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14. ABSTRACT
The Federal Aviation Administration, Office of Environment and Energy (FAA-AEE) has developed the Aviation Environmental Design Tool (AEDT) version 2a software system with the support of the following development team: FAA, National Aeronautics and Space Administration (NASA), U.S. DOT Volpe National Transportation Systems Center (Volpe Center), ATAC Corporation, Metron Aviation, Wyle Laboratories, CSSI, Inc., Foliage, MIT, and Georgia Tech. AEDT 2a is designed to dynamically model aircraft performance in space and time to compute aircraft noise, emissions, and fuel burn. In the U.S., the model is used to evaluate aircraft noise, emissions, and fuel burn of proposed air traffic airspace actions under the current version of FAA Order 1050.1E. This Technical Manual describes the technical methodology in AEDT 2a.

15. SUBJECT TERMS
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PREFACE

This document is the Technical Manual for the Federal Aviation Administration (FAA) Office of Environment and Energy (AEE) Aviation Environmental Design Tool Version 2a (AEDT 2a) computer software, which is designed to compute noise, fuel burn, and emissions.

The USDOT Volpe National Transportation Systems Center (Volpe Center), the ATAC Corporation, Metron Aviation, CSSI, Inc., and the FAA AEE have jointly prepared this document.

DISCLAIMER

This document was produced by USDOT Volpe National Transportation Systems Center (Volpe Center), the ATAC Corporation, Metron Aviation, and CSSI, Inc., 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 AEDT 2a Technical Manual does not constitute a standard, specification, or regulation.

It is to be noted that the aircraft performance models and data contained in BADA have been developed by ERUOCONTROL from a set of aircraft operational conditions available to EUROCONTROL. EUROCONTROL has validated BADA aircraft models only for those conditions and can therefore not guarantee the model's accuracy for operating conditions other than this reference.

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1 Introduction

1.1 Overview

The Federal Aviation Administration Office of Environment and Energy (FAA-AEE) is developing the next generation of airport analysis tool, known as the Aviation Environmental Design Tool (AEDT). The FAA-AEE recognizes that the environmental consequences stemming from the operation of commercial aviation – primarily noise, emissions, and fuel burn – are highly interdependent and occur simultaneously throughout all phases of flight. The Aviation Environmental Design Tool (AEDT) is a software system that is designed to dynamically model aircraft performance in space and time to compute fuel burn, emissions, and noise. Full flight gate-to-gate analyses are possible for study sizes ranging from a single flight at an airport to scenarios at the regional, national, and global levels[i].

AEDT 2a replaced the Noise Integrated Routing System (NIRS) as the official FAA compliance tool for modeling aircraft noise, emissions, and fuel burn for air traffic airspace and procedural actions. Upon release of the full AEDT2b version, AEDT will also replace the current public-use aviation air quality and noise analysis tools such as the Integrated Noise Model (INM – single airport noise analysis) and the Emissions and Dispersion Modeling System (EDMS – single airport emissions analysis).

1.2 System Architecture

AEDT 2a is built on the Microsoft .NET Framework and is capable of running on Windows XP Professional, Windows 7, and Windows Server operating systems. It is supported by extensive system databases covering airports, airspace, and fleet information that span the global nature of the aviation industry.

All information is rendered in a geo-spatial nature given the Esri-based core of the tool, which supports the compatibility with other geo-spatial applications. State-of-the-art software technology is used to enhance the capabilities of AEDT, such as the XML-based AEDT Standard Input File (ASIF) that allows for the input of large datasets of 4D trajectories, fleet information, and event assignments.

AEDT 2a outputs include reports, graphs, and tables that describe the fleet mix, receptor sets, flight performance, noise, contours, fuel burn, and local air quality and greenhouse gas emissions. Figure 1-1 displays a diagram of the AEDT 2a system structure.

[i] Not all functionality is available in the AEDT 2a release.

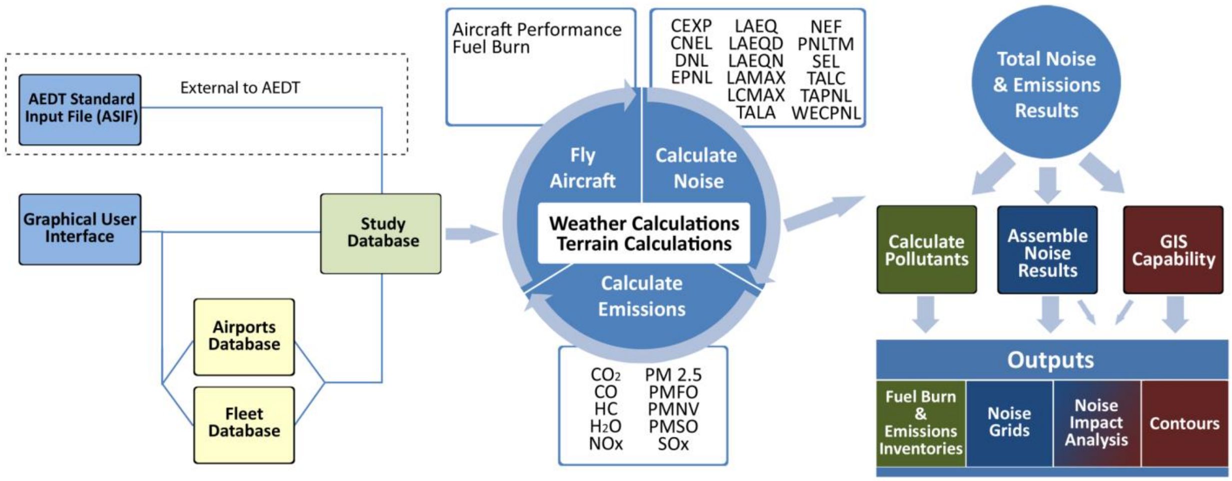


Figure 1-1 AEDT 2a System Structure

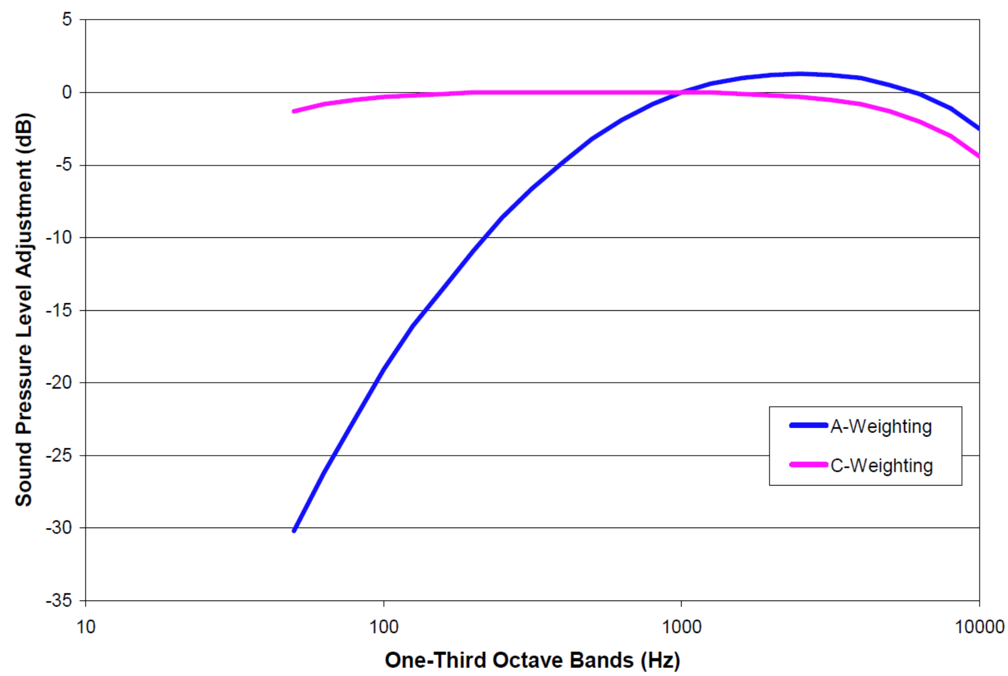
1.3 About this Technical Manual

This manual presents the technical details of the methodologies employed by AEDT 2a with respect to its primary functionality. The intended target audience is composed of users who would like a deeper understanding of the technical details of how AEDT models noise, fuel burn, and emissions. Documentation related to the use of AEDT 2a is available in the AEDT 2a User Guide[1].

This Technical Manual is organized into the following Sections:

- Section 2 describes the AEDT 2a databases and input data.
- Section 3 presents the models for aircraft performance.
- Section 4 presents the models related to noise computations and adjustments.
- Section 5 presents the models related to emissions computations.
- Section 6 provides an overview of annualization.
- Section 7 describes the methodology employed for change analysis and impact evaluation.
- Section 8, the appendices, presents information on noise metric derivations, noise data development and aircraft noise and performance data submittal, verification and validation.
- Section 9 lists the referenced material in this manual.

1.4 Terminology

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 1-2 :  Figure 1-2 A-weighted and C-weighted Adjustment Curves
Above Field Elevation (AFE)	Altitude relative to the airport elevation. The FAA defines the airport elevation as the highest point of an airport's usable runways and is measured in height above mean sea level.
Above Ground Level (AGL)	Altitude relative to the elevation of the ground.
Acoustic Impedance Adjustment	A sound level adjustment, computed as a function of **receptor** temperature, pressure, and elevation, which 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 Hard Surface	A highly reflective surface where the phase of the incident sound is essentially preserved upon reflection; example surfaces include water, asphalt, and concrete.
Acoustically Soft Surface	A 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**.
Aircraft Speed Adjustment	An adjustment made to exposure-based **noise** levels when aircraft speed differs from 160 knots, the **reference speed** for the AEDT **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 AEDT utilizes different formats specific to different metrics.
Annualization	Weighting factor used to approximate results for a year.
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[28] and SAE Aerospace Information Report (AIR) 1845[14].
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 AEDT 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 AEDT 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 4-5.
Boeing Fuel Flow Method 2 (BFFM2)	Boeing Fuel Flow Method 2 is used to compute NO_x, HC, and CO in AEDT 2a. See Section 5.2.1.

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 1-2.
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[ii].
Closest Point of Approach (CPA)	Point on the **flight path segment**, not the **extended flight path segment**, which is the closest point of approach to the **receptor**.
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.
Decibel (dB)	A unit of measure for defining a **noise** level or a **noise exposure** level. The number of decibels is calculated as $10\log_{10}$ of the ratio of mean-square pressure or **noise exposure**. The reference root-mean-square pressure is 20 µPa, the threshold of human hearing.
Density Ratio	The ratio of density to the **ISA** sea-level value.
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 4-5.
Detectability	The ability to detect a signal in the presence of **noise**, based on signal detection theory. For the purposes of AEDT modeling the terms "**audibility**" and "detectability" are used 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 AEDT, 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}).

[ii] It is important to note that in AEDT, 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.

