
  metric_id         = LAMAX
  fq_type           = A (A-weighted,C-weighted,Perceived)
  metric_type       = M (Exposure,MaxLevel,TimeAbove)
  metric_weight     = 1.00, 1.00, 1.00 (flight multipliers)
  metric_time       = 0.00 dB
  modify_npd        = 0 (0=no,1=yes)
  do_terrain        = N
  nodata_terrain_elev = -9999
  ground_type       = S (Soft,Hard,File,None)
  terrain_dir       = D:\INMSTUDY\SFO\RWY\Terrain3CD
  ground_file       =
  ambient_file      =
  spectra_file      =
  boundary_file     =
  do_contours       = N
  do_standard_grids = 0 (0=no,1=yes)
  do_detailed_grids = 1 (0=no,1=yes)
```

```
  do_100_percent    = 1 (0=no,1=yes)
  use_boundary_file = N
  do_metrics        = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
  numb_ngroup       = 12
  numb_noise        = 124
  numb_apln_ops     = 79
  numb_helo         = 2
  numb_helo_ops     = 1
  numb_grid         = 1
  numb_pop_pts      = 0
  numb_loc_pts      = 0
  numb_scr_pts      = 0

AIRPLANE NOISE (index, id, fq_type, thrust, op_type, 10 SEL/EPNL @ 160 kt, 10 LAMAX/PNLTM)
  0  3JT8DQ       A  3000.0 A  96.6  92.8  89.8  86.8  81.8  75.4  71.0  65.6  59.2  52.2
                               96.9  90.2  85.6  80.6  72.8  64.3  58.1  51.2  43.3  34.8
  1  3JT8DQ       A  6000.0 A 101.8  98.0  95.1  92.0  87.0  80.9  76.2  70.8  64.4  57.4
                              101.1  94.4  89.8  84.8  77.0  68.5  62.3  55.4  47.5  39.0
  2  3JT8DQ       A  8000.0 D 106.3 102.6  99.7  96.7  91.7  85.7  81.1  75.8  69.6  62.8
                              106.1  99.4  94.8  89.8  82.0  73.6  67.5  60.6  52.9  44.6
  3  3JT8DQ       A 10000.0 D 111.0 107.2 104.5 101.5  96.6  90.6  86.1  81.0  74.9  68.3
                              111.2 104.5  99.9  95.0  87.2  78.8  72.8  66.1  58.5  50.5
  4  3JT8DQ       A 12000.0 D 115.8 112.1 109.4 106.5 101.6  95.8  91.3  86.2  80.4  74.1
                              116.6 109.9 105.3 100.4  92.5  84.3  78.4  71.7  64.4  56.6
  5  3JT8DQ       A 14000.0 D 121.1 117.4 114.8 112.0 107.1 101.4  97.0  92.1  86.4  80.4
                              122.1 115.4 110.8 106.0  98.1  89.9  84.1  77.6  70.4  62.9
  6  3JT8DQ       P  3000.0 A 100.6  96.4  93.1  89.4  83.4  76.4  71.1  65.0  57.5  48.8
                              108.2 101.2  96.1  90.5  81.7  71.9  64.8  56.8  47.4  36.9
  7  3JT8DQ       P  6000.0 A 106.4 102.2  98.9  95.2  89.2  82.2  76.9  70.8  63.3  54.6
                              114.0 107.0 101.9  96.3  87.5  77.7  70.6  62.6  53.2  42.7
  8  3JT8DQ       P  8000.0 D 110.7 106.5 103.3  99.7  93.8  87.1  82.0  76.3  69.3  61.1
                              118.3 111.3 106.3 100.8  92.1  82.6  75.7  68.1  59.2  49.2
  9  3JT8DQ       P 10000.0 D 115.2 111.2 108.0 104.5  98.8  92.2  87.5  82.1  75.6  68.0
                              122.8 116.0 111.0 105.6  97.1  87.7  81.2  73.9  65.5  56.1
 10  3JT8DQ       P 12000.0 D 119.4 115.8 112.7 109.3 103.7  97.4  93.0  88.0  82.0  75.0
                              127.0 120.6 115.7 110.4 102.0  92.9  86.7  79.8  71.9  63.1
 11  3JT8DQ       P 14000.0 D 124.8 120.9 117.9 114.6 109.2 103.1  99.0  94.4  89.0  82.6
                              132.4 125.7 120.9 115.7 107.5  98.6  92.7  86.2  78.9  70.7
(etc.)

AIRPLANE OPERATIONS
0
```

```
  acft_id     = 747200
  eng_type    = J (Jet,Turboprop,Piston)
  stat_thrust = 45500 (Pounds)
  thrust_type = L (P=Percent, L=Pounds, X=Other)
  owner_cat   = C (Commercial,GenAviation,Military)
  op_type     = R (A=appr,D=dep,T=touch&go,F=circuit,V=overflight,R=runup)
  numb_ops    = 10.0000, 0.0000, 0.0000 (day,eve,ngt)
  frst_a_nois = 24
  numb_a_nois = 5
  frst_p_nois = 29
  numb_p_nois = 5
  model_type  = I (Inm,Noisemap)
  spect_nums  = 207, 107, 0 (approach,depart,afterburner)
  runup_id    = A01
  point       = 0.0, 0.0
  heading     = 93.0
  thrust      = 41971.0
  duration    = 1.0
1
  acft_id     = 727Q15
  eng_type    = J (Jet,Turboprop,Piston)
  stat_thrust = 15500 (Pounds)
  thrust_type = L (P=Percent, L=Pounds, X=Other)
  owner_cat   = C (Commercial,GenAviation,Military)
  op_type     = A (A=appr,D=dep,T=touch&go,F=circuit,V=overflight,R=runup)
  numb_ops    = 19.6000, 0.0000, 2.8000 (day,eve,ngt)
  frst_a_nois = 52
  numb_a_nois = 6
  frst_p_nois = 58
  numb_p_nois = 6
  model_type  = I (Inm,Noisemap)
  spect_nums  = 201, 132, 0 (approach,depart,afterburner)
  flt_path    = A-09R-TR9-0-USER-1
  numb_segs   = 21
  seg  start-x   start-y  start-z   unit-x  unit-y  unit-z   length   speed  d.spd   thrust    d.thr  op  flaps   bank  duration

   0 -127253.4  -13322.5   6000.0   0.9834  0.1754 -0.0454  12171.2   273.4  -17.7   2495.2      0.0   A -NONE-   0.0     27.3
   1 -115283.7  -11187.5   5446.9   0.9834  0.1754 -0.0454  11357.6   255.7  -17.7   2495.2      0.0   A -NONE-   0.0     27.3
   2 -104114.1   -9195.2   4930.8   0.9834  0.1754 -0.0454  10544.1   238.0  -17.7   2495.2      0.0   A -NONE-   0.0     27.3
   3  -93744.5   -7345.6   4451.6   0.9834  0.1754 -0.0454   9730.6   220.4  -17.7   2495.2      0.0   A -NONE-   0.0     27.3
```

```
   4  -84175.1   -5638.7   4009.5   0.9834  0.1754 -0.0454   8917.0   202.7  -17.7   2495.2      0.0   A -NONE-   0.0     27.3
   5  -75405.6   -4074.5   3604.2   0.9834  0.1754 -0.0454   8103.5   185.0  -17.7   2495.2      0.0   A -NONE-   0.0     27.3
   6  -67436.3   -2653.1   3236.0   0.9831  0.1754 -0.0523  16382.6   167.3   -7.5   2495.2    367.5   A -NONE-   0.0     59.4
   7  -51330.3     219.7   2378.7   0.9899  0.1317 -0.0523    955.7   159.8   -0.5   2862.7     20.0   A -NONE-   0.0      3.5
   8  -50384.2     345.6   2328.7   0.9986  0.0113 -0.0523    955.7   159.3   -0.5   2882.7     19.9   A -NONE-   0.0      3.6
   9  -49429.8     356.4   2278.7   0.9981 -0.0329 -0.0523  12128.1   158.9   -5.9   2902.5    241.1   A -NONE-   0.0     46.1
  10  -37324.9     -42.3   1644.0   0.9981 -0.0329 -0.0523  12169.0   153.0   -3.2   3143.6   1711.0   A -NONE-   0.0     47.6
  11  -25179.2    -442.4   1007.0   0.9981 -0.0329 -0.0523  12168.9   149.8   -2.2   4854.6   -172.3   A -NONE-   0.0     48.5
  12  -13033.6    -842.5    370.0   0.9981 -0.0329 -0.0522   6125.2   147.6   -6.5   4682.3   4136.1   A -NONE-   0.0     25.1
  13   -6920.1   -1043.9     50.0   0.9981 -0.0329 -0.0522    957.1   141.1   -1.1   8818.4    481.6   A -NONE-   0.0      4.0
  14   -5964.8   -1075.3      0.0   0.9995 -0.0329  0.0000    880.8   140.0  -18.3   9300.0  -1291.7   A -NONE-   0.0      4.0
  15   -5084.5   -1104.3      0.0   0.9995 -0.0329  0.0000    757.4   121.7  -18.3   8008.3  -1291.7   A -NONE-   0.0      4.0
  16   -4327.5   -1129.3      0.0   0.9995 -0.0329  0.0000    634.0   103.3  -18.3   6716.7  -1291.7   A -NONE-   0.0      4.0
  17   -3693.9   -1150.1      0.0   0.9995 -0.0329  0.0000    510.5    85.0  -18.3   5425.0  -1291.7   A -NONE-   0.0      4.0
  18   -3183.7   -1167.0      0.0   0.9995 -0.0329  0.0000    387.1    66.7  -18.3   4133.3  -1291.7   A -NONE-   0.0      4.0
  19   -2796.8   -1179.7      0.0   0.9995 -0.0329  0.0000    263.7    48.3  -18.3   2841.7  -1291.7   A -NONE-   0.0      4.0
  20   -2533.2   -1188.4      0.0   0.9995 -0.0329  0.0000      1.0    30.0    0.0   1550.0      0.0   A -NONE-   0.0      0.0
(etc.)

HELICOPTER NOISE
0
  helo_id     = A109
  helo_index  = 0
  rotor_diam  = 36.1 feet
  rotor_rpm   = 385 rpm
  ref_weight  = 5730 pounds
  ref_speeds  = 60.0, 60.0, 116.0 knots (approach,depart,level)
  b_left      = -0.10, 46.30, 249.37
  b_center    = 0.10, 53.26, 318.98
  b_right     = 0.65, 53.98, 746.90
  model_type  =   (Inm,Noisemap)
  spect_nums  = 217, 115, 301 (approach,depart,level)
  numb_npd_a  = 32  (fq_type=A, npd_index, side_type, 10 SEL @ 160 kt, 10 LAMAX)
     A  0 L   93.0  89.5  87.1  84.3  79.7  74.3  70.2  65.6  61.3  56.9
              91.3  85.4  81.5  77.2  70.2  62.5  56.9  50.7  44.8  38.9
     A  0 C   95.2  91.9  89.5  87.0  82.7  77.5  73.5  68.6  64.3  59.6
              93.5  87.8  83.9  79.9  73.2  65.7  60.2  53.7  47.8  41.6
     A  0 R   94.2  90.8  88.4  85.8  81.5  76.7  72.7  67.9  63.6  59.0
              92.5  86.7  82.8  78.7  72.0  64.9  59.4  53.0  47.1  41.0
     A  1 L   92.0  88.5  86.0  83.3  78.7  73.2  69.0  63.9  59.4  54.5
              90.3  84.4  80.4  76.2  69.2  61.4  55.7  49.0  42.9  36.5
     A  1 C   89.4  85.8  83.3  80.5  75.6  69.9  65.4  60.3  55.6  50.6
              87.7  81.7  77.7  73.4  66.1  58.1  52.1  45.4  39.1  32.6
     A  1 R   90.8  87.3  84.7  82.0  77.4  71.9  67.7  62.8  58.4  53.6
              89.1  83.2  79.1  74.9  67.9  60.1  54.4  47.9  41.9  35.6
```

```
(etc.)
  numb_npd_p  = 0  (fq_type=P, npd_index, side_type, 10 EPNL @ 160 kt, 10 PNLTM)
  numb_direc  = 8 (ground_type, op_mode, dB @ -180 to +180 deg in 15-deg increments)
     H      G   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
         0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
     H      H   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
         0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
     H      I  -2.6  -1.1   0.9   2.6   3.3   2.5   0.5  -2.0  -3.6  -3.6  -2.2  -0.6   0.0
        -0.9  -2.4  -3.1  -2.2   0.0   2.2   2.9   2.0  -0.1  -2.1  -3.1  -2.6
     H      J   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
         0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
     S      G   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
         0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
     S      H   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
         0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
     S      I  -3.8  -5.1  -4.0  -1.9  -0.1   1.1   1.9   2.4   2.1   0.5  -2.1  -3.9  -3.5
        -1.0   1.7   2.2  -0.1  -3.3  -4.8  -3.2   0.2   2.7   2.2  -0.7  -3.8
     S      J   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
         0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
(etc.)

HELICOPTER OPERATIONS
0
  helo_id     = A109
  helo_index  = 0
  op_type     = D (A=app,D=dep,T=taxi,V=ovf)
  weight      = 5730 pounds
  numb_ops    = 2.0000, 0.0000, 0.0000 (day,eve,ngt)
  flt_path    = D-HELO-DEPHELO-0-STANDARD-1
  use_direc   = 1 (0=no,1=yes)
  numb_segs   = 14
  seg  start-x   start-y  start-z   unit-x  unit-y  unit-z   length   speed  d.spd  time head npd
   0       0.0       0.0      0.0   0.0000  1.0000  0.0000      0.0     0.0    0.0  30.0  000   3
   1       0.0       0.0      0.0   0.0000  1.0000  0.0000      0.0     0.0    0.0  30.0  000   4
   2       0.0       0.0      0.0   0.0000  0.0000  1.0000     15.0     0.0    0.0   1.5  000   7
   3       0.0       0.0     15.0   0.0000  1.0000  0.0000      0.0     0.0    0.0   1.5  000   7
   4       0.0       0.0     15.0   0.0000  1.0000  0.0000     25.0     0.0   15.0   0.0  000  13
   5       0.0      25.0     15.0   0.0000  1.0000  0.0000     75.0    15.0   15.0   2.0  000  13
   6       0.0     100.0     15.0   0.0000  0.9996  0.0300    208.4    30.0   15.0   3.3  000  14
```

```
   7       0.0     308.3     21.3   0.0000  0.9996  0.0300    291.8    45.0   15.0   3.3  000  14
   8       0.0     600.0     30.0   0.0000  0.9637  0.2671   3631.9    60.0    0.0  35.9  000   1
   9       0.0    4100.0   1000.0   0.0000  1.0000  0.0000    735.4    60.0   18.7   6.3  000  13
  10       0.0    4835.4   1000.0   0.0000  1.0000  0.0000    933.3    78.7   18.7   6.3  000  13
  11       0.0    5768.7   1000.0   0.0000  1.0000  0.0000   1131.3    97.3   18.7   6.3  000  13
  12       0.0    6900.0   1000.0   0.0000  1.0000  0.0000  93100.0   116.0    0.0 475.5  000   2
  13       0.0  100000.0   1000.0   0.0000  1.0000  0.0000      1.0   116.0    0.0   0.0  000   2
(etc.)