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 AEDT **NPD** data only for data corrected using the simplified data adjustment procedure in SAE-AIR-1845[14].
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 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 4-5.
Emissions Index (EI)	A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., grams of carbon dioxide emitted per barrel of fossil fuel consumed).
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**.
Equivalent Airspeed	For an aircraft experiencing a given incompressible dynamic pressure, equivalent airspeed is the true airspeed at which the aircraft would experience the same incompressible dynamic pressure at ISA sea-level density.
Esri	Software development and services company providing GIS software and geodatabase management applications.
Extended Flight Path Segment	A mathematical extension from either end of a geometrical flight path segment to infinity.
First Order Approximation (FOA)	First Order Approximation is used in AEDT 2a to compute particulate matter below the mixing height. See Section 5.2.2.
Flight Idle	A static helicopter state of 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 Operation	A moving (or dynamic) aircraft operation. There are three kinds of flight operations for fixed-wing aircraft in AEDT 2a: **approach**, **departure**, and **overflight**. There are two kinds of flight operations for helicopters in AEDT 2a: **approach** and **departure**.

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 **ground speed** (this is also the aircraft's **true airspeed** in situations of no 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 **ground 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 state of 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	The speed of an aircraft from a frame of reference where the ground is still.
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 state of 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.
Hover out of Ground Effect (HOGE)	A static helicopter state of 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 AEDT **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[14]. See the definition of the **Simplified Adjustment Procedure** for comparison.
Internally Mixed Turbofan	Turbofan in which the bypass flow is also included during the measurement of the smoke number, indicating that the flow must take the bypass ratio into effect.
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[2].
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[29].
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.
Mach	A dimensionless number representing the speed of an object moving through air divided by the local speed of sound.
Maximum Noise Level	The maximum of a series of modeled sound pressure levels from a single flight.
Mean Sea Level (MSL)	The level of the surface of the sea with respect to the land, taken to be the mean level between high and low tide, and used as a standard base for measuring heights and depths. The MSL designation is used to indicate that an altitude is specified with respect to mean sea-level.
Mean-Square Sound Pressure	A running time-average of frequency-weighted, squared instantaneous acoustic pressure. For example: $$p(t)_{AS}^2 = \int_{-\infty}^{t} P_A^2(\tau) \cdot e^{\frac{\tau}{t_0}} \frac{d\tau}{t_0}$$ 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.
Mixing Height	The height at the top layer of atmosphere where relatively vigorous mixing of pollutants and other gases will take place for the airport in a given month. The mixing height varies both diurnally and seasonally. In AEDT 2a, 3,000 feet (AFE) is assumed for mixing height at all times[7].
Net Thrust	The gross thrust of a jet engine minus the drag due to the momentum of the incoming air.
Noise	Any unwanted sound. "Noise" and "sound" are used interchangeably in this document.
Noise Exposure	See **Sound Exposure**.
Noise Fraction	The ratio of **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 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 AEDT NPD data are corrected for aircraft speed, **atmospheric absorption**, **distance duration**, and spherical spreading. For helicopters, **noise** levels are presented as a function of: (1) operation mode; and (2) distance.
Noise Significance Tests	Tests performed by AEDT 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.

<table>
<tr><td>One-Third Octave-Bands</td><td>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”[3] and ANSI S1.11-2004 “Specification for Octave-Band and Fractional-Octave- Band Analog and Digital Filters.”[4] The standard one-third octave-bands used in AEDT are presented in Table 1-1.

Table 1-1 Definition of One-Third Octave-Bands
<table>
<tr><th>One-Third Octave-Band Number</th><th>Nominal Center Frequency (Hz)</th></tr>
<tr><td>17</td><td>50</td></tr>
<tr><td>18</td><td>63</td></tr>
<tr><td>19</td><td>80</td></tr>
<tr><td>20</td><td>100</td></tr>
<tr><td>21</td><td>125</td></tr>
<tr><td>22</td><td>160</td></tr>
<tr><td>23</td><td>200</td></tr>
<tr><td>24</td><td>250</td></tr>
<tr><td>25</td><td>315</td></tr>
<tr><td>26</td><td>400</td></tr>
<tr><td>27</td><td>500</td></tr>
<tr><td>28</td><td>630</td></tr>
<tr><td>29</td><td>800</td></tr>
<tr><td>30</td><td>1000</td></tr>
<tr><td>31</td><td>1250</td></tr>
<tr><td>32</td><td>1600</td></tr>
<tr><td>33</td><td>2000</td></tr>
<tr><td>34</td><td>2500</td></tr>
<tr><td>35</td><td>3150</td></tr>
<tr><td>36</td><td>4000</td></tr>
<tr><td>37</td><td>5000</td></tr>
<tr><td>38</td><td>6300</td></tr>
<tr><td>39</td><td>8000</td></tr>
<tr><td>40</td><td>10000</td></tr>
</table></td></tr>
<tr><td>Overflight</td><td>A flight operation that begins in the air, and remains in the air, in the study boundary, with optional user-specified changes in altitude and speed during the flight.</td></tr>
<tr><td>Procedure Steps</td><td>A prescription for flying part of 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.</td></tr>
<tr><td>Pressure Ratio</td><td>The ratio of pressure to the ISA sea-level value</td></tr>
<tr><td>Profile Points</td><td>The set of points that make up a flight profile. Profile points can be input directly into the AEDT or can be calculated by AEDT from a set of procedure steps.</td></tr>
<tr><td>°R</td><td>Degrees Rankine, which uses the Fahrenheit scale adjusted so that 0 degrees Rankine is equal to absolute zero.</td></tr>
</table>

Receptor	A receiver or grid point at which **noise** or time values are computed.
Reference Day Conditions	The atmospheric conditions corresponding to 77 degrees Fahrenheit (25 degrees Celsius), 70% 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 **FAR** 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 AEDT is 160 knots. Thus, $\mathbf{L_{AE}}$ and $\mathbf{L_{EPN}}$ values in the **NPD** database are referenced to 160 **kts**. The $\mathbf{L_{ASmx}}$, $\mathbf{L_{CSmx}}$, and $\mathbf{L_{PNTSmx}}$ values are assumed to be independent of aircraft speed.
Refraction	Change in the direction of sound propagation as a result of 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 set of **receptor** 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 flight path segment at a **regular grid** point. Flight path segments considered significant are those whose cumulative **noise** (time) first equals or exceeds 97% 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 at a user-defined level for a time period.
Scattering	Irregular reflection or diffraction of sound in many directions.
Segment Proximity Test	A **noise** significance test in which a flight path segment, which is first determined to be insignificant by the flight path segment **noise** test, is further tested based on its distance to a **regular grid** point. If it is determined that the flight path segment is within a certain distance of the grid point, the flight path 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 AEDT 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[14].
Slant Range Distance (SLR)	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. $$SPL = 10log_{10}\left[\frac{p^2}{p_0^2}\right]$$ where p^2 mean-square pressure (Pa^2); and p_0 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: $$E_{12} = \int_{t_1}^{t_2} p^2(t)dt$$ 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**. $$L_E = 10log_{10}\left[\frac{E}{E_0}\right]$$ where E **sound exposure** (Pa^2s); E_0 (20 µPa)^2 (1 s) for **A- weighted** and **C-weighted sound exposure**; and E_0 (20 µPa)^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**: $$\frac{E}{E_0} = 10^{\frac{L_E}{10}}$$ where E **sound exposure** (Pa^2s); E_0 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 AEDT **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 AEDT. There are four kinds of static operational modes for helicopters in AEDT: **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, **ISA** conditions.
Temperature Deviation	The difference between the temperature at a given location and time and the corresponding temperature in another atmosphere at the same location and time
Temperature Ratio	The ratio of temperature to the **ISA** sea-level value.
Thrust Reverser Adjustment	An empirically-derived **noise** adjustment to account for **noise** from thrust reverser deployment during the landing ground roll.
Thrust-Specific Fuel Consumption (TSFC)	The flow rate of fuel (mass/time) consumed by an engine per unit of thrust (force) produced by that engine. TSFC is a measure of the efficiency of the engine, with smaller values indicating higher efficiency.
Time-Above	The duration that a time-varying sound level is above a given sound level threshold.
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: $$Time - Averaging\ Constant = 10log_{10}[N_T]$$ where $N_T = \frac{T_i}{T_{ref}}$; 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.

Tone-Corrected Perceived Noise Level	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 **FAR** Part 36[27].
True Airspeed (TAS)	The speed of an aircraft (kt) relative to its surrounding 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.

1.5 Abbreviations

A term in bold indicates that it is defined in the Terminology or Abbreviations table.

AEDT	Aviation Environmental Design Tool
AEE	Office of Environment and Energy
AFE	Above Field Elevation
AGL	Above Ground Level
AFR	Air-to-Fuel Ratio
ANP	Aircraft Noise and Performance Model. See Section 2.1.4.
APEX	Aircraft Particle Emissions eXperiment. See Section 5.2.2.
BADA	Base of Aircraft Data. See Section 3.2 Performance Model.
BFFM2	Boeing Fuel Flow Method 2
°C	Degrees Celsius (temperature)
CAEP	ICAO Committee on Aviation Environmental Protection
CAS	Calibrated Air Speed
CPA	Closest Point of Approach
CO	Carbon Monoxide
CO_2	Carbon Dioxide
dB	Decibel
EDMS	Emissions and Dispersion Modeling System
EI	Emissions index
Eurocontrol	European Organization for the Safety of Air Navigation
°F	Degrees Fahrenheit (temperature)
FAA	United States Federal Aviation Administration
FAR	Federal Aviation Regulation
ft	Feet
FOA	First Order Approximation
FSC	Fuel Sulfur Content
GIS	Geographic Information System
GUI	Graphical User Interface
HAPs	Hazardous Air Pollutants
HC	Total Hydrocarbons
HIGE	Hover In Ground Effect
HOGE	Hover Out of Ground Effect
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
In-Hg	Inches of Mercury (barometric pressure)
INM	Integrated Noise Model

ISA	International Standard Atmosphere
km	Kilometers
kt, kts	Knots (international nautical miles per hour)
L_{AE}	A-weighted sound exposure level (SEL)
L_{ASmx}	Maximum A-weighted sound level with slow-scale exponential time weighting (LAMAX)
L_{CE}	C-weighted sound exposure level (CEXP)
L_{CSmx}	C-weighted maximum sound level with slow-scale exponential weighting characteristics (LCMAX)
L_{EPN}	Effective tone-corrected perceived noise level (EPNL)
L_{PNTSmx}	Maximum tone-corrected perceived noise level with slow-scale exponential time weighting (PNLTM)
lb, lbf	Pounds force or weight
LTO	Landing and Takeoff
m	Meters
MSL	Mean Sea Level
N	Newtons
NASA	National Aeronautics and Space Administration
nmi	International Nautical Miles (1852 m)
NO_x	Nitrogen Oxides
NPD	Noise-Power-Distance
NMHC	Non-Methane Hydrocarbons
OG	Speciated Organic Gases
PM	Particulate Matter
PIT	Population Import Tool
°R	Degrees Rankine
ROC	Rate of Climb
Pa	Pascal (unit of pressure, one Newton per square meter)
PCPA	Perpendicular Closest Point of Approach
s, sec	Second (time duration)
SLR	Slant Range Distance
SPL	Sound Pressure Level
SO_x	Sulfur Oxides
TAS	True Air Speed
TOG	Total Organic Gases
TSFC	Thrust-Specific Fuel Consumption
VOC	Volatile Organic Compounds

2 Data

2.1 AEDT 2a Databases

All of the data used by AEDT 2a are stored in Microsoft SQL Server 2008 R2 databases. These databases contain airports, airspace, and fleet information that represent the global scope of the aviation industry. AEDT 2a contains the following set of system databases:

STUDY_ROOT	Configuration settings for existing studies;
STUDY	Baseline format for creating and importing new studies;
AIRPORT	Global set of airport-specific data using standard FAA, International Civil Aviation Organization (ICAO), and International Air Transport Association (IATA) codes; and
FLEET	Data for all available aircraft models.

2.1.1 STUDY

The AEDT 2a Study database consists of 120 tables containing user inputs and system data, including a subset of tables from the Airport and Fleet databases.

In AEDT 2a, the AEDT Standard Input File (ASIF) must be used to create a new study. When an AEDT study is created via an ASIF import, the airport tables in the Study database are populated with only the data pertinent to the airports referenced in the ASIF. In contrast, all aircraft information is populated in the fleet tables of the Study database. The Study database contains 29 Airport database tables. These tables can be easily distinguished by their name as they all start with APT_ (e.g. APT_RWY).

The Study database contains 37 Fleet database tables. The Fleet database tables in the Study can be easily distinguished by name as they all start with FLT_ (e.g. FLT_AIRFRAMES). These tables are populated upon study creation with entries for all aircraft in the Fleet database. The aircraft used in a specific Study are referenced in the AIR_OPERATION_AIRCRAFT table.

An ASIF can be imported into AEDT and the study contents and analyses can be visualized in various formats (e.g. tabular, graphical, and geographically via GIS). Most inputs can be changed either directly in the AEDT 2a GUI, or partial import of an ASIF. Any changes made to the study through the AEDT 2a GUI are saved to the AEDT 2a Study database when the study is saved or when a job is run. When a job is run, the system will compute results for the set of inputs and parameters specified and will save the results to the Study database. When resetting a job and clearing invalid results of a study, AEDT 2a makes the necessary changes in the AEDT 2a Study database directly. The user does not have to save the study for these changes to be committed to the database.

For more information regarding the Study database refer to the Study Database Description Document (Study DDD)[5]. The Study DDD is available by request from aedt-support@dot.gov.

For more information on the ASIF, refer to the AEDT 2a ASIF Reference Guide[6].

2.1.2 STUDY_ROOT

The AEDT 2a Study Root (*STUDY_ROOT*) database contains a single table named *AVAILABLE_STUDIES*. This table consists of 4 columns and contains the list of studies that exist in the AEDT 2a databases. This list also appears in the *Load_Study* dialog box, which allows the user to select an existing study to open in AEDT 2a.

2.1.3 AIRPORT

The AEDT 2a Airport database consists of 31 tables containing a global set of airports and airport data such as runways, flight tracks, historical atmospheric conditions, and time zones.

An AEDT 2a study contains airport data. As described in Section 2.1.1, the airport tables are populated with data pertinent to the airports referenced in the study. Therefore, the airport tables in a study always contain a subset of the data contained in the AEDT 2a Airport database.

For more information regarding the Airport database, refer to the Airport Database Description Document (Airport DDD)[7]. The Airport DDD is available by request from aedt-support@dot.gov.

2.1.4 FLEET

The AEDT 2a Fleet database contains 90 tables that store aircraft information for use by the AEDT system. The AEDT 2a Fleet database tables are relationally linked and each falls into one of three tiers – physical, modeling, and type.

The physical tier contains information records on a per aircraft basis, addressing those aircraft by serial number. When available on input operations data, tail number and/or carrier assignments for pertinent aircraft can be used to address physical aircraft or a subset of physical aircraft to provide better precision in the modeling step. The AEDT 2a Fleet database contains approximately 35,000 individual aircraft.

The modeling tier contains aircraft modeling parameters specific to the three aircraft representations used to evaluate the environmental impacts of interest in AEDT 2a. These three models are:

1. International Civil Aviation Organization (ICAO) Engine Emissions Databank[8] (EEDB)
2. ICAO Aircraft Noise and Performance Model (ANP)[9] which is closely related to the SAE-AIR-1845 model
3. Eurocontrol Base of Aircraft Data[10] (BADA)

The aircraft in the physical tier are assigned links to aircraft representations from each of the three models in the modeling tier. This mapping effectively condenses the fleet of physical aircraft into a modeling set of less than 4,000 equipment records.

The type tier is the most abstract layer of the AEDT 2a Fleet database. This representation is based on the ICAO Aircraft Type document, ICAO 8643[11], and the IATA Aircraft Type Table[12]. These Types address aircraft at the airframe level and are typically used by, for example, air traffic management systems to reference aircraft in schedule and operational records.

For more information regarding the Fleet database refer to the Fleet Database Description Document (Fleet DDD)[13]. The Fleet DDD is available by request from aedt-support@dot.gov.

2.1.4.1 Noise-Power-Distance Data Sets

The AEDT 2a Fleet database contains noise vs. power (or operational mode for helicopters) vs. distance (NPD) acoustic data, augmented by a database of spectral characteristics (known as spectral classes). The NPD data for fixed-wing aircraft consist of a set of decibel (dB) levels for various combinations of aircraft operational modes, engine power settings and slant distances from aircraft to receptor. Engine power setting, also known as thrust setting, is expressed on a per engine basis in a variety of units, as listed in Table 2-1. A decibel level on an NPD includes the noise generated the airframe, and all engines.[iii] These data are usually obtained from the AEDT 2a Fleet database, but they can also be user-defined.

Table 2-1 Engine Power Setting Units

Engine Power (Thrust) Setting	Description	Units
Pounds	Corrected net thrust per engine	Pounds force
TurbineInletTemperatureDegC	Turbine inlet temperature	Degrees Celsius
EnginePressureRatio	Engine pressure ratio	Dimensionless
EquivalentShaftPower	Equivalent shaft power	Horsepower
ManifoldPressureInHg	Manifold pressure	Inches of mercury
PoundsPerHourFuelFlow	Fuel mass flow rate	Pounds per hour
Percent	Percent of ISA sea-level static thrust	Percent (dimensionless)
PercentCorrectedRotorSpeed	Percent of maximum corrected rotor design speed	Percent (dimensionless)
FanSpeed	Fan speed	Rotations per minute
PercentFanSpeed	Percent of fan design speed	Percent (dimensionless)
PercentLowPressureCompressorSpeed	Percent of low pressure compressor design speed	Percent (dimensionless)
PowerLeverAngle	Power lever angle	Degrees (in decimals)
PercentPropellerOrCompressorRPM	Percent of propeller or compressor design speed	Percent (dimensionless)
PropellerOrCompressorRPM	Propeller or compressor speed	Rotations per minute

For fixed-wing aircraft, NPD data consist of two or more noise curves for each operational mode. Operational modes are sub-categories of phases of modeled flight. See Table 2-2 for a complete list of fixed-wing aircraft operational modes. A noise curve is associated with an engine power parameter (as listed in Table 2-1), an operational mode, and a noise metric. Noise levels at the following ten distances are provided for each noise curve: 200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, and 25000 ft.

[iii] It is important to note that although engine power setting for a NPD is expressed on a per engine basis, the corresponding noise level on the NPD represents all engines on the aircraft.

Table 2-2 Operational Mode for Each Aircraft NPD Data Set

Operational Mode	Description
A	Approach
D	Departure
L	Level flight

Each set of NPDs in the database includes separate NPDs for four different metrics:

- 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 AEDT 2a, including C-weighted and time-based metrics, are computed using these four basic noise level metrics.

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, see Section 4.2.2.

While the underlying databases for fixed-wing aircraft, helicopters, and military aircraft are based on the same data format (NPDs in conjunction with spectral data), there are several key differences in the AEDT 2a Fleet database between helicopter and fixed-wing NPDs that warrant a more detailed description. The helicopter NPDs main differences are that:

1. They are delineated according to operational mode instead of thrust/power setting;
2. No interpolation is performed between multiple operational modes;
3. For the dynamic operational modes they come in sets of three curves to represent helicopter noise lateral directivity; and
4. For static operational modes each single NPD curve is paired with a helicopter-specific directivity adjustment to represent helicopter noise directivity.

The noise-distance data for a helicopter, either from the AEDT 2a Fleet database or user-defined, is organized according to dynamic operation modes (departure, approach, overflight , accelerate, decelerate, etc.) and static operational modes (ground idle, flight idle, hover in and out of ground effect). See Table 2-3 for a complete list of helicopter operational modes. For dynamic operational modes, there are three sets of noise levels for various combinations of helicopter operational modes (instead of thrust levels) at the 10 standard distances. This set of three NPD curves is used to account for the asymmetrical directivity associated with helicopter noise; the three curves correspond to noise levels at locations directly below the helicopter (center) and at approximately 45° to either side (left/right) of the centerline. For static operational modes, there is a single set of noise levels for various combinations of helicopter operational modes and slant distances from the helicopter to receptor. This single set of NPD curves is used in conjunction with a helicopter-specific directivity adjustment to account for static operational mode directivity.

Table 2-3 Operational Mode for Each Helicopter NPD Data Set

Operational Mode	Description
A	Approach at constant speed
D	Depart at constant speed
L	Level flyover at constant speed
G	Ground idle
H	Flight idle
I	Hover in ground effect
J	Hover out of ground effect
V	Vertical ascent in ground effect
W	Vertical ascent out of ground effect
B	Approach with horizontal deceleration
C	Approach with descending deceleration
E	Depart with horizontal acceleration
F	Depart with climbing acceleration

All noise levels in the NPD data have been adjusted for time-varying aircraft speed (exposure-based noise levels only), atmospheric absorption, distance-duration effects (exposure-based noise levels only)[iv], and spherical divergence in accordance with the methodology presented in SAE-AIR-1845[14]. An underlying assumption with the SAE-AIR-1845 methodology is that the NPD data represent an aircraft proceeding along a straight flight path of infinite length, parallel to the ground.

2.1.4.2 Spectral Data Sets

The spectral data in AEDT 2a 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 ft (305 m) using the SAE-AIR-1845[14] atmospheric absorption coefficients. These spectral data are used in AEDT 2a to compute the following:

1. Atmospheric absorption adjustment based on local temperature and relative humidity;
2. C-weighted noise metrics; and
3. Line-of-sight blockage adjustment due to terrain.

The spectral data in AEDT 2a are in the form of spectral classes, which represent the spectral shape at time of maximum sound level for a group of aircraft deemed to have similar spectral characteristics for each different operation mode (approach, departure, overflight/afterburner). Sensitivity and validation tests were conducted on aircraft to identify appropriate spectral class groupings[15.]

The spectral class data was originally developed for the FAA's Integrated Noise Model[15]. During the initial development process, aircraft were grouped together by engine type and/or number of engines

[iv] A specific adjustment is used to account for distance-duration effects computed with the simplified adjustment process. For 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 AEDT 2a, since it represents a best-fit empirical relationship for those aircraft.

(i.e., low-bypass ratio jet, high-bypass ratio jet, four engine jet, turboprop, piston, etc.); the groups were then 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, because of differences in engine type and engine placement/configuration on the aircraft. Aircraft added since the initial development were assigned to a spectral class using 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 calculations over the 10 NPD slant distances for 5 different temperature and humidity conditions[v] and line-of-sight blockage calculations over the 10 NPD slant distances for 7 path length differences[vi], 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 Appendix 8.2.2.