GRID POINTS
0
  grid_id    = D01
  grid_type  = D (Contour,Standard,Detailed,Population,Location)
  origin     = 11000.2, 2999.8 feet
  angle      = 0.0 deg, counterclockwise from x axis
  delta_i,j  = 3038.1, 3038.1 feet
  numb_i,j   = 2, 2
  ta_thresh  = 85.0 dB
  do_ambient = 0 (0=no,1=yes)
  delta_amb  = 3.0 dB
  do_percent = 0 (0=no,1=yes)
  ref_time   = 24.00 hours
   i   j     x (ft)     y (ft)
   0   0    11000.2     2999.8
   0   1    11000.2     6037.8
   1   0    14038.2     2999.8
   1   1    14038.2     6037.8
POPULATION POINTS
LOCATION POINTS
SCREENING POINTS
```

Table A-1: Flight Path Parameter Descriptions

Flight Path Parameter	Description
seg	segment number, each point in the list defines the starting point of a flight path segment
start-x	x-position in feet relative to the study's origin
start-y	y-position in feet relative to the study's origin
start-z	z-position in feet relative to the study's origin
unit-x	unit vector representing the x component of the segment's direction
unit-y	unit vector representing the y component of the segment's direction
unit-z	unit vector representing the z component of the segment's direction
length	length of the segment in feet
speed	starting speed of the segment in knots
d.spd	change in speed over the segment in knots
thrust[1]	starting thrust for the segment, units dependent upon aircraft type
d.thr[1]	change in thrust over the segment, units dependent upon aircraft type
op[1]	NPD curve operation type (A =approach, D = Departure, X = Afterburner)
flaps[1]	flap setting used for the segment
bank[1]	bank angle at the beginning of the segment in degrees, positive in a left turn and negative in a right turn
duration[1]	time spent on the segment in seconds
time[2]	time spent on the segment in seconds
head[2]	heading of a helicopter while on the ground or in hover relative to its ground track in degrees
npd[2]	helicopter operational mode index, see Table A-2

1 – For fixed-wing aircraft only

2 – For helicopters only

Table A-2: Helicopter Operational Mode Indices

Index	Operational Mode
0	Approach
1	Departure
2	LevelFly
3	GndIdle
4	FltIdle
5	HovInGE
6	HovOutGE
7	DepVertInGE
8	DepVertOutGE
9	AppVertInGE
10	AppVertOutGE
11	AppHorDec
12	AppDesDec
13	DepHorAcc
14	DepClmAcc
15	Taxi

APPENDIX B: ACOUSTIC IMPEDANCE ADJUSTMENT

The majority of noise level data in the INM database were derived from data originally measured during aircraft noise certification tests conducted in accordance with Federal Aviation Regulation, Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification" (FAR Part 36).[11] Section 36.5(c)(1) of FAR Part 36 states that the noise measurements must be corrected to the following [homogeneous] noise certification reference atmospheric conditions:

1. Sea level pressure of 2116 psf (76 cm mercury),
2. Ambient temperature of 77 degrees Fahrenheit (25 degrees Celsius),
3. Relative humidity of 70 percent, and
4. Zero wind.

The concept of acoustic impedance (denoted by the symbol $\rho \cdot c$) is used in INM to correct the reference-day NPD data to the off-reference, non-sea level conditions associated with the user-specified case airport. Acoustic impedance is the product of the density of air and the speed of sound, and it is a function of temperature, atmospheric pressure, and indirectly altitude. An acoustic impedance of 409.81 newton-seconds/m^3 corresponds to the reference atmospheric conditions as defined by FAR Part 36. Acoustic impedance adjustments are made to move from reference-day sea-level conditions to airport-specific temperature and altitude.

Harris[13] and Beranek[14] both contain empirical curves showing acoustic impedance adjustment as a function of temperature and atmospheric pressure (see Figure B-1 and Figure B-2). These curves can be used to obtain a general sense for the magnitude and direction of the adjustment. However they are not appropriate for correcting INM NPD data because the curves are referenced to an acoustic impedance of 406 and 400 newton-seconds/m^3, respectively, not the 409.81 newton-seconds/m^3 associated with NPD reference-day conditions.

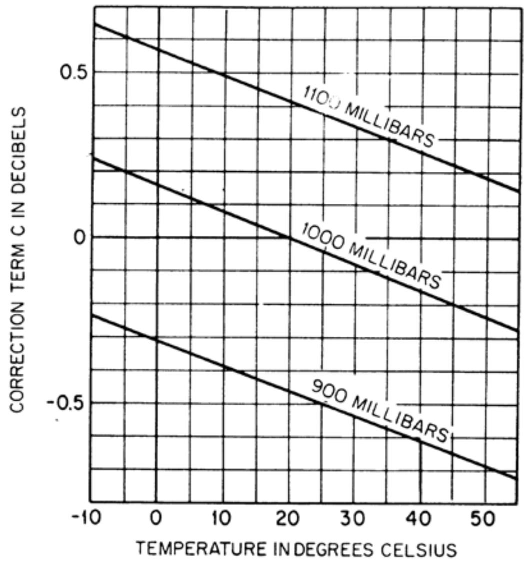

Figure B-1: Acoustic Impedance Adjustment re. 406 newton-second/m^3

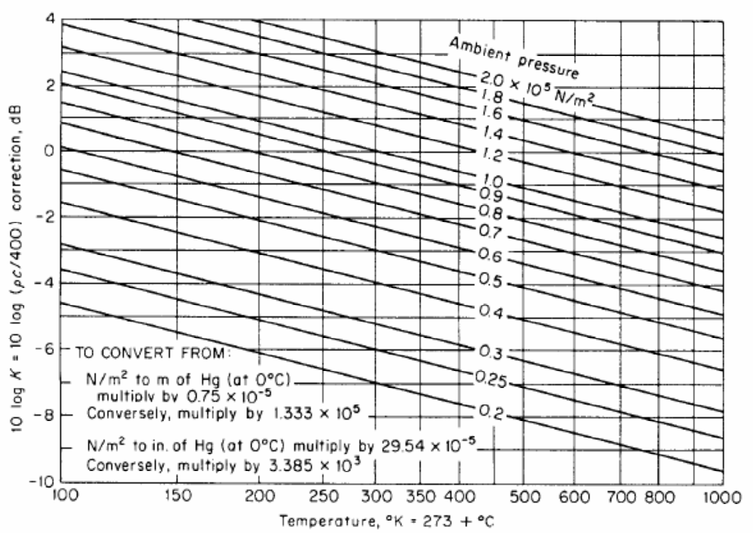

Figure B-2: Acoustic Impedance Adjustment re. 400 newton-second/m^3

The acoustic impedance adjustment is relatively small, usually less than a few tenths of a dB. However, when there is a significant variation in temperature and atmospheric pressure relative to reference-day conditions, the adjustment can be fairly substantial. For example, Denver International Airport is at an elevation of approximately 5000 feet, and assuming a temperature of 70°F and an atmospheric pressure of 29.92 in-Hg, an acoustic impedance adjustment of –0.77 dB is added to NPD noise curves.

The acoustic impedance adjustment is computed by:

$$AI_{ADJ} = 10 \cdot \log_{10}\left[\frac{\rho \cdot c}{409.81}\right] \qquad \text{Eq. B-1}$$

where

AI_{ADJ} acoustic impedance adjustment to be added to noise level data in the INM NPD database (dB),

$\rho \cdot c$ acoustic impedance at observer altitude and pressure (newton-seconds/m^3),

$$\rho \cdot c = 416.86 \cdot \left[\frac{\delta}{\theta^{½}}\right] \qquad \text{Eq. B-2}$$

δ ratio of atmospheric pressure at observer altitude to standard-day pressure at sea level,

$$\delta = \left[\left(\frac{P}{29.92}\right)^{\frac{1}{5.256}} - \left(\frac{0.003566A}{518.67}\right)\right]^{5.256} \qquad \text{Eq. B-3}$$

θ ratio of absolute temperature at observer altitude to standard-day temperature at sea level,

$$\theta = \frac{[459.67 + T - 0.003566 \cdot (A - E)]}{518.67} \qquad \text{Eq. B-4}$$

A observer elevation MSL (feet),
E airport elevation MSL (feet),
T temperature at airport (°F), and
P atmospheric pressure at airport relative to MSL (in-Hg).

Reference 13 and Reference 14 explain the acoustic impedance adjustment in terms of sound intensity and sound pressure. In a free field for plane waves or spherical waves, the sound pressure and particle velocity are in phase, and the magnitude of the intensity (power per unit area) in the direction of propagation of the sound waves is related to the mean-square sound pressure by:

$$I = \frac{p^2}{\rho \cdot c} \qquad \text{Eq. B-5}$$

where

I sound intensity (power per unit area),
p^2 mean-square sound pressure,
$\rho \cdot c$ acoustic impedance.

Two sound intensities at a given distance from a given acoustical power source, one measured under actual conditions (no subscript), and the other measured under reference-day conditions ("ref" subscript), are equivalent:

$$\frac{p^2}{\rho \cdot c} = \frac{p^2{}_{ref}}{\rho \cdot c_{ref}} \qquad \text{Eq. B-6}$$

By rearranging terms and dividing by a constant p_o = 20 μPa, the equation becomes:

$$\frac{p^2}{p_0{}^2} = \left(\frac{p^2{}_{ref}}{p_0{}^2}\right)\left(\frac{\rho \cdot c}{\rho \cdot c_{ref}}\right) \qquad \text{Eq. B-7}$$

Converting to decibels,

$$10 \cdot \log_{10}\left[\frac{p^2}{p_0{}^2}\right] = 10 \cdot \log_{10}\left[\frac{p^2{}_{ref}}{p_0{}^2}\right] + 10 \cdot \log_{10}\left[\frac{\rho \cdot c}{\rho \cdot c_{ref}}\right] \qquad \text{Eq. B-8}$$

and substituting symbols, produces the noise level adjustment equation (in decibels):

$$L = L_{ref} + 10 \cdot \log_{10}\left[\frac{\rho \cdot c}{\rho \cdot c_{ref}}\right] \qquad \text{Eq. B-9}$$

where

L	corrected NPD level at an airport,
L_{ref}	NPD level in the INM database for reference-day conditions,
$10 \cdot \log_{10}\left[\frac{\rho \cdot c}{\rho \cdot c_{ref}}\right]$	acoustic impedance adjustment, AI_{ADJ}, as seen in Equation B-1.

APPENDIX C: DERIVATION OF NOISE EXPOSURE FRACTION AND TIME-ABOVE EQUATIONS

This Appendix presents a derivation of the noise exposure fraction and time-above equations used in INM Version 7.0. The assumptions are that the aircraft is on a straight and level flight path flying at constant speed. The equations are based upon a fourth-power, 90-degree dipole model of sound radiation. The geometry for the derivation is shown in Figure C-1.

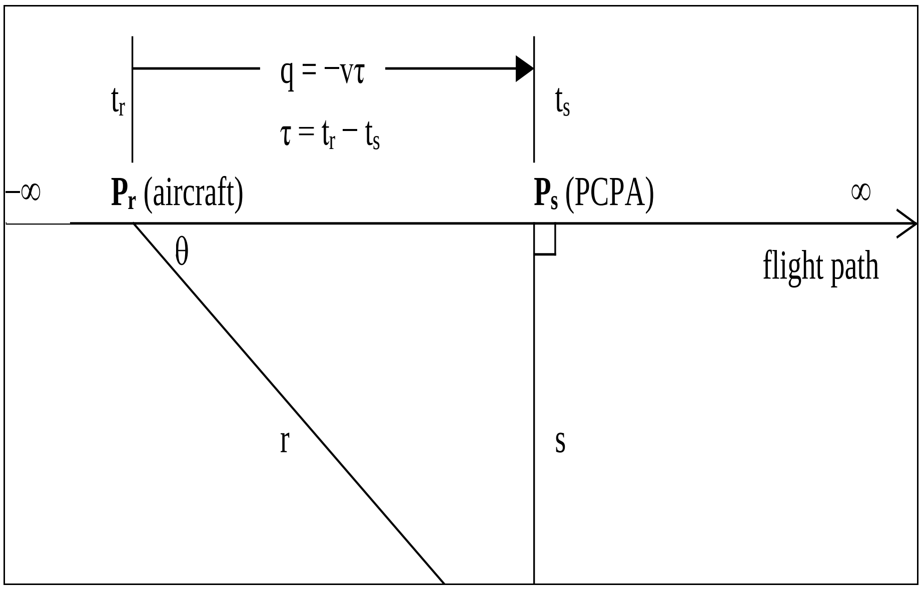

Figure C-1: Observer/Flight-Path Geometry

r	distance from the observer at point **P** to the aircraft at point $\mathbf{P}_r$ (feet),
s	perpendicular distance from the observer at point **P** to PCPA at point $\mathbf{P}_s$ (feet),
q	distance along the flight path relative to PCPA (feet),
v	speed of the aircraft (feet/s),
t_r	time at which the aircraft is located at point $\mathbf{P}_r$ (seconds),
t_s	time at which the aircraft is located at point $\mathbf{P}_s$ (seconds),
τ	time difference, t_r minus t_s (seconds),
θ	angle formed by the flight path and a connecting segment from the aircraft at point $\mathbf{P}_r$ to the observer at point **P**,
p_r	root-mean-square sound pressure generated by the aircraft at point $\mathbf{P}_r$, and
p_s	root-mean-square sound pressure generated by the aircraft at point $\mathbf{P}_s$.

The relative distance, q, along the flight path from point $\mathbf{P}_r$ to point $\mathbf{P}_s$ is computed from the scalar product of two vectors: $\mathbf{P}_r\mathbf{P}$, from the aircraft to the observer; and the unit vector, **u**, in the direction of the flight path.

$$q = \mathbf{P_r P} \cdot \mathbf{u} = \frac{\mathbf{P_r P} \cdot \mathbf{P_r P_s}}{\left|\mathbf{P_r P_s}\right|} \qquad \text{Eq. C-1}$$

The value of q is positive if the aircraft is located behind PCPA (as pictured in Figure C-1), and the value of q is negative if the aircraft is ahead of PCPA. In terms of speed and time,

$$q = -v \cdot \tau \qquad \text{Eq. C-2}$$

The negative sign is because τ is negative when the aircraft is behind PCPA.

The noise fraction algorithm is derived from a fourth-power, 90-degree dipole time history model. In this model, p_r^2 is the mean-square sound pressure at the observer due to the aircraft, located at point $\mathbf{P}_r$; and p_s^2 is the mean-square sound pressure at the observer when the aircraft is located at PCPA at point $\mathbf{P}_s$. The mean-square pressure, p_r^2, at the observer is expressed in terms p_s^2 by

$$p_r^{\ 2} = p_s^{\ 2} \cdot \left(\frac{s^2}{r^2}\right) \cdot \sin^2(\theta) \qquad \text{Eq. C-3}$$

which becomes

$$p_r^{\ 2} = p_s^{\ 2} \cdot \frac{s^4}{r^4} \qquad \text{Eq. C-4}$$

In this equation, the mean-square sound pressure for an aircraft flying along a straight path is determined by r^2 spherical spreading loss and by a $\sin^2\theta$ "90-degree dipole" term that accounts for a variety of physical phenomena. These phenomena include atmospheric absorption, which is accentuated in front of the airplane due to Doppler shift, sound refraction away from the hot gases behind the airplane, and ground attenuation. The purpose of the dipole term is to shape the sides of the time-history curve to fit empirical data.[26] When the sinθ term is replaced by s/r, the mean-square sound pressure is seen to vary inversely as r^4; therefore, another name for the model is the "fourth-power" time-history model.