Similar spectral data for military aircraft from the Noisefile Database in the United States Air Force NOISEMAP computer program[30] are included in AEDT 2a. 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 the referenced report[16].

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 physical fleet 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.

2.1.4.3 Helicopter Static Directivity Data Sets

The AEDT 2a Fleet database includes directivity data for modeling noise from helicopter static operations (ground idle, flight idle, hover-in-ground-effect (HIGE), and hover-out-of-ground-effect (HOGE)). The static directivity data account for changes to the sound level as a function of the helicopter azimuth angle, which is measured clockwise from the nose of the helicopter. These data are based on empirical measurements, and account for relative differences in sound level at 15-degree increments around the helicopter at a nominal radial distance of approximately 200 ft. Many helicopters in the AEDT 2a Fleet database have both acoustically hard and soft ground directivity data.

2.1.4.4 Profile Point Input Data

An ordered set of profile records specifies a two-dimensional trajectory (altitude v. along-track distance). For each point, the following data are given:

d horizontal coordinate (ft) relative to the distance origin;

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[v] The 5 temperature and humidity conditions used in the atmospheric absorption calculations are the SAE standard atmosphere and the 4 extremes for the Annex 16[52] allowable test window.

[vi] The 7 path length differences used in the line-of-sight blockage calculations are -1.2, 0, 1.2, 2.4, 3.6, 6.1, and 31 meters.

z	altitude of the aircraft above: the start-of-takeoff runway end (ft) for departure operations, the runway end (ft) at the point of landing for approach operations, or mean sea-level for overflight operations;
v_T	aircraft profile speed, as defined below (kts); and
F_n/δ	noise thrust per engine (lb, %, or other units) at the point, see Section 3.6.2.1.1.2.1.

The distance origin (where the horizontal coordinate is equal to zero) depends on the type of flight operation flown:

- An approach origin is at the touchdown point; horizontal coordinate values are negative during descent and positive during rollout on the runway.
- A departure origin is at the start-roll point on a runway; horizontal coordinate values are positive.
- An overflight origin is at the first point; horizontal coordinate values are positive.

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

Profile speed is the aircraft speed, relative to a location on the ground, at the profile point; it is the magnitude of the aircraft velocity vector. If there is no wind, it is the same as true airspeed.

The noise thrust per engine is in units of pounds, percent, or some other unit that is consistent with the noise curves. See Section 2.1.4.1 for a complete table of thrust settings.

2.1.4.5 Procedure Step Input Data

Procedure steps define how aircraft fly a profile (altitude v. along-track distance) and serve an alternative but more accurate role as the Profile Point data. Procedure Step data allow the performance of the aircraft to vary as a function of aircraft altitude and atmospheric conditions; Profile Point data do not. The following set of procedure steps describes an example jet departure profile:

1. Takeoff using 15-deg flaps and max-takeoff thrust.
2. Climb to 1000 ft AFE, using 15-deg flaps and max-takeoff thrust.
3. Accelerate to 175 kts CAS, while climbing at 2000 fpm (ft-per-minute) and using 15-deg flaps after cutting back to max-climb thrust.
4. Accelerate to 195 kts CAS, while climbing at 1000 fpm and using 5-deg flaps and using max-climb thrust.
5. Climb to 3000 ft AFE, using zero flaps and max-climb thrust.
6. Accelerate to 250 kts CAS, while climbing at 1000 fpm and using zero flaps and max climb thrust.
7. Climb to 5500 ft AFE, using zero flaps and max-climb thrust.
8. Climb to 7500 ft AFE, using zero flaps and max-climb thrust.
9. Climb to 10000 ft 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 ft AFE, 2000 fpm, max-climb thrust, etc.).

2.2 Input Data

2.2.1 Summary of Input Data for Noise Computation

2.2.1.1 Receptor Information

Information about receptor locations is required for noise computations. AEDT 2a receptor locations are expressed as either regularly spaced grids or population centroids.

Receptor locations for a regular grid are defined by the location of the lower-left corner of the grid (latitude, longitude), 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). Regular grids intended for rendering contours cannot be rotated.

A special case of a regular grid is the grid consisting of a single receptor, where the starting point for the grid is given by the lower-left corner, 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 are considered sensitive.

The computation of population receptors is also performed by using single-grid-point methods. Population receptors can be input through the ASIF or through the Population Import Tool (PIT). The population receptor locations are represented by (x,y) coordinates. For more information on the PIT, refer to Appendix E of the AEDT 2a User Guide[1].

2.2.1.2 Noise Metric Information

AEDT 2a includes 16 different noise metrics, as well as the capability to create user-defined noise metrics, see Table 2-4.

Table 2-4 Summary of AEDT 2a Noise Metric Abbreviations and Definitions

Metric Type	AEDT 2a Name	Standard Name	Definition/Full Name
A-Weighted Noise Metrics			
Exposure	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
	LAEQD	L_{d}	Day-average noise level
	LAEQN	L_{n}	Night-average noise level
Maximum Level	LAMAX	L_{ASmx}	A-Weighted Maximum Sound Level
Time-Above	TALA	TA_{LA}	Time-Above A-Weighted Level
C-Weighted Noise Metrics			
Exposure	CEXP	L_{CE}	C-Weighted Sound Exposure Level
Maximum Level	LCMAX	L_{CSmx}	C-Weighted Maximum Sound Level
Time-Above	TALC	TA_{LC}	Time-Above C-Weighted Level
Tone-Corrected Perceived Noise Metrics			
Exposure	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	TAPNL	TA_{PNL}	Time-Above Perceived Noise Level

All of the noise metrics in Table 2-4 are computed using the following four base noise level metrics:

L_{AE} A-weighted sound exposure level (SEL);
L_{ASmx} A-weighted maximum sound level (LAMAX);
L_{EPN} Effective perceived noise level (EPNL); and
L_{PNTSmx} Tone-corrected maximum perceived noise level (PNLTM).

Each NPD in the AEDT 2a Fleet database has noise level data that correspond to one of these four base metrics. In addition, A-weighted NPDs (L_{AE} and L_{ASmx}) and the corresponding spectral class data are used to approximate the following C-weighted noise metrics to complement the AEDT 2a Fleet database:

L_{CE} C-weighted sound exposure level (CEXP); and
L_{CSmx} C-weighted maximum sound level with slow-scale exponential weighting characteristics (LCMAX).

The C-weighting approximation method is described in Section 4.2.1.2.

The base metrics are then used to compute three types of metrics in AEDT 2a:

1. Exposure-based metrics, including change in exposure;
2. Maximum noise level metrics; and
3. Time-based metrics.

The exposure-based metrics represent the total sound exposure for a given time period, often 24 hours, at a receptor location based upon average annual day conditions at an airport. AEDT 2a base 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 base sound exposure metrics are used by AEDT 2a to generate average noise metrics by applying associated time-averaging constants and/or day, evening, and night-time weighting factors. AEDT 2a standard average-level metrics based on SEL 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); and
L_n	9-hour (2200-0700) night-average noise level (LAEQN).

AEDT 2a standard average-level metrics based on CEXP are:

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

The maximum noise level metrics represent the maximum noise level at a receptor location, taking into account a particular set of aircraft operations. AEDT 2a 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).

The time-based metrics represent the time (minutes) that the noise level is above a specified threshold, taking into account aircraft operations for a particular time period (e.g., 24 hours). In AEDT 2a, time-based metrics are derived from either exposure or maximum noise level metrics, or both. The derivation of the time-above metrics is presented in Appendix 8.1.1. AEDT 2a standard time-based metrics are:

TALA	Time that the A-weighted noise level is above a user-defined sound level during the time period (TALA);
TALC	Time that the C-weighted noise level is above a user-defined sound level during the time period (TALC); and
TAPNL	Time that the tone-corrected perceived noise level is above a user-defined noise level during the time period (TAPNL).

In addition to the AEDT 2a standard noise metrics, user-defined metrics are available. User-defined metrics must be derived from the base noise metrics in AEDT 2a. The methods for calculating these types of metrics in AEDT 2a are presented in Section 4.6.

2.2.2 External Data

2.2.2.1 Weather

Average annual weather is provided for all airports included in AEDT 2a. Alternatively, the user can provide high fidelity weather for use in aircraft performance modeling; AEDT 2a accepts the following data formats: RUC[17,18] (13 or 20), GEOS[19], and NCAR[20,21]. Weather data are applied to a study based on a hierarchy of data available within an AEDT 2a study, as follows:

1. High fidelity weather data (user input), in the following order:
    a. RUC13
    b. RUC20
    c. GEOS
    d. NCAR
2. Average annual weather[22] from the AEDT 2a Airport database; and
3. International standard atmosphere (ISA) weather conditions are applied when no other weather data are available.

High fidelity weather data are available from the following external sources:

Table 2-5 Sources for High Fidelity Weather

Dataset	Download URL
Rapid Update Cycle (RUC20/RUC13)	RUC 20: http://nomads.ncdc.noaa.gov/thredds/catalog/ruc/ RUC 13: http://nomads.ncdc.noaa.gov/thredds/catalog/ruc13/
NCEP/NCAR (NCAR)	*NCAR data are not publically available, and may be retrieved only with permission from NASA*. For more information, visit http://acdb-ext.gsfc.nasa.gov/Data_services/accounts/accounts.html
GEOS	*GEOS-5 data are not publically available, and may be retrieved only with permission from NASA.* See contact information in the GEOS Section in Appendix G of the AEDT 2a User Guide[1].

Detailed instructions to process and import high-fidelity weather into AEDT are given in Appendix G of the AEDT 2a User Guide[1].

2.2.2.2 Terrain

Varying terrain can greatly affect noise propagation. The terrain feature in AEDT 2a allows for terrain elevation data of the modeling area to be included in noise computation. When terrain data are not included, AEDT 2a assumes flat ground. Terrain elevation data are accepted in the following formats: 3CD, National Elevation Dataset (NED) GridFloat, and Digital Elevation Model (DEM). Terrain data are only supported if they are in one of the following projections: NAD83 or WGS84. If the terrain data are not in one of the supported projections, AEDT 2a will notify the user with an exception. Multiple resolutions of data are available among the different formats and multiple files may be required to cover a desired geographical area.

3CD terrain elevations are a regular grid 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 are available in many resolutions, but 1/3 arc-second resolution is recommended because these data are available across the entire United States, whereas other resolutions are not. The area covered by a single file can vary. The spacing between points is dependent on location. For example, the three arc-second spacing in the Boston area is approximately 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 approximately 241 feet by 303 feet. NED Gridfloat data are available from the United States Geological Survey (USGS) website at http://seamless.usgs.gov/ned13.php. For information on downloading NED GridFloat terrain data, refer to Appendix F in the AEDT 2a User Guide[1].

USGS stopped offering DEM data as of November 14, 2006, however AEDT supports the DEM format as a convenience. Information about DEM data is available from the USGS website at http://eros.usgs.gov/#/Guides/dem.

AEDT 2a processes terrain data with Esri ArcGIS software using a nearest neighbor interpolation to evaluate elevations at any given point covered by a given dataset.