The Pythagorean theorem can be used to solve for r^2

$$r^2 = s^2 + q^2 \qquad \text{Eq. C-5}$$

Which can be rewritten as follows, given Equation C-2:

$$r^2 = s^2 + (v\tau)^2 \qquad \text{Eq. C-6}$$

$$\left(\frac{r}{s}\right)^2 = 1 + \left(\frac{v \cdot \tau}{s}\right)^2 \qquad \text{Eq. C-7}$$

Equation C-7 can then be substituted into Equation C-4, in order to derive the mean-square pressure as a function of time:

$$p_r^{\ 2}(\tau) = \frac{p_s^{\ 2}}{\left(1 + \left(\frac{v \cdot \tau}{s}\right)^2\right)^2} \qquad \text{Eq. C-8}$$

The integral of the mean-square pressure, from time τ_1 to τ_2, is the segment noise exposure E_{12}

$$E_{12} = \int_{\tau_1}^{\tau_2} p_r^{\,2}(\tau)d\tau \qquad \text{Eq. C-9}$$

By using the substitution

$$\alpha = \frac{v \cdot \tau}{s} \qquad \text{Eq. C-10}$$

the segment noise exposure integral becomes

$$E_{12} = p_s^{\,2} \cdot \left(\frac{s}{v}\right) \cdot \int_{\alpha_1}^{\alpha_2} \frac{1}{(1+\alpha^2)^2} d\alpha \qquad \text{Eq. C-11}$$

and its solution is

$$E_{12} = p_s^{\,2} \cdot \left(\frac{s}{v}\right) \cdot \left(\frac{1}{2}\right) \cdot \left\{ \left[\frac{\alpha_2}{\left(1+\alpha_2^{\,2}\right)} + \tan^{-1}(\alpha_2) \right] - \left[\frac{\alpha_1}{\left(1+\alpha_1^{\,2}\right)} + \tan^{-1}(\alpha_1) \right] \right\} \qquad \text{Eq. C-12}$$

The total noise exposure from $\tau_1 = -\infty$ to $\tau_2 = \infty$ is

$$E_\infty = \frac{1}{2} \cdot \pi \cdot \mathrm{p_s}^{2} \cdot \frac{\mathrm{s}}{\mathrm{v}} \qquad \text{Eq. C-13}$$

The noise exposure fraction, F_{12}, is the noise exposure between time τ_1 and τ_2 divided by the total noise exposure:

$$F_{12} = \frac{\mathrm{E}_{12}}{\mathrm{E}_\infty} \qquad \text{Eq. C-14}$$

$$F_{12} = \left(\frac{1}{\pi}\right) \cdot \left[\frac{\alpha_2}{\left(1+\alpha_2^{\,2}\right)} + \tan^{-1}(\alpha_2) - \frac{\alpha_1}{\left(1+\alpha_1^{\,2}\right)} - \tan^{-1}(\alpha_1) \right] \qquad \text{Eq. C-15}$$

The next part of the derivation shows how to calculate α_1 and α_2.

The INM NPD database contains noise exposure level data referenced to 160 knots, $L_{E.160}$, and maximum noise level data, L_{Smx}. These noise level data are related to the parameters in the above equations by

$$L_{E,160} = 10 \cdot \log_{10}\left[\left(\frac{v}{v_0}\right) \cdot \frac{E_\infty}{\left(\mathrm{p}_0^{\,2} \cdot t_0\right)} \right] \qquad \text{Eq. C-16}$$

$$L_{Smx} = 10 \cdot \log_{10}\left[\frac{p_s^{\;2}}{\text{p}_0^{\;2}}\right] \qquad \text{Eq. C-17}$$

where

p_o 20 μPa,

t_o 1 sec for L_{AE} and L_{CE}, or 10 sec for L_{EPN}, and

v_o 270.05 feet/s (160 knots).

To ensure that the total exposure obtained from the fourth-power time-history model in Equation C-13 is consistent with INM NPD data, the following relationship must hold:

$$L_{E,160} - L_{Smx} = 10 \cdot \log_{10}\left[\left(\frac{v}{v_0}\right) \cdot \frac{\left(\frac{1}{2} \cdot \pi \cdot \text{p}_\text{s}^{\;2} \cdot \frac{s}{v}\right)}{\left(p_0^{\;2} \cdot t_0\right)}\right] - 10 \cdot \log_{10}\left[\frac{p_s^{\;2}}{p_0^{\;2}}\right] \qquad \text{Eq. C-18}$$

Therefore

$$\frac{1}{2} \cdot \pi \cdot \frac{s}{(v_0 \cdot t_0)} = 10^{\frac{\left[L_{E,160} - L_{Smx}\right]}{10}} \qquad \text{Eq. C-19}$$

and the distance, s, is scaled to fit the NPD data:

$$\text{s} = \left(\frac{2}{\pi}\right) \cdot v_0 \cdot t_0 \cdot 10^{\frac{\left[L_{E,160} - L_{Smx}\right]}{10}} \qquad \text{Eq. C-20}$$

Using the symbol s_L to indicated a scaled distance, rather than the actual distance, the NPD-consistency requirement becomes

$$\text{s}_\text{L} = s_0 \cdot 10^{\frac{\left[L_{E,160} - L_{Smx}\right]}{10}} \qquad \text{Eq. C-21}$$

where

s_0 a constant dependant on the type of noise exposure level:
s_0 = 171.92 feet (52.4 meters) for L_{AE} and $L_{CE,}$, and
s_0 = 1719.2 feet (524.0 meters) for L_{EPN}.

Using the scaled distance, s_L, and Equations C-2 and C-10, the two α-numbers that are needed to calculate the noise exposure fraction, F_{12}, are determined by $q = q_1$ at the start of a segment:

$$\alpha_1 = \frac{-q_1}{s_L}$$ Eq. C-22

$$\alpha_2 = \frac{(-q_1 + L)}{s_L}$$ Eq. C-23

where

q_1	relative distance (feet) from segment start point to point $\mathbf{P}_s$, and
L	length of segment (feet).

The next part of the derivation shows how to calculate time-above.

Using the previously developed time-history equation and substituting $s = s_L$, the mean-square pressure is written as a function of time, τ, and speed, v, using Equation C-8:

$$p_r^2 = \frac{p_s^2}{\left(1 + \left(\frac{v \cdot \tau}{s_L}\right)^2\right)^2}$$ Eq. C-24

The time-history equation is solved for τ as a function of p_r:

$$\tau = \left(\frac{s_L}{v}\right) \cdot \left(\frac{p_s}{p_r - 1}\right)^{½}$$ Eq. C-25

Given a noise threshold level, L_x, of root-mean-square pressure, p_x,

$$L_x = 10 \cdot \log_{10}\left[\frac{p_x^2}{p_0^2}\right]$$ Eq. C-26

the time duration (in seconds) during which the noise level exceeds L_x, Δt_x, is twice the τ-value at $p_r = p_x$:

$$\Delta t_x = 2 \cdot \left(\frac{s_L}{v}\right) \cdot \left[\left(\frac{p_s^2}{p_x^2}\right)^{½} - 1\right]^{½}$$ Eq. C-27

which can be written as

$$\Delta t_x = \begin{cases} 2 \cdot \left(\frac{\mathrm{s_L}}{\mathrm{v}} \right) \cdot \left[10^{\frac{[L_{Smx,adj} - L_x]}{20}} - 1 \right]^{½} & L_x < L_{Smx,adj} \\ 0.0 & L_x \geq L_{Smx,adj} \end{cases} \qquad \text{Eq. C-28}$$

where

$L_{Smx.adj}$ the adjusted maximum noise level at the observer.

Note that

$$\frac{\mathrm{s_L}}{\mathrm{v}} = \left(\frac{2}{\pi} \right) \cdot \left(\frac{t_0 \cdot v_0}{v} \right) \cdot 10^{\frac{[L_{E,160,adj} - L_{Smx,adj}]}{10}} \qquad \text{Eq. C-29}$$

and that

$$L_{E,adj} = L_{E,160,adj} + 10 \cdot \log_{10} \left[\frac{v_0}{v} \right] \qquad \text{Eq. C-30}$$

where

$L_{E.160.adj}$ adjusted noise exposure level referenced to 160 knots,
$L_{E.adj}$ adjusted noise exposure level at the observer, and
$L_{Smx.adj}$ adjusted maximum noise level at the observer.

Equation C-27 can be written to express time-above duration (in minutes) in terms of adjusted exposure and maximum levels:

$$\Delta t_x = \left(\frac{1}{60} \right) \cdot \left(\frac{4}{\pi} \right) \cdot t_0 \cdot \left[10^{\frac{[L_{E,adj} - L_{Smx,adj}]}{10}} \right] \cdot \left[10^{\frac{[L_{Smx,adj} - L_x]}{20}} - 1 \right]^{½} \qquad \text{Eq. C-31}$$

APPENDIX D: OVERVIEW OF SPECTRAL CLASS DEVELOPMENT

This appendix provides an example of the derivation of a spectral class for the INM database. Departure spectral class #104 is used in this example. The class originally consisted of the Fokker F28-2000, the McDonnell-Douglas MD80 series aircraft (i.e., MD81, MD82 and MD83), and the Gulfstream GIIB and GIII twin-engine, high bypass ratio turbofan aircraft. The original development and assignment of spectral classes was performed in 1999 and documented in Reference 21.

The hushkit retrofitted B737N17, B737N19 and B737700 have NPD curves referenced to spectral class 104. They were added to the INM database after the original derivations were performed and were found to agree with an already developed class based on the criteria described in Step 1 through Step 4 below and Reference 3.

Step 1: Group Similar Aircraft/Engine Combinations

The first step in deriving a spectral class is the grouping of aircraft considered similar based on the combination of the aircraft and engine types. Considerations for grouping aircraft include the airframe, type of engine, number of engines, location of engine, and bypass ratio.

Step 2: Visual Inspection of Potential Spectral Class Data

After having grouped the aircraft by similar aircraft/engine types, the maximum-level spectra are compared. Specifically, each spectrum at the time of A-weighted Maximum Sound Level (L_{ASmx}) is graphed on a single chart and visually inspected for similarity. Similarity is based on the shape of the spectrum and the relative location of any tones below 1000 Hz. The spectra for class 104 are presented in Figure D-1.

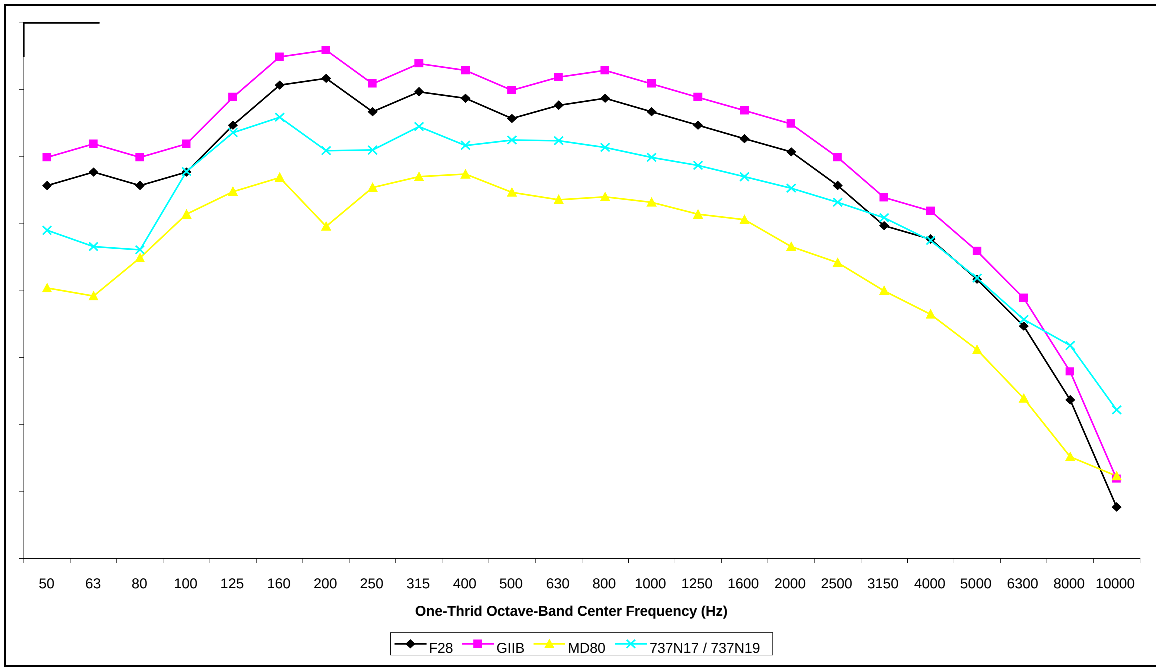

Figure D-1: Departure Class 104

To aid in the visual inspection of the spectra, each one is normalized to a value of 70 dB at 1000 Hz. Figure D-2 presents the normalized spectra along with the *proposed* spectrum that would represent this spectral class. The representative spectrum for this spectral class is the weighted arithmetic average of the individual one-third octave-band spectral data. The weighting was based on a recent annual survey of the number of departures for each aircraft type.

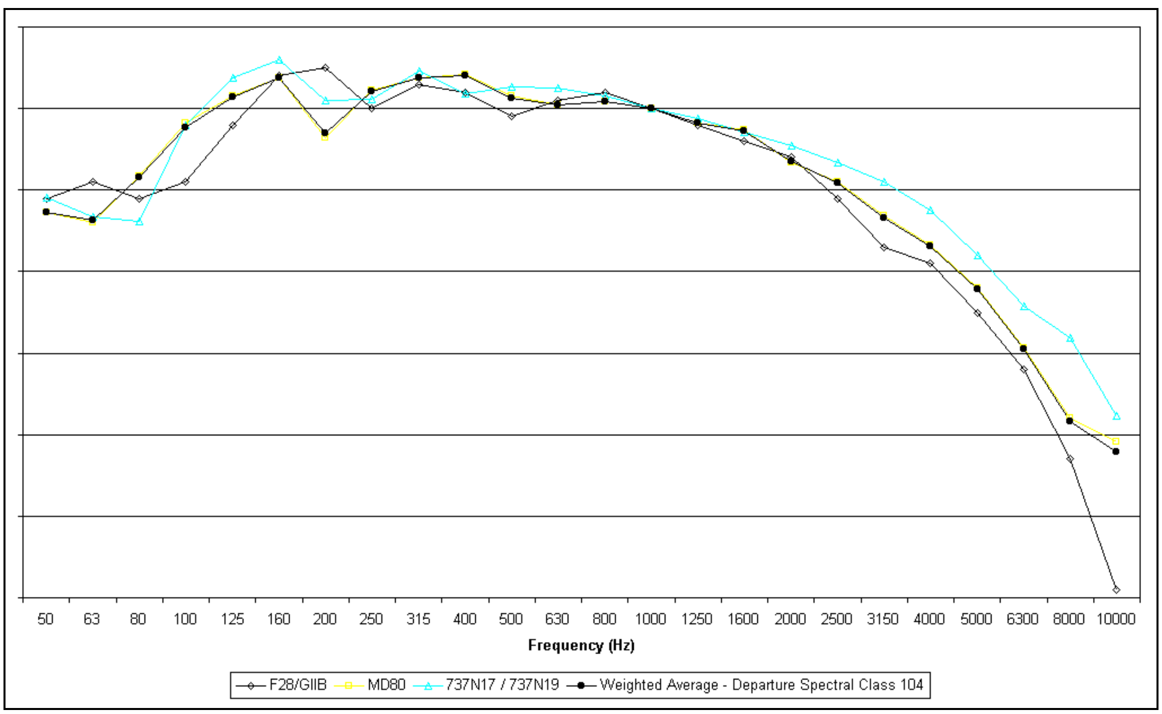

Figure D-2: Normalized Spectral Class 104 Data

Step 3: Verification of Proposed Spectral Class

In order to verify the appropriateness of the proposed spectral class, the individual spectra and the representative spectrum are used in a series of acoustical calculations that require third-octave band spectra data. One example is the algorithm that calculates the theoretical ground effect for a source-to-receiver separation distance of 1000 meters. The EPD Model (see References 45, 46, 47), which was originally documented by Tony Embleton, Joe Piercy and Giles Daigle of the National Research Council in Canada, was used. This model employs spectral data to calculate the ground effect for propagation over ground with different effective flow resistivities. A flow resistivity of 150 cgs rayls (essentially soft ground cover) was used for this validation.

Figure D-3 presents the calculated ground effects as a function of source-to- receiver elevation angle for the proposed representative spectrum and the individual aircraft spectra. Additionally, limit curves are drawn ±1 dB from the proposed representative spectrum ground effect. The proposed representative spectrum is considered appropriate to represent the spectral class if the ground effect curves for each aircraft generally fall within the proposed representative spectrum limit curves for all elevation angles.

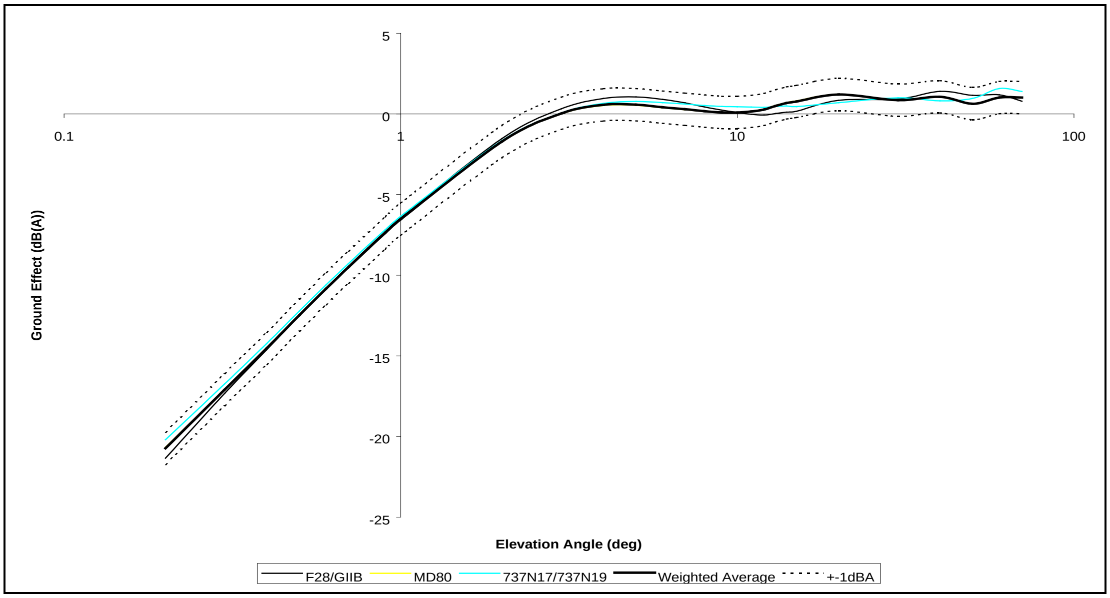

Figure D-3: Spectral Class 104 Ground Effect

Step 4: Final Spectral Class

Given that the ground effect curves for each individual aircraft spectrum fall within the ±1-dB limit curves for all elevation angles, the proposed representative spectrum is considered to adequately represent the individual spectra used to derive the spectral class. Figure D-4 presents the final spectral class.

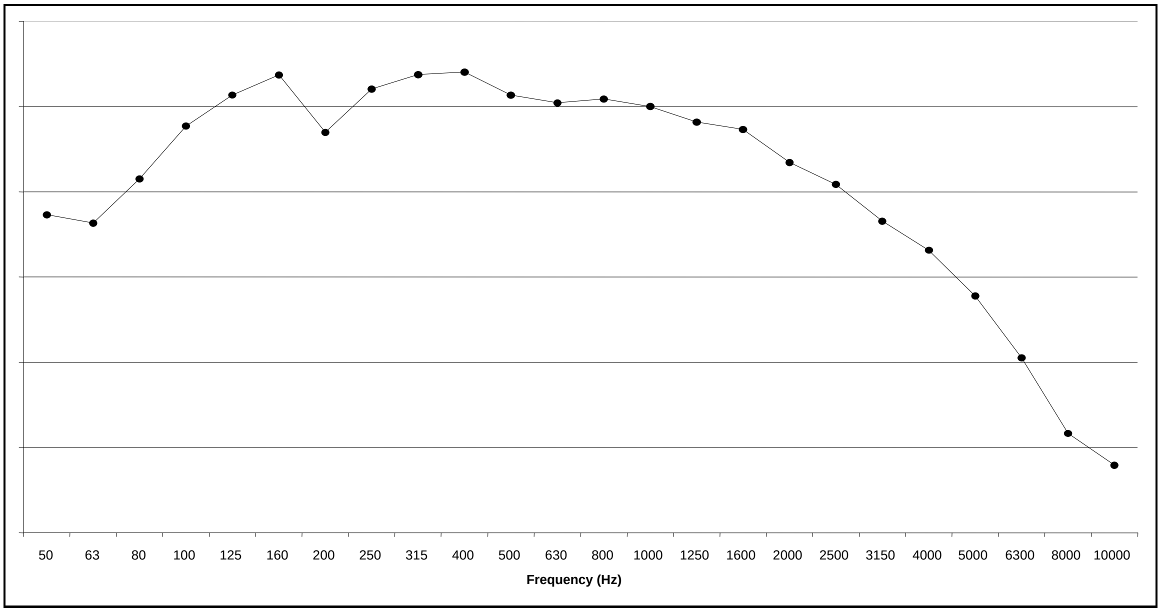

Figure D-4: Departure Spectral Class 104

APPENDIX E: CALCULATING AUDIBILITY

This appendix provides a description of the computation of the Time Audible (TAud) metric in INM.

Audibility is defined as the ability for an attentive listener to hear aircraft noise. Detectability is based on signal detection theory[43,44], and depends on both the actual aircraft sound level ("signal") and the ambient sound level (or "noise"). As such, audibility is based on many factors including the listening environment in which one is located. Conversely, detectability is a theoretical formulation based on a significant body of research. For the purposes of INM modeling the terms "audibility" and "detectability" are used interchangeably. The detectability level (d') calculated in INM is based on the signal-to-noise ratio within one-third octave band spectra for both the signal and noise, using a 10log(d') value of 7 dB.

There are three parts to the calculation of audibility in INM:

1. Calculate the detectability level ($D'L_{band}$) for each one-third octave band of the signal for a single contributing flight path segment;
2. Calculate the detectability level ($D'L_{total}$) for the overall signal for a single contributing flight path segment; and
3. Calculate absolute or percentage of time a signal is audible (detectable by a human) for a flight path (TAud or %TAud).

Definitions

$L_{signal,band}$	sound level of the signal (aircraft) for a particular frequency band
$L_{noise,band}$	sound level of the ambient noise for a particular frequency band
η_{band}	efficiency of the detector (a scalar value known for each frequency band)
bandwidth	one-third octave bandwidth
$D'L_{band}$	detectability level for a particular frequency band
$D'L_{total}$	total detectability level
d'_{band}	detectability for a particular frequency band
d'_{total}	sum of squares of detectability over all frequency bands
TAud	absolute amount of time a signal is audible by humans
%TAud	percentage of a time period that a signal is audible

Note that values of $L_{signal,band}$ and $L_{noise,band}$ are calculated for each segment-receiver pair and then the total audibility for a given flight track is summed from the individual segments.

Part I of Calculations

Calculate the detectability level for each one-third octave frequency band, and then determine if the signal for that frequency band is detectable.

The theory of detectability level is based on the following equation:

$$D'L_{band} = 10 \cdot \log_{10}\left[\eta_{band} \cdot (bandwidth)^{1/2} \cdot \left(\frac{signal}{noise}\right)\right] \quad \text{Eq. E-1}$$

The following one-third octave band filter characteristics are used in the calculation of detectability:

Table E-4-3: One-Third Octave Band Characteristics

ANSI Band #	Nominal Center Frequency (Hz)	Bandwidth (Hz)	$10\log[\eta_{band}]$
17	50	11	-6.96
18	63	15	-6.26
19	80	19	-5.56
20	100	22	-5.06
21	125	28	-4.66
22	160	40	-4.36
23	200	44	-4.16
24	250	56	-3.96
25	315	75	-3.76
26	400	95	-3.56
27	500	110	-3.56
28	630	150	-3.56
29	800	190	-3.56
30	1000	220	-3.56
31	1250	280	-3.76
32	1600	400	-3.96
33	2000	440	-4.16
34	2500	560	-4.36
35	3150	750	-4.56
36	4000	950	-4.96
37	5000	1100	-5.36
38	6300	1500	-5.76
39	8000	1900	-6.26
40	10000	2200	-6.86

1) Calculate the detectability level for each one-third octave frequency band.

$$D'L_{band} = (L_{signal,band} - L_{noise,band}) + \{10 \cdot \log_{10}[\eta_{band}] + 0.5 \cdot 10 \cdot \log_{10}[bandwidth]\}$$

Eq. E-2

where

$10\log[\eta_{band}]$	one-third octave band specific constant (see Table E-4-3), and
$L_{noiseband}$	the addition of the un-weighted, measured one-third octave band ambient levels and the appropriate EASN level (see Table E-4-4).

Figure E-1 and Table E-4-4 below present the Equivalent Auditory System Noise (EASN)[40] levels derived for modeling audibility using one-third octave band data.

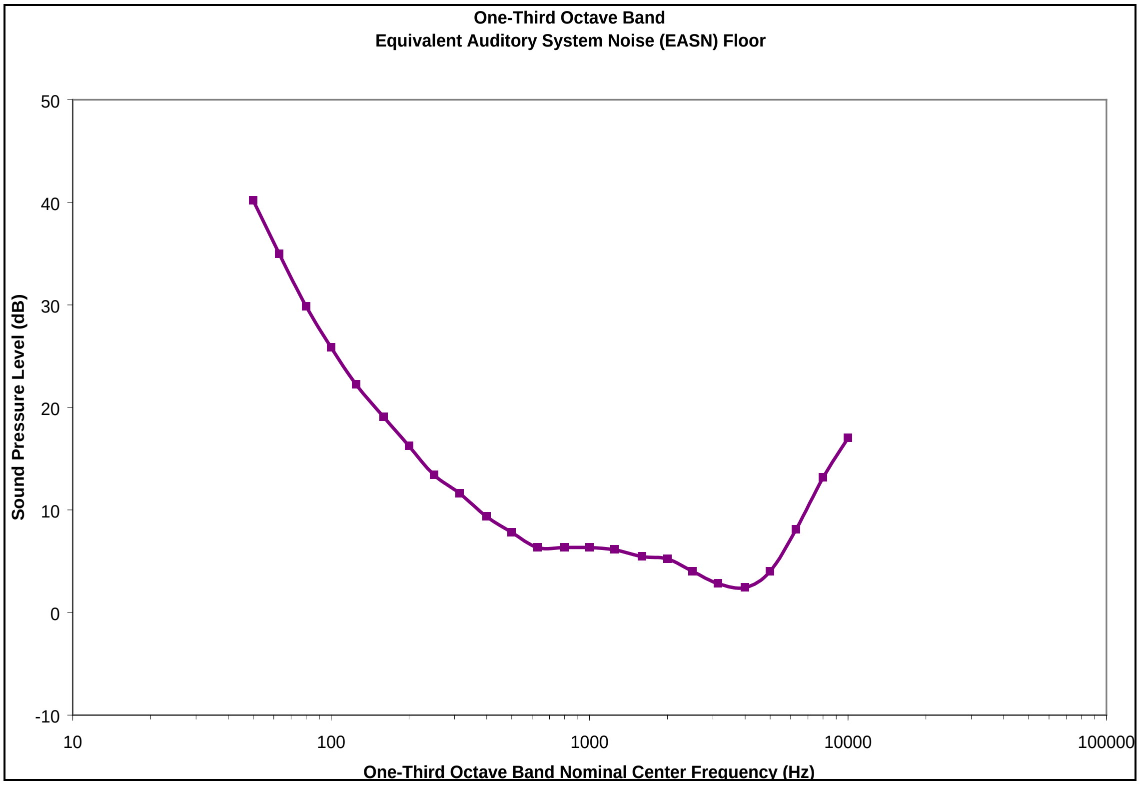

Figure E-1: EASN Threshold

Table E-4-4: EASN Threshold

One-Third Octave Band Nominal Center Frequency (Hz)	EASN Threshold (dB)
50	40.2
63	35.0
80	29.8
100	25.8
125	22.2
160	19.0
200	16.2
250	13.4
315	11.6
400	9.3
500	7.8
630	6.3
800	6.3
1000	6.3
1250	6.1
1600	5.4
2000	5.2
2500	4.0
3150	2.8
4000	2.4
5000	4.0
6300	8.1
8000	13.1
10000	17.0

2) Determine if the signal for that frequency band is detectable.
   If $D'L_{band} \geq 7$, the signal is flagged as **detectable** for that frequency band.

Part II of Calculations

Determine if the overall signal is detectable.

1) Calculate the detectability for each one-third octave frequency band using the band detectability levels from Part I.

$$d'_{band} = 10^{\frac{D'L_{band}}{10}}$$ Eq. E-3

2) Calculate the square root of the sum of squares of detectability over all frequency bands.

$$d'_{total} = \left[\sum_{band=17}^{40} \left(d'_{band}\right)^2\right]^{1/2}$$ Eq. E-4

3) Calculate the total detectability level.

$$D'L_{total} = 10 \cdot \log_{10}\left[d'_{total}\right]$$ Eq. E-5

4) Determine if the overall signal is detectable.

$$D'L_{total} \geq 7 \quad \textit{the overall signal is detectable.}$$
$$D'L_{total} < 7 \quad \textit{the overall signal is not detectable.}$$ Eq. E-6

Part III of Calculations

Calculate the absolute or percentage of time a signal is audible by a human; the time for a single contributing flight path segment is first calculated, then the absolute or percent time is calculated for an overall event or larger period of time (multiple flights for an average day or other time period).

1) Calculate the time audible (in seconds) for a single flight path.

For each segment, calculate time it takes aircraft to travel through flight path segment

$$segtime = \left(\frac{seglength}{segspeed}\right) \cdot \#\ of\ operations$$ Eq. E-7

where

seglength	length (in feet) of contributing flight path segment,
segspeed	average speed (in feet/s) during contributing flight path segment, and
segtime	time passed during contributing flight path segment (s).

If segment is flagged as detectable, then

$$TAud = TAud + segtime$$ Eq. E-8

Once ***segtime*** has been totaled for all segments, the percent Time Audible over the user-specified time period will be:

$$\%TAud = \frac{TAud}{(T)} \qquad \text{Eq. E-9}$$

where

T the user-specified time period (s).

2) Calculate the time audible (in minutes) for a time period.

$$TAud = \frac{TAud}{\left(\frac{60\,\text{seconds}}{\text{minute}}\right)} \qquad \text{Eq. E-10}$$

APPENDIX F: ATMOSPHERIC ABSORPTION AND LINE-OF-SIGHT BLOCKAGE ADJUSTMENT EXAMPLE CALCULATIONS

This appendix provides two example calculations: atmospheric absorptions adjustment (AA_{ADJ}) and line-of-sight blockage adjustment (LOS_{ADJ}) in INM, presented in Sections 3.4.1 and 3.4.6 respectively.

Atmospheric Absorption Adjustment Example

For example, the following illustrates the derivation of the atmospheric absorption correction for INM departure spectral class #103, using the absorption associated with a temperature of 59°F (15°C) and relative humidity equal to 70%. First, the values for spectral class #103 are presented below. This is a flat (un-weighted) spectrum, corrected using SAE-AIR-1845 [8] to 1000 feet (305 meters) and normalized to 70 dB at 1000 Hz.

Table F-4-5: INM Departure Class #103

Frequency (Hz)	50	63	80	100	125	160	200	250	315	400	500	630
Normalized Level (dB)	56.7	66.1	70.1	72.8	76.6	73.0	74.5	77.0	75.3	72.2	72.2	71.2
Frequency (Hz)	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**
Normalized Level (dB)	70.2	70.0	69.6	71.1	70.6	67.1	63.4	63.5	58.2	51.5	42.3	37.7

The following data represent the A-weighted spectral class data corrected to the source (a theoretical distance of 0 feet) for atmospheric absorption.

Table F-4-6: A-weighted Spectral Class Corrected to Source

Frequency (Hz)	50	63	80	100	125	160	200	250	315	400	500	630
Normalized Level (dB)	26.6	40.0	47.7	53.9	60.7	59.9	64.0	68.8	69.3	68.1	69.9	70.4
Frequency (Hz)	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**
Normalized Level (dB)	70.8	71.8	72.5	75.1	75.8	73.6	71.6	74.0	69.7	67.4	63.2	65.2

The following data represent the "source" spectral class corrected to a distance of 1000 feet.