2.2.2.3 Boundary

AEDT 2a accepts a user-defined study boundary as a geospatial boundary containing the area to be modeled. A study boundary must be created and/or modified through an ASIF (or partial ASIF) and is defined as a polygon, with each vertex consisting of a latitude and longitude pair. Latitude-longitude pairs can be specified in either Degree-Minute-Second (DMS) or Universal Transverse Mercator (UTM) coordinates.

A study boundary is not required to run AEDT 2a; however one must exist to import high-fidelity weather and population census data. The study boundary acts as the geographical bounding constraint on data imported into the study. When the study boundary is invoked for processing, only data within the boundary are processed. Flight paths are truncated and/or extended to the boundary. This affects the performance, fuel burn, emissions, and noise computations for aircraft operations on the affected flight paths.

The following matrix describes how AEDT 2a responds to various boundary, profile/track altitude control (see Section 3.7.1 for more information on altitude controls), and study altitude cutoff settings when the study boundary is invoked or not invoked during processing:

Table 2-6 Boundary, Altitude Control, Study Altitude Cutoff Relationships in AEDT 2a

<table>
<tr><th></th><th>No Controls</th><th>With Controls</th></tr>
<tr><td>No Boundary</td><td>No altitude cutoff: all profiles/tracks are flown as defined
With altitude cutoff: all profiles/tracks have a node where performance passes through the cutoff altitude
Cruise altitude – defined but not used, null for helicopters</td><td>Controls are followed and when the controls end, the flight stops.</td></tr>
<tr><td>With Boundary</td><td>No altitude cutoff:<ol type="a">
Departures or arrivals are vertically extended to cruise altitude and horizontally extended to the boundary.
Overflights are horizontally extended to the boundary at both ends.
With altitude cutoff: same as no altitude cutoff, except there are nodes wherever the flight passes through the altitude cutoff. Noise is not computed at flight path segments above the altitude cutoff.</td><td>Cruise altitude:<ol type="a">
Above: fly level for the last control, extending to boundary
Below: fly to cruise and level, extending to boundary
Overflights extend level in both directions (ignoring cruise altitude)</td></tr>
</table>

When the study boundary is invoked for processing and the cruise altitude exceeds the maximum operating altitude as specified by BADA in the AEDT 2a Fleet database, the maximum operating altitude is used for cruise. If altitude controls have been defined, the maximum operating altitude is not used and the flight is not processed.

3 Aircraft Performance

AEDT 2a calculates aircraft performance information (such as flight path, thrust levels and fuel burn) for terminal-area and runway-to-runway operations. These calculations employ performance models to approximate the state of an aircraft through each full air operation. The calculated performance serves as the primary input to noise and emissions calculations.

3.1 Trajectories

AEDT 2a calculates a complete four-dimensional representation of each segment of the flight path as well as thrust, fuel burn, and emissions mode values. Since the variation of an aircraft's position is included, this progression of aircraft states is called a trajectory.

3.1.1 Properties

A trajectory is approximated by a set of segments. Each segment is associated with one initial and one final instantaneous aircraft state, along with a description of aircraft performance between those states. Given two adjacent segments, the final state of the first segment is equivalent to the initial state of the second segment.

Table 3-1 Properties and Units of Instantaneous States

Property	Units
Cumulative horizontal distance	m
Time	s
Altitude with respect to the associated field elevation	m
Altitude with respect to mean sea level	m
Groundspeed	m/s
Corrected net thrust per engine	N
Weight	kg
Noise thrust	N, %, other (see Section 3.6.2.1.1)
Projected unit vector	(dimensionless) (see 3.7.1.3)
Bank angle (for fixed-wing)	degrees
Heading (for rotary-wing)	degrees
Latitude	degrees
Longitude	degrees

Table 3-2 Properties and Units of Segments

Property	Units
Horizontal length	m
Change in noise thrust per engine	N, %, other (see Section 3.6.2.1.1)
Change in speed	m/s
Fuel flow rate per engine	kg/s
Amount of fuel burned (all engines)	kg
Duration	s
Total length	m
Noise operation mode or helicopter mode	(dimensionless, see Section 2.1.4.1)
Trajectory mode	(dimensionless, see Section 5.1)
Nominal Mach number	(dimensionless, see Section 3.6.3.1.6)
Dew point temperature	K
Pressure	N/m/m
Relative humidity	%
Temperature	K
Sea-level pressure	N/m/m
Wind vector	m/s
Mixing height	m
Pressure ratio	(dimensionless, see Section 1.4)
Temperature ratio	(dimensionless, see Section 1.4)

3.1.2 Targets and Extensions

Performance in AEDT 2a can be driven by a target flight profile or a target trajectory. Both methods require ground track specification, but the target states provided by profiles may be reached at any distance along the track, whereas target trajectories fully integrate altitude and speed targets with the surface coordinate targets of the track. Ground tracks, profiles, and target trajectories each feature an explicitly-defined portion. Any of those portions may also feature an extension, implicitly defined during processing in AEDT 2a. These extensions are discussed in section 3.5.2 Ground Track Extensions, section 3.6.3 Trajectory Extension, section 3.7.1.1 Track Extensions, section 3.7.1.4.2.3 Departure Boundary Extensions, section 3.7.1.4.3.3 Approach Boundary Extensions, and section 3.7.1.4.4.5 Overflight Boundary Extension and Post-Processing.

Profile-driven flight performance is described in Section 3.6. Trajectory-driven flight performance is described in Section 3.7.

3.2 Performance Model

The performance model in AEDT 2a is primarily based on recommendations from two aircraft flight performance specifications. The first is presented in European Civil Aviation Conference (ECAC) Doc 29[23], and since it is largely based on Society of Automotive Engineers Aerospace Information Report No. 1845[14], it is referred to herein as 1845/Doc29. This specification is intended for use only within the terminal area. Note that AEDT 2a also uses the Senzig-Fleming-Iovinelli (SFI) fuel burn model[24,25] in the terminal-area when the proper coefficients are available. The second specification used for performance calculations is presented in EUROCONTROL's User Manual for the Base of Aircraft Data[26] (BADA). BADA flight dynamics equations and modeling coefficients are defined for all phases of flight, but within AEDT 2a, they are primarily used for modeling the en-route phase. Note that BADA includes a fuel burn model, which is used for terminal area modeling when coefficients for the SFI fuel burn model are not available, and for en-route modeling regardless of coefficient availability

Both performance specifications maintain a core set of features including standard flight procedures. Each supplies an atmospheric model, equations that model the physics of flight, calculations of aerodynamic quantities for standard flap configurations, and thrust as a function of state for standard power settings. Furthermore, each specification has an associated database that includes modeling coefficients by aircraft for these calculations. The BADA specification is associated with the BADA database, while the 1845/Doc29 specification is associated with the Aircraft Noise and Performance (ANP) database.

Data from the BADA and ANP databases are stored in the AEDT 2a Fleet database and contain modeling data for a limited set of equipment combinations (airframe, engine model, and engine modifications). For some equipment combinations that lack modeling data, alternative modeling combinations are provided that will approximate the combination. When modeling an aircraft in AEDT 2a, it is possible for the BADA and ANP equipment combinations to be different. Each combination approximates the AEDT 2a aircraft to the extent of the available data.

3.3 Weather Model

The variation of thermodynamics and wind over a given domain in space and time constitutes a weather field. Although the 1845/Doc29 performance model specifies the ISA for its weather model, AEDT 2a uses a model that allows for customization of weather conditions based on high fidelity or airport-specific average weather data. AEDT 2a assigns an order of precedence to the types of weather data it supports, so that when a weather value is required at a given location and time, the data are taken from the highest-ranked sources that encompass the coordinate. Where these domains overlap, the weather field is a cascade of sources of weather data that the user makes available in formats as described in Section 2.2.2.1.

The hierarchy of weather data sources is traversed for every required location and time. When a location and time is specified, AEDT 2a first checks whether or not there are RUC13 data available at the requested location and time. If there are, then the weather at that location and time is taken from that dataset. If not, then it goes through the same process for RUC20 data. The cycle continues for GEOS data, then NCAR data, and finally for the AIRPORT database. If no data are available for the given location and time from any of these sources, ISA weather is used.

3.3.1 Common Elements

3.3.1.1 Pressure Altitude

Pressure altitude is defined as the MSL altitude in an International Standard Atmosphere (ISA) at which a given pressure or pressure ratio occurs. AEDT 2a calculates pressure altitude, h_P, for a given pressure ratio, δ, by the equation:

$$h_P = \left(\frac{T_{SL_{ISA}}}{\alpha_{ISA}}\right) \cdot \left(1 - \delta^{\frac{1}{5.256}}\right) \quad \text{Eq. 3-1}$$

where

h_P	pressure altitude (ft);
$T_{SL_{ISA}}$	ISA sea-level temperature 518.67 °R;
α_{ISA}	ISA temperature lapse rate 0.003566 °R/ft; and
δ	pressure ratio at aircraft altitude (dimensionless).

3.3.1.2 Temperature Deviation from ISA

Temperature deviation from ISA is defined as the difference between the actual temperature at a given location and time and the temperature in the ISA.

$$\Delta T(x, y, z, t) = T(x, y, z, t) - T_{ISA}(z) \quad \text{Eq. 3-2}$$

where

$\Delta T(x, y, z, t)$	temperature deviation from ISA as a function of location and time (K);
$T(x, y, z, t)$	temperature as a function of location and time (K); and
$T_{ISA}(z)$	ISA temperatures as a function of altitude (K).

Temperature deviation from ISA is used in calculations discussed in Section 3.6.3.1.

3.3.2 Airport Average Atmospheric Models

AEDT 2a supports weather fields that are based on 30-year annual average values associated with an airport relevant to the flight.

3.3.2.1 AEDT 2a Thermodynamic Profiles

Reference values for thermodynamic properties (temperature and pressure) are given at specified altitudes and atmospheric profiles are constructed to fit those data in a physically realistic manner, similar to the manner in which the ISA was derived. These quantities are a function of altitude. In AEDT 2a, the reference temperatures and pressures are 30 year annual average values associated with an airport relevant to the flight. There is no variation with respect to surface coordinate or time.

Temperature, T (°R), at a given altitude, h (with respect to mean sea-level), is calculated by the equation:

$$T = T_{airport} - \alpha_{ISA} \cdot (h - h_{airport}) \quad \text{Eq. 3-3}$$

where

$h_{airport}$	airport elevation above MSL (ft);
h	altitude above MSL (ft);
$T_{airport}$	airport temperature (°R); and
α_{ISA}	ISA temperature lapse rate 0.003566 °R/ft.

Pressure, P (inches Hg), is calculated by the equation:

$$P = P_{SL_{ISA}} \left[\left(\frac{P_{SL}}{P_{SL_{ISA}}} \right)^{\frac{1}{5.256}} - \frac{\alpha}{T_{SL_{ISA}}} h \right]^{5.256}$$

where

P_{SL} sea-level pressure associated with the airport (inches Hg);
$P_{SL_{ISA}}$ ISA sea-level pressure 29.92 inches Hg; and
$T_{SL_{ISA}}$ ISA sea-level temperature 518.67 °R.

3.3.2.2 Omnidirectional Wind

In AEDT 2a, wind has a constant speed and varies such that it is always directed against the course of an aircraft (always a headwind). This value of headwind applies throughout the flight, without regard to altitude, latitude, longitude, time, or direction of travel. AEDT 2a uses an average headwind value associated with the nearest airport, and scales it by a multiplier associated with the runway corresponding to the operation.