Table F-4-7: Source Spectrum Corrected to Distance of 1000 Feet using SAE-866A

Frequency (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**
Normalized Level (dB)	26.5	39.9	47.6	53.8	60.5	59.7	63.7	68.4	68.9	67.5	69.2	69.5
Frequency (Hz)	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**
Normalized Level (dB)	69.6	70.3	70.7	72.7	72.8	69.6	66.1	66.4	60.6	54.6	44.6	37.8

Table F-4-8: Source Spectrum Corrected to Distance of 1000 Feet using SAE-AIR-1845

Frequency (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**
Normalized Level (dB)	26.5	39.9	47.5	53.7	60.5	59.6	63.6	68.4	68.7	67.4	69.0	69.3
Frequency (Hz)	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**
Normalized Level (dB)	69.4	70.0	70.2	72.1	71.8	68.4	64.6	64.5	58.7	51.4	41.2	35.2

This example illustrated the process for developing a spectrum at 1000 feet. The same process is repeated for all 10 INM NPD distances.

The mean-square pressure associated with the spectral data corrected to 1000 feet above (for all 24 one-third octave bands) is then summed and converted to decibels to produce the values of 81.1 (for Table F-4-7) and 80.6 (for Table F-4-8). This is in turn repeated for all 10 INM NPD distances. Table F-4-9 below shows the final step of the process with the delta dB differences computed. This difference, calculated for each of the ten standard INM NPD distances, represents the atmospheric adjustment (AA_{ADJ}) which is applied to the NPD curves.

Table F-4-9: Calculated Difference between Corrected Sound Pressure Levels using SAE-ARP-866A and SAE-AIR-1845 (ALL INM Distances)

Distance	A-Weighted ARP-866A (15ºC 70%)	A-Weighted SAE-AIR-1845	Difference dB
200	83.2	83.1	0.1
400	82.6	82.3	0.3
630	82.0	81.6	0.4
1000	81.1	80.6	0.5
2000	79.3	78.5	0.8
4000	76.7	75.7	1.0
6300	74.5	73.4	1.1
10000	72.0	70.7	1.3
16000	68.9	67.3	1.6
25000	65.2	63.3	1.9

The A-Weighted levels calculated above are for a normalized spectral class, assuming 70 dB at the 1000 Hz one-third octave-band. The deltas in this example are then applied across all power settings and all A-weighted NPD curves (SEL and LAMAX).

Line-of-Sight Blockage Adjustment Example

Given the relationship between the variables in Equations 3-34 through 3-36 for calculating LOS_{ADJ} (see Section 3.4.6), an increase in the path length difference will result in an increase in the Fresnel number and, thus, an increase in barrier attenuation. If the frequency increases, barrier attenuation increases as well. For illustrative purposes, Figure F-1 shows the relationship between path length difference and barrier effect for four different one-third octave-bands: 50 Hz, 550 Hz, 1000 Hz and 5000 Hz.

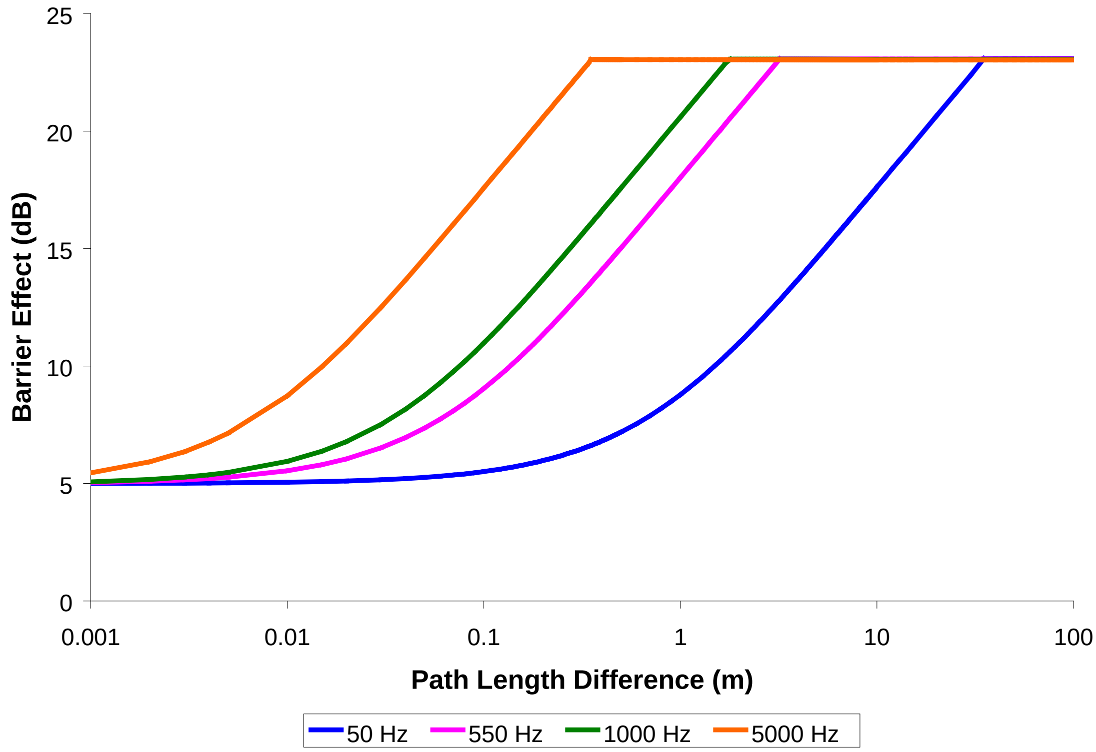

Figure F-1: Barrier Effect Versus Path Length Difference

APPENDIX G: INM DATABASE SUBMITTAL FORM

The INM database submittal form implements the data requirements for a noise model as given in the following documents: Society of Automotive Engineers (SAE), Airspace Information Report (AIR), SAE-AIR-1845 "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports"[1]; European Civil Aviation Conference, "ECAC.CEAC Doc 29, Report on Standard Method of Computing Noise Contours around Civil Airports"[2]; and International Civil Aviation Organization (ICAO), "Recommended Method for Computing Noise Contours around Airports, Circular 205"[3] and "Environmental Protection, Annex 16, Volume 1, Aircraft Noise"[22]. The following describes the aircraft performance (SAE-AIR-1845 Appendix A) and noise data (Appendix B) required for aircraft to be included in the database of the Federal Aviation Administration's INM. Some items in this request form include enhancements to these documents, which are currently under review.

The fixed-wing aircraft portion of the INM database is harmonized with ICAO's Aircraft Noise and Performance (ANP) database, which accompanies ECAC's Doc 29 [2]. All fixed-wing aircraft submittals to the INM database will likewise be considered for implementation in the ANP database. ICAO's ANP database is located at: http://www.aircraftnoisemodel.org/ .

The following describes the performance and noise data required for aircraft to be included in the FAA's INM database. The form in Appendix G.1 is intended for the submittal of fixed wing aircraft noise and performance data for the INM database. Although propeller aircraft data may also be submitted with Appendix G.1, a simplified submittal form for propeller aircraft is provided in Appendix G.2. The form in Appendix G.3 is available for helicopter noise and performance data submittals.

APPENDIX G.1: INM DATABASE SUBMITTAL FORM FOR FIXED-WING AIRCRAFT

1. REFERENCE CONDITIONS FOR PERFORMANCE DATA

Table G-4-10: Reference Conditions for Performance Data

Wind	4 m/s (8 knots) headwind, constant with height above ground
Runway elevation	Mean Sea Level (MSL)
Runway gradient	None
Surface Air temperature	15ºC (59ºF)
Number of engines supplying thrust	All
Atmosphere	International Standard Atmosphere (ISA)

The Jet thrust coefficients of Section 4, may be validated for conditions other than 15°C, sea level. For these equations, it has been shown that coefficients may be developed for temperatures of 15°C to temperatures up to the engine break point and for takeoff altitudes of sea level up until 5000 feet above sea level.

Other SAE parameters such as rate-of-climb are not as flexible in their use and should be developed for a specific atmosphere. As per SAE-AIR-1845, the default operating procedures described in Section 5 will be provided for airports at 15°C, sea level condition assuming the International Standard Atmosphere. As an example, the parameters for rate-of-climb, target speed, and cutback height for a procedure will be developed specifically for sea level ISA.

2. AIRCRAFT AND ENGINE DATA

Where there are variations in certification weights and engine thrusts for a given model, provide data for the heaviest aircraft in terms of maximum gross takeoff weight in the model classification. **NOTE:** Aircraft should reference a certification equivalent. Where there are variations in weight and engine thrusts for a given model, data for the heaviest aircraft that has been delivered in the model classification should be provided.

Aircraft model			
Engine model			
Number of engines			
Engine type (jet, turboprop, piston)			
Engine Installation (tail- or wing-mounted)			
Noise stage number (2, 3, 4)			
Maximum static thrust (lb/engine)			
Automated thrust restoration (yes, no)			
Weight class (small, large, heavy)			
Maximum gross takeoff weight (lb)			
Maximum gross landing weight (lb)			
Maximum landing distance (ft)			
Reference Certification Levels	TO:	SL:	AP:

3. GUIDANCE FOR DEFAULT WEIGHTS AND PROCEDURES

Default procedures should be developed for ranges suitable for representing the normal operating range of the aircraft. In this way, users may interpolate to other weights provided they have justification or other data. In the absence of more detailed data, users will resort to default weights corresponding to the trip length of the aircraft. Takeoff weights should be developed so as to increase with an increase in mission trip length. Weight assumptions should use industry planning assumptions for load factor, average passenger weight, excess cargo beyond passenger weight, and fuel required to complete mission trip length. Weights should be developed for the trip length ranges using the default mission planning rules below.

Departure Takeoff Weights

Stage number	Trip length (nmi)	Representative Range	Weight (lb)
1	0-500	350	lb
2	500-1000	850	lb
3	1000-1500	1350	lb
4	1500-2500	2200	lb
5	2500-3500	3200	lb
6	3500-4500	4200	lb
7	4500-5500	5200	lb
8	5500-6500	6200	lb
9	>6500		lb

The following guidance has been established to provide common mission planning rules for determining default weights to the stage lengths given in the table above.

Table G-4-11: Guidance for Determining Departure Takeoff Weights

Parameter	Planning Rule
Representative Trip Length	Min Range + 0.70*(Max Range – Min Range)
Load Factor	65% Total Payload.
Fuel Load	Fuel Required for Representative Trip Length + ATA Domestic up to 3000 nm and International Reserves for trip length > 3000 nm. As an example, typical domestics reserves include 5% contingency fuel, 200 nm alternate landing with 30 minutes of holding.
Cargo	No additional cargo over and above the assumed payload percentage

Not all nine trip lengths will be required for every aircraft as not all aircraft will be able to fly the higher trip length ranges. In addition to providing the trip length ranges for which an aircraft is able to fly, weights and procedures should also be developed for the aircraft maximum takeoff weight. If relevant, a lower bound weight may also be provided that would be more representative of operations that would occur at weights below trip lengths of 350 nautical miles using the mission planning rules above.

4. AERODYNAMIC COEFFICIENTS

Aerodynamic coefficients for use with the SAE-AIR-1845 equations are required for available flap settings. The flap settings may be identified in degrees and abbreviations. Please provide data for all flap settings specified in Sections 6 and 7, and include separate coefficients per flap setting for cases with landing gear up and with landing gear down as appropriate.

Flap Configuration Identifier	Operation (A, D)[1]	Gear	Takeoff B (ft/lb)	Takeoff C (kt/√lb)	Land D (kt/√lb)	Drag/Lift R
	D	down				
	D	down				
	D	up	[2]			
	D	up				
	D	up				
	A	up				
	A	up				
	A	down				
	A	down				
	A	down				

[1] A = Approach, D = Depart
[2] Not applicable

5. ENGINE COEFFICIENTS

For jet aircraft, engine coefficients in accordance with SAE-AIR-1845 equations are required for maximum takeoff, maximum climb, and general thrust in terms of EPR or N1. The Max-Takeoff coefficients should be valid to 6000 feet MSL, the Max-Climb and General Thrust coefficients should be valid to 16000 feet MSL. This is necessary so that the INM accurately models operations at high altitude airports such as Denver and Salt Lake City.

In addition, high temperature coefficients are required for operations above the thrust break temperature. INM uses the Max-Takeoff and Max-Climb coefficients below the breakpoint temperature and uses the Hi-Temp coefficients above the breakpoint temperature. The breakpoint temperature is at the intersection of the two curves. An example of Max-Takeoff and Hi-Temp Max-Takeoff curves is shown in Figure G-1.

Thrust Type	E (lb)	F (lb/kt)	Ga (lb/ft)	Gb (lb/ft^2)	H (lb/ºC)
Max-Takeoff					
Hi-Temp Max-Takeoff					
Max-Climb					
Hi-Temp Max-Climb					
General Thrust					
Hi-Temp General Thrust					
	K1a (lb/EPR)	K1b (lb/EPR^2)	or	K2 $lb/(N1/\sqrt{\theta})$	K3 $lb/(N1/\sqrt{\theta})^2$
General Thrust					
Hi-Temp General Thrust					

For propeller-driven aircraft, engine coefficients in accordance with SAE-AIR-1845 equations are required for propeller efficiency and installed net propulsive power. Note that turboprop engine performance may be better modeled with the jet engine coefficients given above.

Thrust Type	Propeller Efficiency	Installed net propulsive horsepower (hp)
Max-Takeoff		
Max-Climb		

6. DEPARTURE PROCEDURES

Departure procedures consist of a takeoff segment, and a combination of climb and acceleration segments up to an altitude of 10000 feet AFE. A climb segment is defined by its endpoint altitude. An acceleration segment is defined by its rate-of-climb and the calibrated airspeed at its endpoint. The flap settings are indicated for endpoints of segments. These flap settings should coincide with those given in Section 4 above. Please provide procedural data for each stage length given in Section 3 above.

Default takeoff procedures include an ICAO A, an ICAO B, and a BBN/AAAI reference* procedure. Guidelines for the all three procedures are included below. In developing these procedures, manufactures should use best judgment based on experience with their customers in determining a default takeoff flap setting and an appropriate power cutback point. Manufacturers of propeller-driven aircraft should use their own recommended procedures.

* Historically, the BBN/AAAI reference procedure is known as the “STANDARD” procedure.

Table G-4-12: Default Takeoff Procedures

Standard Procedure* Modified BBN/AAAI Procedure	ICAO A	ICAO B
Takeoff at MaxToPower and Climb to 1000 feet altitude	Takeoff MaxToPower	Takeoff at MaxToPower
Pitch over and cutback to climb power. Accelerate to zero flaps retracting flaps on schedule†.	Climb at constant KCAS to 1500 feet	Climb to 1000 feet and pitch-over to accelerate at full power to clean configuration
Climb at constant speed to 3000 feet altitude.	Reduce thrust to Climb Power	At Clean Configuration, cutback top climb power
	Climb at KCAS to 3000 feet	Climb at constant speed to 3000 feet
Upon achieving 3000 feet altitude, accelerate to 250 knots*.	Accelerate while retracting flaps to Zero.	Upon achieving 3000 feet AFE, accelerate to 250 knots
	Continue accelerating to 250 knots.	
Upon achieving 250 knots, climb out to 10000 feet.	Upon achieving 250 knots, climb to 10000 feet	Upon achieving 250 knots, climb to 10000 feet

The table below should be completed for each submitted procedure (ICAO A, BBN/AAAI, etc) over each takeoff weight given in section 3.0. The number and sequence of the SAE/Doc 29 procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Additional information on CLIMB and ACCELERATION procedures steps is provided in SAE-AIR-1845.