3.3.3 High-Fidelity Weather Model

AEDT 2a supports a high-fidelity model of weather that allows variation of all atmospheric properties (temperature, pressure, wind magnitude and direction, density, dew point, and relative humidity) along all three spatial dimensions, as well as in time. This is done by reading and interpolating weather data defined on 4-D grids. These grids are supplied by the user as files from sources described in Section 2.2.2.1. The data are defined on grids that are regularly spaced in time and along geographic coordinate systems, but irregularly spaced along the vertical direction.

In AEDT 2a, all atmospheric data given for any specific time are interpolated linearly in space to define 3-D weather for that time. The atmosphere is assumed to remain static until the next time available in the data set. Whenever headwind is required, the wind vector field is interpolated to the desired location, and then the component of the interpolated vector that is opposite to the aircraft's direction of travel (i.e., headwind) is used.

3.4 Fuel Burn Models

For fixed-wing aircraft flights within AEDT 2a, the fuel burned over each flight path segment in the terminal area is calculated in one of two ways. The first method is simply to calculate the fuel burn for each segment in accordance with Section 3.9 of the BADA User Manual[26] (see Section 3.4.1). The second choice, available only in the terminal area, is the Senzig-Fleming-Iovinelli method (see Section 3.4.2). There is also a time-in-mode fuel burn model in place for helicopters (see Section 3.4.3). Note that all of these methods specify the fuel flow rate; the amount of fuel burned during a segment is calculated by multiplying the fuel flow rate by the segment duration and the number of engines. Also note that fuel burn is only calculated for aircraft for which thrust is available as a force (which is not the case for the military aircraft included in AEDT 2a).

3.4.1 Fixed-Wing BADA Fuel Burn

The BADA fuel consumption model provides expressions for nominal fuel flow rate. These expressions depend on the engine type (jet, turboprop, or piston), if the aircraft is in the cruise phase of flight, and if the engine is operating at an idle thrust rating.

The nominal total rate of fuel flow f_{nom} (kg/min) for an aircraft, which is applicable for all situations where the aircraft is neither in the cruise phase of flight nor operating at an idle thrust setting, is given by:

$$f_{nom} = \begin{cases} \left(1 + \frac{V_T}{C_{f_2}}\right) C_{f_1} F, \text{(jet)} \\ \left(1 - \frac{V_T}{C_{f_2}}\right) \frac{C_{f_1}}{1000} V_T F, \text{(turboprop)} \\ C_{f_1}, \text{(piston)} \end{cases} \quad \text{Eq. 3-4}$$

where

- V_T aircraft true airspeed (speed in the still-air frame of reference) (kt);
- C_{f_1} aircraft-specific 1st thrust specific fuel consumption coefficient (kg/min/kN for jet, kg/min/kN/kt for turboprop, kg/min for piston);
- C_{f_2} aircraft-specific 2nd thrust specific fuel consumption coefficient (kt); and
- F aircraft total net thrust from its engines (kN).

The BADA total fuel flow rate f_{CR} (kg/min) for an aircraft in a cruise state is calculated by scaling the nominal flow rate:

$$f_{CR} = C_{f_{CR}} f_{nom} \quad \text{Eq. 3-5}$$

where

- $C_{f_{CR}}$ aircraft-specific cruise fuel flow correction coefficient (dimensionless); and
- f_{nom} nominal total rate of fuel flow (kg/min).

The BADA total fuel flow rate f_{min} (kg/min) for an aircraft in an idle state is given by:

$$f_{min} = \begin{cases} \left(1 - \frac{h}{C_{f_4}}\right) C_{f_3}, \text{(jet or turboprop)} \\ C_{f_3}, \text{(piston)} \end{cases} \quad \text{Eq. 3-6}$$

where

- h Altitude above MSL (ft);
- C_{f_3} aircraft-specific 1st descent fuel flow coefficient (kg/min); and
- C_{f_4} aircraft-specific 2nd descent fuel flow coefficient (ft).

3.4.2 Fixed-Wing Senzig-Fleming-Iovinelli Fuel Burn

In the Senzig-Fleming-Iovinelli method, operation type and terminal area specific fuel burn methods developed by the Volpe National Transportation Systems Center[25] are used. For this method, fuel flow rate per engine during departure $f_{n_{dep}}$ (kg/min) is calculated as:

$$f_{n_{dep}} = (C_1 + C_2 M + C_3 h_{MSL} + C_4 F_n / \delta)\sqrt{\theta} F_n \quad \text{Eq. 3-7}$$

where

- C_1 aircraft-specific 1st terminal-area departure TSFC coefficient (kg/min/kN),

	(i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF1] field);
C_2	aircraft-specific 2nd terminal-area departure TSFC coefficient (kg/min/kN), (i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF2] field);
C_3	aircraft-specific 3rd terminal-area departure TSFC coefficient (kg/min/kN/foot), (i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF3] field);
C_4	aircraft-specific 4th terminal-area departure TSFC coefficient (kg/min/kN/lb); (i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF4] field);
h_{MSL}	aircraft altitude with respect to MSL (ft);
M	aircraft Mach number (dimensionless);
θ	ratio of temperature at aircraft altitude to sea level temperature (dimensionless);
F_n / δ	aircraft corrected net thrust per engine (lbf); and
F_n	aircraft net thrust per engine (kN).

Fuel flow rate per engine during approach $f_{n_{arr}}$ (kg/min) is calculated as:

$$f_{n_{arr}} = \left(C_1 + C_2 M + C_3 e^{-\frac{C_4 F_n/\delta}{F_{n_0}}}\right)\sqrt{\theta} F_n \qquad \text{Eq. 3-8}$$

where

C_1	aircraft-specific 1st terminal-area arrival TSFC coefficient (kg/min/kN), (i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF4] field);
C_2	aircraft-specific 2nd terminal-area arrival TSFC coefficient (kg/min/kN), (i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF1] field);
C_3	aircraft-specific 3rd terminal-area arrival TSFC coefficient (kg/min/kN), (i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF2] field);
C_4	aircraft-specific 4th terminal-area arrival TSFC coefficient (dimensionless); (i.e. [FLT_ANP_AIRPLANE_TSFC_COEFFICIENTS].[COEFF3] field);
M	aircraft Mach number (dimensionless);
θ	ratio of temperature at aircraft altitude to sea level temperature (dimensionless);
F_n / δ	aircraft corrected net thrust per engine (lbf);
F_n	aircraft net thrust per engine (kN); and
F_{n_0}	ISA sea-level static thrust (lbf).

3.4.3 Helicopter Fuel Burn

AEDT 2a uses a helicopter’s engine-specific fuel flow rate that corresponds to the “climbout” ICAO operation mode. Because the helicopter terminal area profile calculations are modal rather than force-based, and unlike predictions for fixed-wing aircraft, the dynamic helicopter weight that results from decrementing the weight value by the amount of fuel burned over each flight path segment does not impact the calculated flight path.

3.5 Ground Track

Ground tracks determine the lateral component of the path followed by an aircraft. They are ultimately represented by an ordered series of points. Each of these points can be expressed as either geographic coordinates (latitude and longitude) or projected coordinates. Projected coordinates are Euclidean x and y values, representing displacement to the east and north, respectively, from the associated airport. Airports in AEDT 2a have a location attribute that indicates the nominal location of the airport. Except where otherwise stated, AEDT 2a performance calculations take place in the projected coordinate space. Each ground track consists of a portion explicitly defined by an AEDT 2a user, and an extension calculated by AEDT 2a.

3.5.1 Explicit Ground Track

AEDT 2a supports two kinds of ground track specifications:

1. An ordered set of points; and
2. An ordered set of vectoring commands (for example, fly straight 5.5 nmi, turn left 90° at a radius of 2.0 nmi).

A pointwise track can be specified in geographic coordinates (in which case AEDT 2a internally creates projected counterparts) or in projected coordinates (in which case no transformation is necessary). A vector track is used to generate a set of points in the projected coordinate system.

3.5.1.1 Points from Vectors

AEDT 2a transforms the vectoring commands into a set of x,y points. To transform vectors into points, AEDT 2a 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.

When processing an approach vector track, there is no information available *a priori* about the track's initial location or direction, so AEDT 2a 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. AEDT 2a makes the last approach track point coincide with the displaced approach threshold point on the runway.

When processing a departure vector track, AEDT 2a makes the first track point coincide with the displaced takeoff threshold point on the runway.

AEDT 2a approximates circular-arc portions of ground tracks with two or more straight-line segments. The method referenced in ECAC Doc 29 is used. First, the number of sub-arcs, n_{sub}, to be used to span the total turning angle ξ (radians) of the arc is computed:

$$n_{sub} = \mathrm{int}\left(1 + \frac{\xi}{40} \cdot \frac{180}{\pi}\right) \qquad \text{Eq. 3-9}$$

where the function $\mathrm{int}(x)$ returns the integer part of x.

Next, the angular extent, $\Delta\xi$ (radians), of each sub-arc is computed:

$$\Delta\xi = \frac{\xi}{n_{sub}} \qquad \text{Eq. 3-10}$$

Each sub-arc is approximated by two straight line segments, bound by three surface coordinates. The first surface coordinate 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 angular extent of the sub-arc, with its distance from the center of the sub-arc, r_2 (m), given by:

$$r_2 = r \cdot \left[\cos\left(\frac{\Delta\xi}{2}\right) + \sqrt{\left(\frac{\Delta\xi}{2}\right)^2 - \sin^2\left(\frac{\Delta\xi}{2}\right)}\right] \quad \text{Eq. 3-11}$$

where

r radius of the arc (m).

This method ensures that a line segment replaces not more than 20˚ 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.

3.5.1.2 Radius of Curvature

The turning radius of an aircraft's ground track is an important consideration in accounting for aircraft banking. For vector tracks, there is no need to calculate the turning radius, since the radius is explicitly defined for each turning portion, and implicitly infinite for each straight portion. For pointwise tracks, the turning radius must be approximated from surface coordinate data. This objective is met through a three step process:

1. Track point coordinates are interpolated at a regular spacing.
2. Turning radius is calculated from the interpolated points.
3. Turning radius values are interpolated back to the original points.

In the first step, each 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 turning radius at each point by considering three consecutive track points at a time. The turning radius is equal to the radius of a circle passing through the three points. The circle radius r (m) is calculated as follows:

$$r = \frac{a \cdot b \cdot c}{4 \cdot K} \quad \text{Eq. 3-12}$$

where

a, b, c distances between three consecutive points in the track (m); and
K area of a triangle formed by the points (m^2).

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 radius at these points is set to infinity (as though the track were straight).

3.5.2 Ground Track Extensions

Departure and overflight ground tracks are given a default extension of 10 track segments at 100 nmi each at the end of the explicitly-defined portion. The same is done at the beginning of approach ground tracks. If there is a study boundary and the option to truncate and/or extend flight paths to study boundary is activated, 100-nmi segments are added at all airborne ends of all ground tracks to reach the boundary.

3.6 Profile-Driven Flight Performance

A flight profile describes the movement of an aircraft in terms of aircraft state characteristics (e.g. altitude, speed, flap setting, and thrust) as a function of horizontal distance over the ground (and in some cases for helicopters, time). A profile does not contain information about the path an aircraft follows over the ground. When performance is driven by a profile, AEDT 2a calculates the explicitly-defined portion of the profile first (as described in Section 3.6.2), then calculates extensions to the study boundary (discussed in Section 3.6.3). In both portions of the calculation, the weather model is localized in the manner presented in Section 3.6.1.

3.6.1 Local Weather

For each step calculated in a procedure, weather conditions are taken to have no lateral or temporal variation. That is, atmospheric profiles at the most recently calculated surface coordinate and time are assumed to remain constant throughout the step. The term *atmospheric profiles* refers to the variation of both thermodynamics and headwind with altitude.

3.6.2 Explicit Profile

The explicitly defined portion of a profile-driven trajectory consists of an ordered sequence of components, all of which are either procedures or states. AEDT 2a processes these components in the order in which they appear in their profile (reflecting their intended temporal order).

3.6.2.1 Airplane Profiles

Airplane profiles describe how the state of an airplane advances as time progresses. When a flight profile is comprised of procedure steps, AEDT 2a processes the steps one at a time to calculate profile points, ultimately expressing the steps in the same format as in Section 2.1.4.4. Otherwise, the profile is already expressed in this form directly as fixed points.

Sections 3.6.2.1.1 through 3.6.2.1.3 discuss aspects of the AEDT 2a profile treatment that are independent of component type. Section 3.6.2.1.4 then details how each specific type of profile component is processed to determine segment end-point values of altitude, speed, noise thrust, and corrected net thrust.

3.6.2.1.1 Thrust Specification

Thrust figures prominently in the force balances used to model aircraft performance from procedural ANP profiles. It is also the primary basis for the determination of noise levels. In some contexts, such as the ANP performance specification or normalized plots in engine performance literature, it is expressed as the corrected net thrust per engine, which is the net thrust scaled by the local atmospheric pressure ratio. For certain profile components, the thrust may be specified as an input. This may take the form of a specific value or a thrust rating. There are also circumstances in which thrust is unknown and therefore calculated through an equation that models flight mechanics, such as the minimum (engine-out) force balance. Specific value, thrust rating, and minimum engine-out thrust (based on force balance) are described below.

Noise thrust indicates the value of an airplane's power setting, (the 'Power' in the Noise-Power-Distance data sets). Each aircraft is associated with empirical datasets that model the aircraft's noise as a function of its noise thrust. Noise thrust is defined as the net corrected thrust when appropriate performance data are available. When appropriate performance data are not available (i.e., net corrected thrust is not directly calculated), the noise thrust can be defined as a percentage of the aircraft static thrust (where aircraft static thrust is in units of Newtons). If performance data or static thrust data are not available[vii], noise thrust values can be taken from engine parameters and provided directly as inputs to the performance calculations; no physics-based performance modeling is done. The units of these inputs, described as "other", are assumed to match the units used for the noise datasets.

3.6.2.1.1.1 Thrust Value

When thrust is provided as a specific value, the value indicates the magnitude of corrected net thrust per engine. For procedure steps, the given thrust is taken to apply throughout the entire step for the purpose of performance modeling. The specific value option is available for takeoff ground roll, constant-CAS climb, or accelerating climb steps, as well as for fixed profile points. It is also available as a percentage for braking ground roll.

3.6.2.1.1.2 Thrust Rating

When thrust is provided as a rating, the corrected net thrust per engine is calculated from a set of parameters from the ANP database. Ratings indicate a standard power level for the aircraft, such as maximum takeoff, reduced climb, idle, etc. Each rating that is defined for an aircraft has its own set of thrust parameter values. The parameter sets and thrust calculations used for aircraft modeled as jets are substantially different from those used for aircraft modeled as propeller-driven. The thrust rating option is available for takeoff ground roll, constant-CAS climb, and accelerating climb steps.

3.6.2.1.1.2.1 Jet Rated Thrust

AEDT 2a calculates jet aircraft corrected net thrust per engine by using a modified version of SAE-AIR-1845[14] equation (A1):

$$\frac{F_n}{\delta} = E + F \cdot v + G_A \cdot h + G_B \cdot h^2 + H \cdot T_C \qquad \text{Eq. 3-13}$$

where

$\frac{F_n}{\delta}$	corrected net thrust per engine (lbf);
v	equivalent/calibrated airspeed (kt);
h	pressure altitude (ft) 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) (lbf, lbf/kt, lbf/ft, lbf/ft^2, lbf/°C, respectively).

[vii] Performance or static thrust data may be unavailable for some military and general aviation aircraft.

AEDT 2a 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.

AEDT 2a 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, AEDT 2a 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. AEDT 2a 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, AEDT 2a calculates high-temperature corrected net thrust by the equation:

$$\left(\frac{F_n}{\delta}\right)_{high} = F_{low} \cdot v + (E_{low} + H_{low} \cdot T_{BC}) \frac{1 - 0.003 \cdot T_F}{1 - 0.003 \cdot T_{BF}} \quad \text{Eq. 3-14}$$

where

$(\frac{F_n}{\delta})_{high}$	high-temperature corrected net thrust (lbf);
$E_{low}, F_{low}, H_{low}$	regression coefficients for the low-temperature equation (lbf, lbf/kt, lbf/°C, respectively);
v	calibrated airspeed (kt);
T_F	temperature (°F) at the aircraft;
T_{BC}	breakpoint temperature, T_{BC} = 30°C; and
T_{BF}	breakpoint temperature, T_{BF} = 86°F.

3.6.2.1.1.2.2 Propeller Rated Thrust

AEDT calculates propeller-driven aircraft corrected net thrust per engine by using SAE-AIR-1845 equation (A4):

$$\frac{F_n}{\delta} = \frac{\left(\frac{325.87 \cdot \eta \cdot P}{v_T}\right)}{\delta} \quad \text{Eq. 3-15}$$

where

325.87	unit conversion: horsepower/kt to lbf;
η	propeller efficiency, which depends on the power state (dimensionless);
P	net power per engine (horsepower, MSL standard day), which depends on the power state (max-takeoff or max-climb);
v_T	true airspeed (kt); and
δ	pressure ratio at aircraft altitude (dimensionless).

3.6.2.1.1.3 Minimum Engine-Out

The only force-balance based thrust level that can be specified as an input to AEDT 2a performance calculations is the minimum engine-out thrust. This thrust is calculated by:

$$\frac{F_n}{\delta} = \frac{\left(\frac{W}{\delta_2}\right) \cdot \left\{ \left[\frac{\sin\left(\tan^{-1}\frac{G}{100}\right)}{K} \right] + R_f \right\}}{N - 1} \quad \text{Eq. 3-16}$$

where

W	departure profile weight (lbf);
δ_2	pressure ratio at altitude A_2 (dimensionless);
G	engine-out percentage climb gradient from FAR Part 25[27] (dimensionless): G = 0% for aircraft with Automatic Thrust Restoration Systems; G = 1.2% for 2-engine aircraft; G = 1.5% for 3-engine aircraft; or G = 1.7% for 4-engine aircraft.
K	speed-dependent constant (dimensionless): K = 1.01 when climb speed ≤ 200 kts; or 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 (dimensionless); and
N	number of engines (N>1) (dimensionless).

This option is available for constant-CAS climb or accelerating climb. Note that this method will underpredict the thrust required, since the R_f value used is for a standard, all-engines operating flight condition – an engine out condition will have significantly more drag than an all-engines operating condition.

3.6.2.1.2 True Airspeed

Procedural profiles specify speed in the form of calibrated airspeed. True airspeed is also relevant to the flight mechanics modeled by AEDT 2a. Calibrated airspeed is assumed to equal equivalent airspeed in the Doc 29 performance specification. True airspeed for the explicitly-defined portion of a profile-driven operation is therefore calculated by using SAE-AIR-1845 equation (A5):

$$v_T = v \,/\, \sqrt{\sigma} \quad \text{Eq. 3-17}$$

where

v_T	true airspeed (kt);
v	calibrated airspeed (kt); and
σ	air density ratio at aircraft altitude (dimensionless).

3.6.2.1.3 Displaced Thresholds and Threshold Crossing Heights

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

$$D = D_{dep} + \Delta_{trk} \quad \text{Eq. 3-18}$$

where

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

An approach flight touches down on the runway at a given distance from the approach end of the runway:

$$D = D_{app} + \Delta_{trk} + \frac{h_{tc} \cdot |d_{-1}|}{z_{-1}} \qquad \text{Eq. 3-19}$$

where

D_{app}	displaced approach threshold (ft) for the runway (user input);
h_{tc}	threshold crossing height (ft) for the runway (user input);
d_{-1}	coordinate value (ft) of the profile point immediately before the touch-down point (it is a negative number); and
z_{-1}	altitude AFE (ft) of the profile point immediately before the touch-down point (the touch-down point has coordinates: $d_0 = 0$, $z_0 = 0$).

Since the duration and horizontal length of some procedure steps changes with local weather variation, the length of a flight profile depends on the time and location where the profile begins. Since airplane profiles are calculated in forward order with respect to time and horizontal distance, their starting time and location are necessarily determined iteratively. The initial location is set to the beginning of the full ground track, while the initial time is set to the arrival on-time. After the profile is calculated from these settings, it is adjusted by the amount by which the respective temporal and spatial touch-down targets were missed.

3.6.2.1.4 Profile Components

The following Sections describe how AEDT 2a processes specific profile component types. 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, when 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 one procedure step are combined with data from an adjacent step before a profile point can be computed. For example, two consecutive descent steps will specify their initial altitude, speed, and angle of descent. AEDT 2a uses the second descent step’s initial altitude as the final altitude for the first step. 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.

3.6.2.1.4.1 Fixed Point

A fixed profile point specifies much of the aircraft’s state at a particular horizontal coordinate and time, as described in Section 2.1.4.4. Altitude, distance, speed, and noise thrust require no calculation, as they are given directly. AEDT 2a does not adjust noise thrusts for non-standard temperature and pressure (that is, the input values of noise thrust are directly used in the noise tables, regardless of its units). If the noise thrust is specified as a percent, the corrected net thrust is calculated by applying the given percentage to the airplane’s static thrust value. No corrected net thrust calculation is required when the noise thrust is specified in pounds (in which case the setting directly specified the corrected net thrust) or any other units not mentioned here (in which case no relationship between noise thrust and actual engine thrust is specified).

3.6.2.1.4.2 Takeoff Ground Roll Step

A takeoff ground roll step models airplane acceleration on the ground before becoming airborne. For this type of step, the initial and final values of aircraft altitude are given (the elevation of the starting runway end), 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 start-roll point is calculated by using the departure thrust equation with v_1 = 0 kts. 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 end of the step.

For jets and props, the corrected net thrust per engine $(F_n/\delta)_2$ at the end of the step is calculated by using rated thrust as described in 3.6.2.1.1.2. The calibrated airspeed at the end of the step, which is used in the thrust equation, is modeled as the initial climb calibrated airspeed, and is calculated by using SAE-AIR-1845 equation (A7):

$$v_2 = C_f \cdot \sqrt{W} \qquad \text{Eq. 3-20}$$

where

- v_2 initial climb calibrated airspeed (kt);
- C_f takeoff speed coefficient that depends on flaps setting (kt/$\sqrt{\text{lbf}}$); and
- W departure profile weight (lbf); 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, then $(F_n/\delta)_2$ is also set to equal the input value.