* In manner cases, the "STANDARD" procedure is the same as the ICAO B procedure. Manufacturers of propeller-driven aircraft should use their own recommended procedures.

†.During acceleration steps, flaps are retracted on scheduled according to the published guidance for the airplane. Power is distributed between climb and acceleration according to the flight management system for the aircraft. This distribution between climb and acceleration should be provided as part of the data submission. As an example, a parameter of 55/45 would signify that 55% power would be for climb and 45% would be for acceleration .

Stage Number	

Repeat table for each takeoff stage number (takeoff weight) listed in Section 2

Segment Type*	Thrust Type† (T/C)	Flap Configuration Identifier‡	Endpoint Altitude (ft AFE)	Rate-of-Climb (ft/min)	Endpoint Speed (KCAS)	Start Thrust§ (lb)
Takeoff						lb
Climb			ft			lb
Climb			ft			lb
Accelerate				fpm	kt	lb
Accelerate				fpm	kt	lb
Climb			ft			lb
Climb			ft			lb
Accelerate				fpm	kt	lb
Accelerate				fpm	kt	lb
Climb			10000			lb

* Add, delete, and sequence the segments as necessary to represent a takeoff procedure.
† T = Max-Takeoff, C = Max-Climb, as defined in Section 4.
‡ Use the identifiers in Section 3.
§ These data are used to compare to INM-computed thrust values.

7. APPROACH PROCEDURES

A landing profile should be calculated for a starting altitude of 10000 feet above field elevation (AFE). The flap-setting identifiers should coincide with those given in Section 4.0 above. Reverse thrust distance is nominally 10% of ground roll distance, which is 90% of the stop distance (FAR Part 25 field length required for maximum gross landing weight) minus 954 feet. The idle/taxi distance is 90% of the stop distance minus 954 feet. Stop distance can be smaller than the maximum landing distance reported in Section 2.0 above. Reverse corrected net thrust is nominally 40% of maximum static thrust for narrow-body aircraft and 10% of maximum static thrust for wide-body aircraft. Taxi/idle corrected net thrust is nominally 10% of maximum static thrust reported in Section 2 above.

The table below should be completed for each submitted landing procedure. The number and sequence of the SAE/Doc 29 procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Additional information on landing procedures steps is provided in SAE-AIR-1845.

Landing weight (lb)	lb
Stopping distance* (ft)	ft

Profile Point	Operation	Starting Flap Configuration†	Starting Altitude (ft AFE)	Decent Angle (deg)	Start Speed‡ (KTAS)	Track Distance (Horizontal Length) (ft)	Start Thrust (% of static thrust)	Start Thrust§ (lb)
1	Descend							
2	Descend							
3	Descend							
4	Level-Decel							
5	Descend							
6	Land							
7	Decelerate							
8	Decelerate					0 ft		

---

* FAR Part 25 field length required for maximum gross landing weight.
† Use identifiers in Section 4.
‡ Landing speed is for reference only; INM calculates landing speed using the D coefficient (Section 3) and landing weight.
§ These data are used to compare to INM-computed thrust values.

8. NOISE DATA

Noise Power Distance data are requested for noise exposure levels (Sound Exposure Level and Effective Perceived Noise Level) and maximum noise levels (Maximum A-weighted Sound Level and Maximum Tone-Corrected Perceived Noise Level). Specific guidelines for developing Noise Power Distance (NPD) data are provided in SAE-AIR-1845. NPDs should be provided for representative corrected net thrust values that span the procedures given in Section 6 and Section 7. In general, noise measurements are collected under certification-like conditions and then are adjusted to different distances based on spherical divergence, altitude duration, time-varying aircraft speed, and atmospheric absorption. Where applicable, be sure to differentiate between approach and takeoff configuration noise data. For example, "6000-A" would be 6000 lb. of corrected net thrust under approach configuration.

Noise data for approach conditions should use the final approach landing speed as the reference speed for the noise data.

All exposure based metrics such as EPNL and SEL should be further normalized to 160 knots using the duration correction equation in SAE-AIR-1845.

Sound exposure levels should be calculated for the distances given on the tables, below which range from 200 feet to 25000 feet. SEL values less than 75 dB may require additional extrapolation and may not be consistently derived or accessed for accuracy across all aircraft types.

Unweighted one-third octave-band spectral data corresponding to the time of L_{PNTSmx} and the time of L_{ASmx} should be provided for each thrust level represented in the NPDs. The spectral data should be measured at a reference distance of 1000 ft, and span the one-third octave-bands from 50 to 10000 Hz. Where applicable, be sure to differentiate between approach and takeoff configuration noise data.

Noise Type*	
Operation†	

Repeat table for each combination of noise type and operation (8 tables)

	Corrected Net Thrust per Engine (lb)					
Distance (ft)	lb	lb	lb	lb	lb	lb
200	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
1000	dB	dB	dB	dB	dB	dB
2000	dB	dB	dB	dB	dB	dB
4000	dB	dB	dB	dB	dB	dB
6300	dB	dB	dB	dB	dB	dB
10000	dB	dB	dB	dB	dB	dB
16000	dB	dB	dB	dB	dB	dB
25000	dB	dB	dB	dB	dB	dB

* NOISE TYPES

L_{AE} = Sound Exposure Level (reference speed 160 knots)
L_{EPN} = Effective Perceived Noise Level (reference speed 160 knots)
L_{ASmx} = Maximum A-weighted Sound Level (at speed close to 160 knots)
L_{PNTSmx} = Maximum Tone-Corrected Perceived Noise Level (at speed close to 160 knots)

† OPERATIONS

A = Approach
D = Depart

Noise Type	
Operation	

Repeat table for each combination of noise type and operation (8 tables)

	Corrected Net Thrust per Engine (lb)					
Distance (ft)	lb	lb	lb	lb	lb	lb
200	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
1000	dB	dB	dB	dB	dB	dB
2000	dB	dB	dB	dB	dB	dB
4000	dB	dB	dB	dB	dB	dB
6300	dB	dB	dB	dB	dB	dB
10000	dB	dB	dB	dB	dB	dB
16000	dB	dB	dB	dB	dB	dB
25000	dB	dB	dB	dB	dB	dB

In addition, tables of third-octave band spectral data are requested, two tables at the time of Maximum A-weighted Sound Level for approach and departure operations, and two tables at the time of Maximum Tone-Corrected Perceived Noise Level for both approach and departure operations. The spectra should be at the same corrected net thrust values as provided in the noise exposure and maximum noise tables. The spectra should be measured at a speed close to 160 knots and adjusted to a reference distance of 1000 feet using the atmospheric absorption table in SAE-AIR-1845.

Third-octave band spectra at time*	
Operation†	

Repeat table for each combination of time and operation (4 tables)

	Corrected Net Thrust per Engine (lb)					
Band (Hz)	lb	lb	lb	lb	lb	lb
50	dB	dB	dB	dB	dB	dB
63	dB	dB	dB	dB	dB	dB
80	dB	dB	dB	dB	dB	dB
100	dB	dB	dB	dB	dB	dB
125	dB	dB	dB	dB	dB	dB
160	dB	dB	dB	dB	dB	dB
200	dB	dB	dB	dB	dB	dB
250	dB	dB	dB	dB	dB	dB
315	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
500	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
800	dB	dB	dB	dB	dB	dB
1000	dB	dB	dB	dB	dB	dB
1250	dB	dB	dB	dB	dB	dB
1600	dB	dB	dB	dB	dB	dB
2000	dB	dB	dB	dB	dB	dB
2500	dB	dB	dB	dB	dB	dB
3150	dB	dB	dB	dB	dB	dB
4000	dB	dB	dB	dB	dB	dB
5000	dB	dB	dB	dB	dB	dB
6300	dB	dB	dB	dB	dB	dB
8000	dB	dB	dB	dB	dB	dB
10000	dB	dB	dB	dB	dB	dB

* At time of LASmx and LPNTSmx
† Operation A = Approach and D = Depart

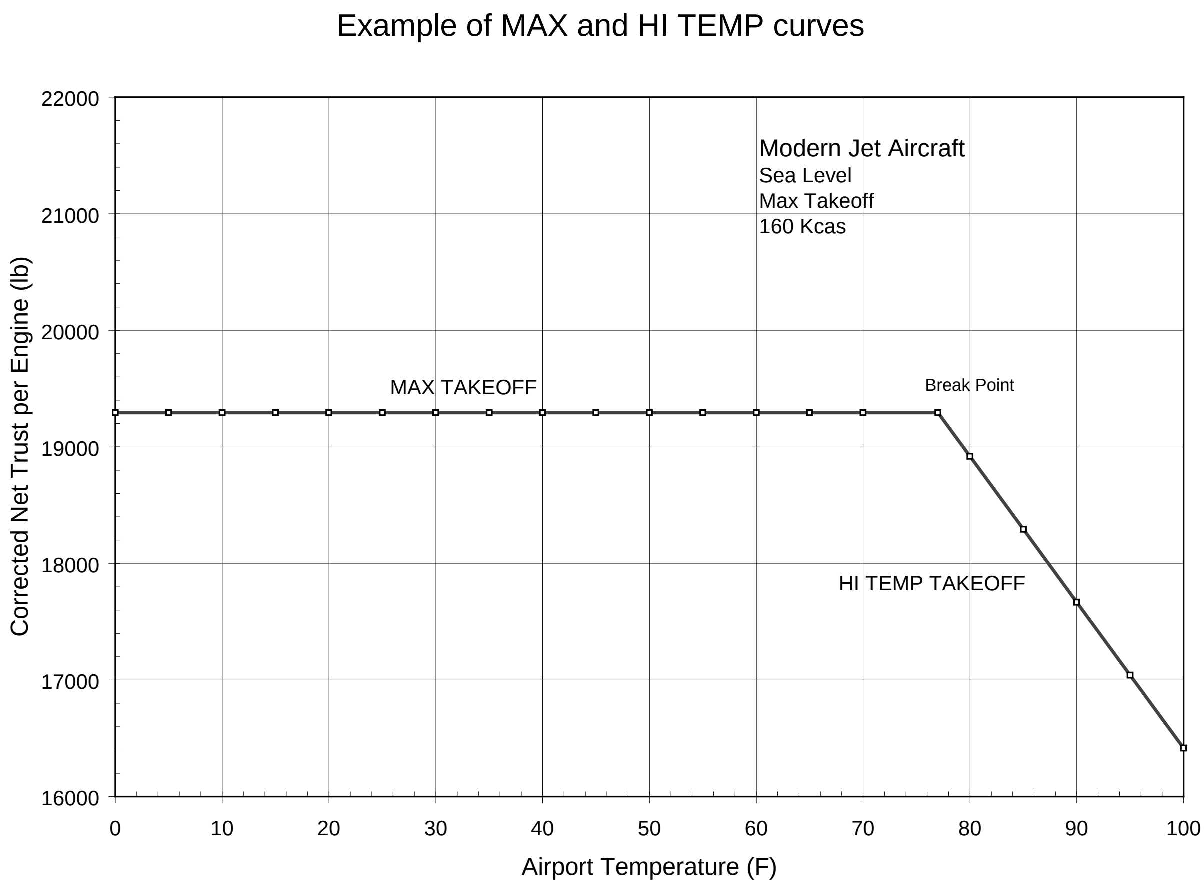

Figure G-1: Example Maximum Takeoff Thrust vs. Temperature

APPENDIX G.2: INM DATABASE SUBMITTAL FORM FOR PROPELLOR-DRIVEN, FIXED-WING AIRCRAFT

Since the form in Appendix G.1 may be used for either jet or propeller fixed-wing aircraft, it is formatted to allow for the entry of information that may be extraneous for propeller aircraft. Therefore, an abbreviated version of that form specific to propeller-driven aircraft is presented in Appendix G.2. It is intended for the submittal of propeller-driven, fixed-wing aircraft noise and performance data for the INM database.

1. REFERENCE CONDITIONS FOR PERFORMANCE DATA

Table G-4-13: Reference Conditions for Performance Data

Wind	4 m/s (8 kts) headwind, constant with height above ground
Runway elevation	Mean Sea Level (MSL)
Runway gradient	None
Surface Air temperature	15ºC (59ºF)
Number of engines supplying thrust	All
Atmosphere	International Standard Atmosphere (ISA)

As per SAE-AIR-1845, the default operating procedures described in Section 5 will be provided for airports at 15°C, sea level condition assuming the International Standard Atmosphere. As an example, the parameters for rate-of-climb, target speed, and cutback height for a procedure will be developed specifically for sea level ISA.

2. AIRCRAFT AND ENGINE DATA

Where there are variations in certification weights and engine thrusts for a given model, provide data for the heaviest aircraft in terms of maximum gross takeoff weight in the model classification. **NOTE:** Aircraft should reference a certification equivalent. Where there are variations in weight and engine power settings for a given model, data for the heaviest aircraft that has been delivered in the model classification should be provided. Furthermore, power should be presented in the form of horsepower.

Aircraft model			
Engine model			
Number of engines			
Engine type (jet, turboprop, piston)			
Engine Installation (tail- or wing-mounted)			
Noise stage number (2, 3, 4)			
Sea Level rated HP (per engine)			
Automated thrust restoration (yes, no)			
Weight class (small, large, heavy)			
Maximum gross takeoff weight (lb)			
Maximum gross landing weight (lb)			
Maximum landing distance (ft)			
FAR Part 36 Reference Certification Levels*, either:			
(a) Appendix B, or	TO:	SL:	AP:
(b) Appendix G	TO:		

3. GUIDANCE FOR DEFAULT WEIGHTS AND PROCEDURES

Default procedures should be developed for ranges suitable for representing the normal operating range of the aircraft. In this way, users may interpolate to other weights provided they have justification or other data. In the absence of more detailed data, users will resort to default weights corresponding to the trip length of the aircraft. Takeoff weights should be developed so as to increase with an increase in mission trip length. Weight assumptions should use industry planning assumptions for load factor, average passenger weight, excess cargo beyond passenger weight, and fuel required to complete mission trip length. Weights should be developed for the trip length ranges using the default mission planning rules below.

* TO = takeoff; SL = sideline; and AP = Approach.

Departure Takeoff Weights

Stage number	Trip length (nmi)	Representative Range	Weight (lb)
1	0-500	350	lb
2	500-1000	850	lb
3	1000-1500	1350	lb
4	1500-2500	2200	lb
5	2500-3500	3200	lb
6	3500-4500	4200	lb
7	4500-5500	5200	lb
8	5500-6500	6200	lb
9	>6500		lb

The following guidance has been established to provide common mission planning rules for determining default weights to the stage lengths given in the table above.

Table G-4-14: Guidance for Determining Departure Takeoff Weights

Parameter	Planning Rule
Representative Trip Length	Min Range + 0.70*(Max Range – Min Range)
Load Factor	65% Total Payload.
Fuel Load	Fuel Required for Representative Trip Length + ATA Domestic up to 3000 nm and International Reserves for trip length > 3000 nm. As an example, typical domestics reserves include 5% contingency fuel, 200 nm alternate landing with 30 minutes of holding.
Cargo	No additional cargo over and above the assumed payload percentage

Not all nine trip lengths will be required for every aircraft as not all aircraft will be able to fly the higher trip length ranges. In addition to providing the trip length ranges for which an aircraft is able to fly, weights and procedures should also be developed for the aircraft maximum takeoff weight. If relevant, a lower bound weight may also be provided that would be more representative of operations that would occur at weights below trip lengths of 350 nautical miles using the mission planning rules above.

4. AERODYNAMIC COEFFICIENTS

Aerodynamic coefficients for use with the SAE-AIR-1845 equations are required for available flap settings. The flap settings may be identified in degrees and/or abbreviations. Please provide data for all flap settings specified in Sections 6 and 7, and include separate coefficients per flap setting for cases with landing gear up and with landing gear down as appropriate. Fixed gear aircraft do not require gear position information.

Flap Configuration Identifier	Operation (A, D)*	Gear	Takeoff **B** (ft/lb)	Takeoff **C** (kt/√lb)	Land **D** (kt/√lb)	Drag/Lift **R**
	D	down				
	D	down				
	D	up				
	D	up				
	D	up				
	A	up				
	A	up				
	A	down				
	A	down				
	A	down				

5. ENGINE COEFFICIENTS

For propeller-driven aircraft, engine coefficients in accordance with SAE-AIR-1845 equations are required for propeller efficiency and installed net propulsive power. In many cases, turboprop engine performance may be better modeled with the jet engine coefficients given in the Appendix G.1.

Note that the current version of the INM uses the Max-Climb power setting from the thrust reduction point up to 10000 feet AFE. If the aircraft engine is flat-rated, no change is required. If the engine is normally aspirated, the average power in the climb should be used. Propeller efficiencies should also be averaged over the conditions when the different power settings are used.

Power Setting	Propeller Efficiency	Installed net propulsive horsepower (hp)
Max-Takeoff		
Max-Climb		

* A = Approach, D = Depart

6. DEPARTURE PROCEDURES

Departure procedures consist of a takeoff segment, and a combination of climb and acceleration segments up to an altitude of 10000 feet AFE. A climb segment is defined by its endpoint altitude. An acceleration segment is defined by its rate-of-climb and the calibrated airspeed at its endpoint. The flap settings are indicated for endpoints of segments. These flap settings should coincide with those given in Section 4 above. Please provide procedural data for each stage length given in Section 3 above.

The table below should be completed for each submitted procedure over each takeoff weight given in Section 3. The number and sequence of the SAE/Doc 29 procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Database submittals should comply with manufacturer's recommended departure procedures. Additional information on CLIMB and ACCELERATION procedures steps is provided in SAE-AIR-1845. Note, certain SAE parameters such as rate-of-climb are not flexible in their use and should be developed for a specific atmosphere.

Stage Number	

Repeat table for each takeoff stage number (takeoff weight) listed in Section 2

Segment Type*	Power Setting† (T/C)	Flap Configuration Identifier‡	Endpoint Altitude (ft AFE)	Rate-of-Climb (ft/min)	Endpoint Speed (KCAS)	Start Thrust§ (lb)
Takeoff						lb
Climb			ft			lb
Climb			ft			lb
Accelerate				fpm	kt	lb
Accelerate				fpm	kt	lb
Climb			ft			lb
Climb			ft			lb
Accelerate				fpm	kt	lb
Accelerate				fpm	kt	lb
Climb			10000			lb

* Add, delete, and sequence the segments as necessary to represent a takeoff procedure.
† T = Max-Takeoff, C = Max-Climb, as defined in Section 4.
‡ Use the identifiers in Section 3.
§ These data are used to compare to INM-computed thrust values.

7. APPROACH PROCEDURES

A landing profile should be calculated for a starting altitude of 6000 feet above field elevation (AFE) and a 3-degree glide slope. The flap-setting identifiers should coincide with those given in Section 4 above. The idle/taxi distance is 90% of the stop distance (FAR Part 25 field length required for maximum gross landing weight) minus 954 feet. Stop distance can be smaller than the maximum landing distance reported in Section 2 above. Taxi/idle power setting is nominally 10% of Sea Level rated horsepower reported in Section 2 above.

The table below should be completed for each submitted landing procedure. The number and sequence of the SAE/Doc 29 procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Additional information on landing procedures steps is provided in SAE-AIR-1845.

Landing weight (lb)	lb
Stopping distance* (ft)	ft

Profile Point	Operation	Starting Flap Configuration†	Starting Altitude (ft AFE)	Decent Angle (deg)	Start Speed‡ (KTAS)	Track Distance (Horizontal Length) (ft)	Taxi/idle power setting	Start Thrust§ (lb)
1	Descend							
2	Descend							
3	Descend							
4	Level-Decel							
5	Descend							
6	Land							
7	Decelerate							
8	Decelerate					0 ft		

* FAR Part 25 field length required for maximum gross landing weight.
† Use identifiers in Section 4.
‡ Landing speed is for reference only; INM calculates landing speed using the D coefficient (Section 3) and landing weight.
§ These data are used to compare to INM-computed thrust values.

8. NOISE DATA

Noise Power Distance data are requested for noise exposure levels (Sound Exposure Level and Effective Perceived Noise Level) and maximum noise levels (Maximum A-weighted Sound Level and Maximum Tone-Corrected Perceived Noise Level). Specific guidelines for developing Noise Power Distance (NPD) data are provided in SAE-AIR-1845. NPDs should be provided for representative corrected net thrust values that span the procedures given in Section 6 and Section 7. Corrected net thrust for propeller-driven aircraft should be calculated using the SAE-AIR-1845 equations (or equation 2-13 in the INM 7.0 Technical manual) and the coefficients provided in this data submittal. In general, noise measurements are collected under certification-like conditions and then are adjusted to different distances based on spherical divergence, altitude duration, time-varying aircraft speed, and atmospheric absorption. Where applicable, be sure to differentiate between approach and takeoff configuration noise data. For example, "200-A" would be 200 lb. of corrected net thrust per engine under approach configuration.

Noise data for approach conditions should use the final approach landing speed as the reference speed for the noise data.

All exposure based metrics such as EPNL and SEL should be further normalized to 160 knots using the duration correction equation in SAE-AIR-1845.

Sound exposure levels should be calculated for the distances given on the tables, below which range from 200 feet to 25000 feet.

Unweighted one-third octave-band spectral data corresponding to the time of L_{PNTSmx} and the time of L_{ASmx} should be provided for each thrust level represented in the NPDs. The spectral data should be measured at a reference distance of 1000 ft, and span the one-third octave-bands from 50 to 10000 Hz. Where applicable, be sure to differentiate between approach and takeoff configuration noise data.

Noise Type*	
Operation†	

Repeat table for each combination of noise type and operation (8 tables)

	Corrected Net Thrust per Engine (lb)					
Distance (ft)	lb	lb	lb	lb	lb	lb
200	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
1000	dB	dB	dB	dB	dB	dB
2000	dB	dB	dB	dB	dB	dB
4000	dB	dB	dB	dB	dB	dB
6300	dB	dB	dB	dB	dB	dB
10000	dB	dB	dB	dB	dB	dB
16000	dB	dB	dB	dB	dB	dB
25000	dB	dB	dB	dB	dB	dB

* NOISE TYPES
  - L_{AE} = Sound Exposure Level (reference speed 160 kt)
  - L_{EPN} = Effective Perceived Noise Level (reference speed 160 kt)
  - L_{ASmx} = Maximum A-weighted Sound Level (at speed close to 160 kt)
  - L_{PNTSmx} = Maximum Tone-Corrected Perceived Noise Level (at speed close to 160 kt)

† OPERATIONS
  - A = Approach
  - D = Depart

Noise Type	
Operation	

Repeat table for each combination of noise type and operation (8 tables)

	Corrected Net Thrust per Engine (lb)					
Distance (ft)	lb	lb	lb	lb	lb	lb
200	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
1000	dB	dB	dB	dB	dB	dB
2000	dB	dB	dB	dB	dB	dB
4000	dB	dB	dB	dB	dB	dB
6300	dB	dB	dB	dB	dB	dB
10000	dB	dB	dB	dB	dB	dB
16000	dB	dB	dB	dB	dB	dB
25000	dB	dB	dB	dB	dB	dB

In addition, tables of third-octave band spectral data are requested, two tables at the time of Maximum A-weighted Sound Level for approach and departure operations, and two tables at the time of Maximum Tone-Corrected Perceived Noise Level for both approach and departure operations. The spectra should be at the same corrected net thrust values as provided in the noise exposure and maximum noise tables. The spectra should be measured at a speed close to 160 knots (if the aircraft is capable) and adjusted to a reference distance of 1000 feet using the atmospheric absorption table in SAE-AIR-1845.

Third-octave band spectra at time*	
Operation†	

Repeat table for each combination of time and operation (4 tables)

	Corrected Net Thrust per Engine (lb)					
Band (Hz)	lb	lb	lb	lb	lb	lb
50	dB	dB	dB	dB	dB	dB
63	dB	dB	dB	dB	dB	dB
80	dB	dB	dB	dB	dB	dB
100	dB	dB	dB	dB	dB	dB
125	dB	dB	dB	dB	dB	dB
160	dB	dB	dB	dB	dB	dB
200	dB	dB	dB	dB	dB	dB
250	dB	dB	dB	dB	dB	dB
315	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
500	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
800	dB	dB	dB	dB	dB	dB
1000	dB	dB	dB	dB	dB	dB
1250	dB	dB	dB	dB	dB	dB
1600	dB	dB	dB	dB	dB	dB
2000	dB	dB	dB	dB	dB	dB
2500	dB	dB	dB	dB	dB	dB
3150	dB	dB	dB	dB	dB	dB
4000	dB	dB	dB	dB	dB	dB
5000	dB	dB	dB	dB	dB	dB
6300	dB	dB	dB	dB	dB	dB
8000	dB	dB	dB	dB	dB	dB
10000	dB	dB	dB	dB	dB	dB

* At time of LASmx and LPNTSmx
† Operation A = Approach and D = Departure/

APPENDIX G.3: INM DATABASE SUBMITTAL FORM FOR HELICOPTERS

The following describes the performance and noise data required for helicopters to be included in the FAA's INM database.

1. REFERENCE CONDITIONS FOR PERFORMANCE DATA

Helicopter noise data required for use in the INM should be corrected for the conditions contained in the following table.

Table G-4-15: Reference Conditions for Performance Data

Wind	Zero
Runway/helipad elevation	Mean Sea Level (MSL)
Atmosphere	SAE-AIR-1845, Appendix B
Number of engines supplying thrust	All
Atmosphere	International Standard Atmosphere (ISA)

2. AIRCRAFT AND ENGINE DATA

NOTE: Aircraft should reference a certification equivalent. Where there are variations in weight for a given model, data for the heaviest aircraft that has been delivered in the model classification should be provided.

Helicopter model				
Description				
Owner category*				
Engine type ('turboshaft', 'piston')				
Number of main rotor blades				
Main rotor diameter (ft)				
Rotor speed (RPM)				
Maximum gross takeoff weight (lb)				
Wheels ('yes' or 'no')				
Engine model				
Number of rotors (main plus tail)				
Maximum Speed in Level Flight w/ Maximum Continuous Power, V_H (kt)				
Speed for Best Rate of Climb, V_Y (kt)				
Never Exceed Speed, V_{NE} (kt)				
FAR Part 36 Reference Certification Levels†, either:				
(a) Appendix H, or	TO:	SL:	AP:	LF:
(b) Appendix J	TO:			LF:

3. SPEED COEFFICIENTS

B_0, B_1 and B_2 are regression coefficients used in the calculation of a source-noise correction *for level flight only*. The correction accounts for changes in sound level associated with the deviation of advancing blade Mach number from that associated with the source data reference conditions (see Section 3.6.1). The coefficients are derived using a least-squares, 2nd order regression through measured L_{PNTSmx} data as a function of test speed.

B_0	
B_1	
B_2	

* COM = commercial aviation, and GA = general aviation.
† TO = takeoff; SL = sideline; AP = approach; and LF = level flyover.

4. DEPARTURE PROCEDURES

Departure procedures consist of ground and flight idle segments, a combination of vertical and horizontal movement segments, and ending in a level flight segment. An idle segment is defined by its duration. A climb segment is defined by its endpoint altitude. An acceleration segment is defined by its calibrated airspeed at its endpoint. Please provide procedural data for each stage length given in Section 2 above.

The table below should be completed for each submitted procedure. The number and sequence of procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. In general Taxi profiles, are modeled separately from departure profiles. Database submittals should comply with manufacturer's recommended departure procedures.

Stage Number	

Repeat table for each takeoff stage number (takeoff weight) listed in Section 2

Segment Type*	Duration (sec)	Endpoint Altitude (ft AFE)	Track Distance (ft)	Endpoint Speed (KCAS)
Ground Idle	sec			
Flight Idle	sec			
Departure Vertical	sec	ft		
Departure Horizontal Accelerate			ft	kt
Departure Climb Accelerate		ft	ft	kt
Departure Constant Speed		ft	ft	
Departure Horizontal Accelerate	sec		ft	kt
Level Fly			ft	

* Add, delete, and sequence the segments as necessary to represent a takeoff procedure.

5. APPROACH PROCEDURES

A landing profile should be calculated for a helicopter starting with a level flight segment, followed by a combination of vertical and horizontal movement segments (corresponding with a 6 degree approach, when appropriate) with , and ending with flight and ground idle segments.

The table below should be completed for each submitted procedure. The number and sequence of procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. In general Taxi profiles, are modeled separately from approach profiles. Database submittals should comply with manufacturer's recommended approach procedures.

Segment Type*	Duration (sec)	Endpoint Altitude (ft AFE)	Track Distance (ft)	Endpoint Speed (KCAS)
Start Altitude†		ft		kt
Level Fly			ft	
Approach Horizontal Decelerate			ft	kt
Approach Constant Speed		ft	ft	
Approach Descend Accelerate		ft	ft	kt
Approach Vertical	sec	ft		
Flight Idle	sec			
Ground Idle	sec			

6. NOISE DATA

For helicopters, NPDdata consist of a set of three noise curves for dynamic operations and a single noise curve for static operations. Noise data are required for noise exposure levels (Sound Exposure Level [SEL] and Effective Perceived Noise Level [EPNL]) and maximum noise levels (Maximum A-weighted Sound Level [LAMAX] and Maximum Tone-Corrected Perceived Noise Level [PNLTM]). Noise levels should be adjusted for spherical spreading, distance duration, time-varying aircraft speed, and atmospheric absorption in accordance with the methodology presented in SAE-AIR-1845.

The following two tables present the noise type and operation mode used to define each noise-

* Add, delete, and sequence the segments as necessary to represent a takeoff procedure.
† Since there are no track distance and duration information associated with a "Start Altitude" segment, the endpoint speed and altitude correspond to the starting speed and altitude.

distance data set.

Table G-4-16: Noise Type for Each Helicopter NPD Data Set

Noise Type	Description
L_{AE}	Sound Exposure Level (note reference speed)
L_{EPN}	Effective Perceived Noise Level (note reference speed)
L_{ASmx}	Maximum A-weighted Sound Level (near reference speed)
L_{PNTSmx}	Maximum Tone-Corrected Perceived Noise Level (near reference speed)

Table G-4-17: Operation Mode for Each Helicopter NPD Data Set

Operation Mode	Procedure Step Description	HNM Code
A	Approach at constant speed	APPR
D	Depart at constant speed	TO
X	Level flyover at constant speed	LFLO
G	Ground idle	GIDLE
H	Flight idle	FIDLE
I	Hover in ground effect	HIGE
J	Hover out of ground effect	HOGE
V	Vertical ascent in ground effect	VASC
W	Vertical ascent out of ground effect	VASC
B	Approach with horizontal deceleration	DCLH
C	Approach with descending deceleration	DCLD
E	Depart with horizontal acceleration	ACLH
F	Depart with climbing acceleration	ACLC
T	Taxi at constant speed	TAXI

Where available, level flyover NPD data may be provided which are representative of different reference flight speeds. Similarly, approach data may be provided which are representative of different reference flight angles (i.e., 3-, 6-, 9- and 12-degree approaches).

6.1 Minimum Required Noise Data

A minimum of nine SEL NPD curves for dynamic operations and two LAMAX curves for static operations are required to model a helicopter in INM. Specifically, three (left, center and right) SEL curves are required for approach, departure and level flyover operations. Additionally, one hover LAMAX curve (either HIGE or HOGE, see 'Operation Types' table above for definitions) and one idle LAMAX curve (either GIDLE or FIDLE) are required.

6.2 Noise Data Tables for Dynamic Operations

NPD data should be provided for each dynamic operations (departure, approach and level flight), including left, center and right curves, representative of 45, 90 and 45 degree elevation angles, respectively.

Repeat the following table for each combination of noise type and dynamic operation.

Noise Type	
Operation	

Distance (ft)	**Type of Operation**		
	____*noise descriptor*___ @ _*xx*_ kts		
	Left	**Center**	**Right**
200	dB	dB	dB
400	dB	dB	dB
630	dB	dB	dB
1000	dB	dB	dB
2000	dB	dB	dB
4000	dB	dB	dB
6300	dB	dB	dB
10000	dB	dB	dB
16000	dB	dB	dB
25000	dB	dB	dB

6.3 Noise Data Tables for Static Operations

A single curve should be provided for each static operation (ground idle, flight idle, hover in ground effect, and hover out of ground effect) collected directly in front of the helicopter (0 degrees) at a nominal distance of approximately 200 feet. These data should be adjusted out to the 10 NPD distances for spherical spreading, distance duration, time-varying aircraft speed, and atmospheric absorption in accordance with the methodology presented in SAE-AIR-1845 [8]. Instead of the three noise curves representing helicopter directivity in dynamic operations (see Section 6.2), directivity for static operations is represented by the single noise curve plus a directivity adjustment (see Section 8).

Repeat the following table for each combination of noise type and static operation.

Noise Type	
Operation	

Distance (ft)	Type of Operation
200	dB
400	dB
630	dB
1000	dB
2000	dB
4000	dB
6300	dB
10000	dB
16000	dB
25000	dB

6.4 NPD Adjustments

As discussed in Section 6.1, many helicopter data submittals may not consist of a comprehensive data set covering all operational modes. Therefore, the INM can perform noise calculations even if noise data is not available for every flight operational mode. When a flight profile uses a particular operating mode for which noise data are not available, the INM substitutes noise data from a similar operating mode. It also adds any dB offsets specified in the helicopter noise data set. The INM makes substitutions for missing NPD data sets as follows:

Table G-4-18: Noise Data Substitutes for Missing Operational Modes

Missing Flight Operational Mode	Use Available Operational Mode
GndIdle	FltIdle
FltIdle	GndIdle
HovInGE	HovOutGE
HovOutGE	HovInGE
DepVertInGE	HovInGE + Vert Asc Adjustment
DepVert.OutGE	HovOutGE + Vert Asc Adjustment
AppVertInGE	HovInGE + Vert Des Adjustment
AppVert.OutGE	HovOutGE + Vert Des Adjustment
AppHorDec	Approach + Decel Hor Adjustment
AppDesDec	Approach + Decel Des Adjustment
DepHorAcc	Depart + Accel Hor Adjustment
DepClmAcc	Depart + Accel Clm Adjustment
Taxi	FltIdle (has wheels) HovInGE (no wheels)

The NPD Adjustments supplied below will only be applied to the corresponding helicopter NPD data. These NPD adjustments are typically manufacturer supplied, fixed noise level adjustments for operational modes that are not directly represented in the INM/AEDT NPD database. Historically, these adjustments are based on empirical data, and it is up to the data supplier's discretion on how to develop these adjustments. These adjustments are always superseded by operation-specific helicopter NPDs, when available. If adjustments are not provided, then default values of 0.0 dB are used.

Type of Operation	NPD Adjustment	NPD Adjustment Level (dB)
Departure Vertical (In Ground Effect and Out of Ground Effect)	Vert Asc Adjustment	
Approach Vertical (In Ground Effect and Out of Ground Effect)	Vert Des Adjustment	
Approach Horizontal Decelerate	Decel Hor Adjustment	
Approach Descend Decelerate	Decel Des Adjustment	
Departure Horizontal Accelerate	Accel Hor Adjustment	
Departure Climb Accelerate	Accel Clm Adjustment	

7. Spectral Data

In addition to NPD data, six tables of one-third octave-band spectral data are requested: maximum A-weighted sound level for approach, maximum A-weighted sound level for departure, maximum A-weighted sound level for level flight, maximum tone-corrected perceived noise level for approach, maximum tone-corrected perceived noise level for departure, and maximum tone-corrected perceived noise level for level flight. All of these data should be collected at the center microphone at the time of the corresponding maximum noise level. The spectra should be for the same operational conditions provided in the noise exposure and maximum noise tables, and based off of the data collected at the center microphone position. The spectra should be measured at a speed close to the indicated reference speed and adjusted to a reference distance of 1000 feet using the atmospheric absorption table in SAE-AIR-1845. Repeat table for each combination of noise type and operation (6 tables).

Noise Type*	
Operation†	

	Reference Speed
One-Third Octave-Band Nominal Center Frequency (Hz)	**_____ kt**
20	dB
25	dB
31.5	dB
40	dB
50	dB
63	dB
80	dB
100	dB
125	dB
160	dB
200	dB
250	dB
315	dB
400	dB
500	dB
630	dB
800	dB

* Noise type represents the third-octave band spectra at time of max (L_{ASmx} and L_{PNTSmx}).
† Operations are abbreviated as follows: A = Approach, D = Depart and L = Level Flight

1000	dB
1250	dB
1600	dB
2000	dB
2500	dB
3150	dB
4000	dB
5000	dB
6300	dB
8000	dB
10000	dB

8. Directivity Data for Static Operations

Directivity data for static operations (HIGE, HOGE, GIDLE and FIDLE) shall be collected for modeling purposes, providing relative differences in sound level as a function of angle around the craft. Data for these operations shall be collected at locations representative of multiple directivity angles around the helicopter. Microphones should be placed around the helicopter at a nominal radial distance of approximately 200 feet. INM accommodates data in 15-degree increments, but will linearly interpolated to fill in missing data. At a minimum data should be collected at 45-degree increments around the helicopter.

Relative directivity adjustment data should be provided for static operations. If possible, directivity adjustments should be supplied for both hard ground (e.g., pavement) and soft ground (e.g., grass).

Helicopter Directivity Angle (deg)	Adjustment (dB)	
	Hard Ground	Soft Ground
180 (L)	dB	dB
165 (L)	dB	dB
150 (L)	dB	dB
135 (L)	dB	dB
120 (L)	dB	dB
105 (L)	dB	dB
90 (L)	dB	dB
75 (L)	dB	dB
60 (L)	dB	dB
45 (L)	dB	dB
30 (L)	dB	dB
15 (L)	dB	dB
0	dB	dB
15 (R)	dB	dB
30 (R)	dB	dB
45 (R)	dB	dB
60 (R)	dB	dB
75 (R)	dB	dB
90 (R)	dB	dB
105 (R)	dB	dB
120 (R)	dB	dB
135 (R)	dB	dB
150 (R)	dB	dB
165 (R)	dB	dB
180 (R) = *180 (L)*	dB	dB

REFERENCES

1. Society of Automotive Engineers, Committee A-21, Aircraft Noise, Procedure for the Computation of Airplane Noise in the Vicinity of Airports, Aerospace Information Report No. 1845, Warrendale, PA: Society of Automotive Engineers, Inc., March 1986.

2. European Civil Aviation Conference (ECAC) Report on Standard Method of Computing Noise Contours around Civil Airports, Doc 29 (3rd Edition), July 2005.

3. International Civil Aviation Organization (ICAO), Recommended Method for Computing Noise Contours around Airports, Circular 205-AN/1/25, March 1987.

4. Dinges, et al., Integrated Noise Model (INM) Version 7.0 User's Guide, Report No. FAA-AEE-07-04, Washington, D.C.: Federal Aviation Administration, April 2007.

5. Fleming, et al., Heliport Noise Model Version 2.2 User’s Guide, Report No. DOT/FAA/EE/94-01, Washington, D.C.: Federal Aviation Administration, February 1994.

6. Society of Automotive Engineers, Committee A-21, Aircraft Noise, Method for Predicting Lateral Attenuation of Airplane Noise, Aerospace Information Report No. 5662, Warrendale, PA: Society of Automotive Engineers, Inc., April 2006.

7. Society of Automotive Engineers, Committee A-21, Aircraft Noise, Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity, Aerospace Research Report No. 866A, Warrendale, PA: Society of Automotive Engineers, Inc., March 1975.

8. International Civil Aviation Organization, Manual of the ICAO Standard Atmosphere, Doc 7488/3, 1993.

9. Preferred Frequencies, Frequency Levels and Band Numbers for Acoustical Measurements, American National Standard, ANSI S1.6-1984 (R2006), New York, NY: American National Standards Institute, 2006.

10. Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters, American National Standard, ANSI S1.11-2004, New York, NY: American National Standards Institute, 2004.

11. Federal Aviation Regulations, Part 36, Noise Standards: Aircraft Type and Airworthiness Certification, Washington, D.C.: Federal Aviation Administration, September 1992.

12. Newman, J. S., Beattie, K. R., Aviation Noise Effects, Report No. FAA-EE-85-2, Washington, DC: FAA, Office of Environment and Energy, March 1985.

13. Harris, C. M. (ed.), Handbook of Acoustical Measurements and Noise Control, Third Edition, New York, NY: McGraw-Hill, 1991.

14. Beranek, L. L., (ed.), Noise and Vibration Control, Revised Edition, New York, NY: McGraw-Hill, 1988.

15. Acoustical Terminology, American National Standard, ANSI S1.1-1994, New York, NY: American National Standards Institute, 1994.

16. Bennett, R. L., Pearsons, K. S., Handbook of Aircraft Noise Metrics, NASA Contractor Report No. 3406, Canoga Park, CA: Bolt Beranek and Newman Inc., 1981.

17. Fleming, et. al., Assessment of Tools for Modeling Aircraft Noise in the National Parks, FICAN report, Cambridge, MA: John A. Volpe National Transportation Systems Center, Arlington, VA: Wyle Laboratories, Winchester, MA: Senzig Engineering, March 2005.

18. Moulton, C .L., Air Force Procedure for Predicting Aircraft Noise Around Airbases: Noise Exposure Model (NOISEMAP), User's Manual, Report No. AAMRL-TR-90-011, Wright-Patterson Air Force Base, Ohio: United States Air Force, February 1990.

19. Bishop, D. E., Beckmann, J. M., Bucka, M. P., Revision of Civil Aircraft Noise Data for the Integrated Noise Model (INM), Report No. 6039, Canoga Park, CA: BBN Laboratories Incorporated, September 1986.

20. Rapoza, et al., “Assessment of Spectral Classes in FAA’s INM,” Noise Control Engineering Journal, draft, 2008.

21. Spectral Classes For FAA’s Integrated Noise Model, Report No. DTS-34-FA065-LR1, Cambridge, MA, John A. Volpe National Transportation Systems Center, December 1999.

22. International Civil Aviation Organization, Environmental Protection, Annex 16, Volume 1, Aircraft Noise.

23. Connor, et. al., Accuracy of the Integrated Noise Model (INM): MD-80 Operational Noise Levels, Washington, D.C.: Federal Aviation Administration and Swedish Civil Aviation Administration, May 1995.

24. Wei-Nian Su, John-Paul Clarke, Aircraft Performance Algorithms in INM, Cambridge, MA: Department of Aeronautics and Astronautics, Massachusetts Institute of Technology.

25. Federal Aviation Regulations, Part 25, Airworthiness Standards: Transport Category Airplanes, Washington, D.C.: Federal Aviation Administration, February 1965.

26. Eldred, K. M., Miller, R. L., Analysis of Selected Topics in the Methodology of the Integrated Noise Model, Report No. 4413, BBN Project No. 09611, Cambridge, MA: Bolt Beranek and Newman Inc., September 1980.

27. Boeing Commercial Airplane Company, Boeing Airplane/Noise Performance Computer

Program - Programmer's Manual, Report No. FAA-EQ-73-7.7, Seattle, WA: Boeing Commercial Airplane Company, December 1973.

28. Kurzweil, L., Relationship Between Atmospheric Temperature, Pressure, Density, Speed of Sound and Altitude When Airport Temperature and Elevation are Prescribed, Memorandum to Thomas L. Connor, FAA/AEE-120, Cambridge, MA: Transportation Systems Center, February 1986.

29. Kurzweil, L., Computation of Fraction (F_{12}) of Data-Base Noise Level Represented by a Finite Length Flight Segment, INM Technical Overview and Work Plan, Cambridge, MA: Transportation Systems Center, March 1987.

30. Eldred, K. M., Approximating Aircraft Noise Using a Model of a Moving Source with a 90° Dipole Radiation Pattern, Memorandum to Dr. R. G. Gados, The Mitre Corporation, Cambridge, MA: Bolt Beranek and Newman, Inc., March 1980.

31. Society of Automotive Engineers, Committee A-21, Aircraft Noise, Prediction Method for Lateral Attenuation of Airplane Noise During Takeoff and Landing, Aerospace Information Report No. 1751, Warrendale, PA: Society of Automotive Engineers, Inc., March 1981.

32. Barry, T.M., Regan, J.A., FHWA Highway Traffic Noise Prediction Model, Research Report FHWA-RD-77-108, Washington, D.C.: Federal Highway Administration, December 1978.

33. Sutherland, et. al., Atmospheric Sound Propagation, Encyclopedia of Acoustics, Vol. 1, 1979, p. 351 – 353.

34. Noel, George, et al., Thrust Reverser Analysis for Implementation in Aviation Environmental Development Tool (AEDT), RTV-4F-FA4T-LR1; PB2007-111124, Cambridge, MA: John A. Volpe National Transportation Systems Center, June 2007.

35. Statistical Loads Data for Airbus A-320 in Commercial Operations, FAA Report DOT/FAA/AR-02/35, April 2002.

36. Statistical Loads Data for Boeing 737-400 in Commercial Operations, FAA Report DOT/FAA/AR-98/28, August 1998.

37. Statistical Loads Data for the B-767-200ER Aircraft in Commercial Operations, FAA Report DOT/FAA/AR-00/10, March 2000.

38. Statistical Loads Data for the Boeing 747-400 in Commercial Operations, FAA Report DOT/FAA/AR-04/44, January 2005.

39. Rickley, et. al.. Noise Measurement Flight Test of Five Light Helicopters. Report No. DOT-VNTSC-FAA-93-5, Cambridge, MA: John A. Volpe National Transportation Systems Center, July 1993.

40. Horonjeff, Richard D., Comparison of ISO Human Threshold of Hearing Standards: ISO R226:1961 and ISO 389-7:1998, Plus Equivalent Auditory System Noise (EASN) 1/3 Octave Band Spectra Therefrom Derived, Plus Modified FORTRAN Implementation of d' Algorithm Using EASN in Place of Threshold of Hearing, December 7, 2004.

41. Wasmer, F., NMPLOT Version 4.6 Computer Program, Champaign, IL: Wasmer Consulting, October, 2000.

42. Anderson, G. S., Lee, C. S. Y., Fleming, G. G., Menge, C. W., FHWA Traffic Noise Model (FHWA TNM®), User's Guide, Version 1.0, Report No. FHWA-PD-96-009, Cambridge, MA: John A. Volpe National Transportation Systems Center, August 1996.

43. Green, David M. and Swets, John A., Signal Detection Theory and Psychophysics, New York: John Wiley and Sons, Inc, 1966.

44. Fidell, et. al., Predicting Annoyance from Detectability of Low-Level Sounds, Journal of the Acoustical Society of America, 66(5), November 1979, p. 1427 – 1434.

45. Embleton, Tony F.W., Piercy, Joe E., Daigle, Giles A., Effective Flow Resistivity of Ground Surfaces Determined by Acoustical Measurements, Journal of the Acoustical Society of America 74(4), 1239-1243 (1983).

46. Embleton, Tony F.W., Sound Propagation Outdoors- Improved Prediction Schemes for the 80's, Noise Control Engineering Journal, 18(1), 30-39 (1982).

47. Embleton, Tony F.W., Piercy, Joe E., Daigle, Giles A., Outdoor Propagation Over Ground of Finite Impedance, Journal of the Acoustical Society of America 59(2), 267-277 (1976).

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