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

$$S_g = \frac{B_f \cdot \theta \cdot \left(\frac{W}{\delta}\right)^2}{N \cdot \left(\frac{F_n}{\delta}\right)_2} \qquad \text{Eq. 3-21}$$

where

- S_g ground-roll distance (ft);
- B_f ground-roll coefficient, which depends on the flaps setting (ft/lbf);
- θ temperature ratio at the airport elevation (dimensionless);
- δ pressure ratio at the airport (dimensionless); and
- $\left(\frac{F_n}{\delta}\right)_2$ corrected net thrust per engine (lbf) at the end of takeoff step.

The takeoff ground-roll distance is corrected for headwind, by using SAE-AIR-1845 equation (A16):

$$S_{gw} = \frac{S_g \cdot (v_2 - w)^2}{(v_2 - 8)^2} \qquad \text{Eq. 3-22}$$

where

- S_{gw} ground-roll distance (ft) corrected for headwind;
- v_2 initial climb calibrated speed (kt); and
- w headwind (kt).

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

$$S_{gc} = \frac{S_{gw} \cdot a}{a - 32.17 \cdot G} \qquad \text{Eq. 3-23}$$

$$a = \frac{\left(v_2/\sqrt{\sigma}\right)^2}{2 \cdot S_{gw}} \qquad \text{Eq. 3-24}$$

$$G = \frac{E_2 - E_1}{L} \qquad \text{Eq. 3-25}$$

where

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

In AEDT 2a, the corrected ground-roll distance S_{gc} is divided into sub-segments with variable lengths, with each segment covering an aircraft speed change of 20 kts. The number of sub-segments N_{segs} for the ground roll is calculated as:

$$N_{segs} = \mathrm{int}\left(1 + \frac{v_2}{20}\right) \qquad \text{Eq. 3-26}$$

where

N_{segs}	number of sub-segments (dimensionless); and
$\mathrm{int(x)}$	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:

$$t = \frac{2 \cdot S_{gc}}{v_2 \cdot N_{segs}} \qquad \text{Eq. 3-27}$$

where

t	time (s) spent on each sub-segment.

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

3.6.2.1.4.3 Constant-CAS Climb Step

A constant-CAS climb segment models the climb of an aircraft at constant calibrated airspeed to a target altitude. For this type of step, 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 according to Eq. 3-17 from their corresponding density ratios.

The nominal corrected net thrust per engine, F_n/δ, and the final corrected net thrust per engine, $(F_n/\delta)_2$ are calculated differently depending on the thrust specification supplied for the procedure step:

1. When a thrust rating is specified, the nominal corrected net thrust per engine is calculated by using the rated thrust equations presented in 3.6.2.1.1.2 at the mid-point altitude $A_m = ½(A_1 + A_2)$. Likewise, a nominal value of the pressure ratio, δ, is sampled at the mid-point altitude $A_{m.}$. The final corrected net thrust per engine is calculated from the same equations, at calibrated airspeed v and the final altitude A_2.

2. When thrust is specified directly by value without a cutback segment, the nominal value of corrected net thrust per engine is set to the specified value, F_n/δ = user-input 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, and the final corrected net thrust per engine is also set to the specified thrust.

3. When a thrust is specified, directly by value with a cutback segment, 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 separated into two sub-segments, both having the same climb angle. The first sub-segment is assigned a 1,000 ft ground distance and the corrected net thrust per engine at the end of 1,000 ft is set equal to the user-cutback thrust value. If the original horizontal distance is less than 2,000 ft, 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 1,000 ft sub-segment restores the thrust from the user-cutback value to the calculated value $(F_n/\delta)_2$ at altitude A_2. This sub-segment is created in the next climb or acceleration segment.

4. When engine-out minimum thrust is specified, the nominal value of corrected net thrust per engine F_n/δ is calculated by using the minimum engine-out procedure described in 3.6.2.1.1.3. The nominal value of the pressure ratio δ is set to the final value calculated at altitude A_2.

   Two 1,000 ft sub-segments are introduced in a manner similar to the user-cutback case.

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

$$\gamma = \sin^{-1}\left(K \cdot \left[\frac{N \cdot \left(\frac{F_n}{\delta}\right)}{\left(\frac{W}{\delta}\right)} - R_f\right]\right) \qquad \text{Eq. 3-28}$$

where

- γ average climb angle (radians)
- K speed-dependent constant (dimensionless); K=1.01 when climb speed ≤ 200 kt; or K=0.95 otherwise.
- N number of engines (dimensionless);
- $\left(\frac{F_n}{\delta}\right)$ nominal value of corrected net thrust per engine (lbf);
- δ nominal value of the pressure ratio (dimensionless);
- W departure profile weight (lbf); and
- R_f drag-over-lift coefficient that depends on the flaps setting (dimensionless).

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 AEDT 2a method is designed to handle 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):

$$\gamma_w = \frac{\gamma \cdot (v - 8)}{(v - w)} \qquad \text{Eq. 3-29}$$

where

- γ_w average climb angle corrected for headwind;
- γ average climb angle (uncorrected);
- v calibrated airspeed (kt) on the climb segment; and
- w headwind (kt).

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

$$S_c = \frac{A_2 - A_1}{\tan \gamma_w} \qquad \text{Eq. 3-30}$$

where

- S_c horizontal distance (ft) for the climb segment;
- A_1 initial altitude (ft) MSL; and
- A_2 final altitude (ft) MSL.

3.6.2.1.4.4 Accelerating Climb Step by Climb Rate

An accelerating climb step models acceleration to a target calibrated airspeed at a specified rate of climb. For this type of step, the initial altitude A1, initial true airspeed v_{T1}, and initial thrust $(Fn/\delta)_1$ 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 ft 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 ft.

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

$$S_a = \frac{0.95 \cdot k \cdot \left(v_{T_2}^2 - v_{T_1}^2\right)}{G_m - G} \qquad \text{Eq. 3-31}$$

where

S_a current iteration horizontal distance (ft);

g gravitational acceleration of Earth (ft/s^2)

k constant to convert kt^2 to ft^2/s^2:

$$k = 2.8487$$

v_{T_1} input initial true airspeed (kt);

v_{T_2} final true airspeed (kt) at current iteration σ_2:

$$v_{T_2} = v_2 \,/\, \sqrt{\sigma_2}$$

where

v_2 input final calibrated airspeed (kt);

σ_2 air density ratio at current iteration final altitude A_2 (dimensionless);

G_m maximum acceleration available, as a fraction of g, for current iteration:

$$G_m = \frac{N \cdot \left(\frac{F_n}{\delta}\right)}{\left(\frac{W}{\delta}\right)} - R_f$$

where

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

$$\left(\frac{F_n}{\delta}\right) = \frac{1}{2}\left[\left(\frac{F_n}{\delta}\right)_1 + \left(\frac{F_n}{\delta}\right)_2\right]$$

where

$(F_n/\delta)_1$ input initial corrected net thrust per engine (lbf);

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

δ pressure ratio at current iteration mid-point altitude, $(A_1 + A_2)/2$ (dimensionless);

G climb gradient for the current iteration value of vT2 (dimensionless):

$$G = \frac{v_{T_z}}{101.2686 \; {}^{1}\!/_{2} \left(v_{T_1} + v_{T_2}\right)}$$

where

v_{T_z} input climb rate (ft/min).

The next-iteration final altitude A'_2 (ft) is calculated by using SAE-AIR-1845 equation (A11):

$$A'_2 = A_1 + \frac{S_a \cdot G}{0.95} \qquad \text{Eq. 3-32}$$

When $A'_2 - A_2 < 1\text{ft}$, 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. AEDT 2a 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 $G < 0.01$, AEDT 2a issues an error message and stops computing the profile. If $G < 0.01$, 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):

$$S_{aw} = \frac{S_a \cdot (v_T - w)}{(v_T - 8)} \qquad \text{Eq. 3-33}$$

where

S_{aw}	horizontal distance (ft) corrected for headwind;
S_a	horizontal distance (ft) for the acceleration segment, uncorrected; and
v_T	average true airspeed (kts) on the segment:

$$v_T = \left(v_{T_1} + v_{T_2}\right)/2$$

3.6.2.1.4.5 Accelerating Climb Step by Energy Share

An accelerating climb step by energy share models acceleration to a target calibrated airspeed with the rate of climb specified indirectly as a percentage of available acceleration. For this type of step, 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 as acceleration segments (see Section 3.6.2.1.4.4 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 uses for climbing vs. accelerating. The climb gradient, G, in Eq. 3-31 is replaced with a climb gradient calculated using the input acceleration percent value (A_p). 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:

$$G = G_m \cdot \left(1 - A_p \,/\, 100\right) \qquad \text{Eq. 3-34}$$

where

G	acceleration available for climbing as a fraction of g also called the climb gradient (dimensionless);
G_m	maximum available acceleration as a fraction of g , see Eq. 2-35 (dimensionless); and
A_p	percentage of thrust applied to acceleration.

Thus, Eq.3-34 is used instead to calculate G in Eq. 3-31, and the process is otherwise identical to the acceleration segment. Note that the limits on $G_m - G$ discussed in Section 3.6.2.1.4.4 will come into play when the value of A_p is very small.

3.6.2.1.4.6 Cruise-Climb Step

A cruise-climb step models a climb at a specific angle to a target altitude and calibrated airspeed. For this type of step. For this type of step, 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 SAE-AIR-1845 equation (A15) with an additive term for climb thrust:

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{\left(\frac{W}{\delta_2}\right) \cdot \left(R_f + \frac{\sin\gamma}{0.95}\right)}{N} \qquad \text{Eq. 3-35}$$

where

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

The horizontal distance is calculated by:

$$S_{cc} = \frac{A_2 - A_1}{\tan\gamma} \qquad \text{Eq. 3-36}$$

where

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

3.6.2.1.4.7 Descent Step

A descent step models descent at a specific angle to a target altitude and calibrated airspeed, neglecting deceleration effects. For this type of step, 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 AEDT 2a, 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 v_{T_2} (kt) is:

$$v_{T_2} = v_2 \,/\, \sqrt{\sigma_2} \qquad \text{Eq. 3-37}$$

where

v_2	input final calibrated airspeed (kt); and
σ_2	density ratio at altitude A_2 (dimensionless).

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

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{\left(\frac{W}{\delta_2}\right) \cdot \left(R_f - \frac{\sin\gamma}{1.03}\right)}{N} \qquad \text{Eq. 3-38}$$

where

$\left(\frac{F_n}{\delta}\right)_2$	corrected net thrust per engine (lbf) at altitude A_2; and
γ	average descent angle (a positive value).

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

$$\left(\frac{F_n}{\delta}\right)_{2w} = \left(\frac{F_n}{\delta}\right)_2 + \frac{1.03 \cdot \left(\frac{W}{\delta_2}\right) \cdot \sin\gamma \cdot (w-8)}{N \cdot v_2} \qquad \text{Eq. 3-39}$$

where

$\left(\frac{F_n}{\delta}\right)_{2w}$	corrected net thrust per engine (lbf) for headwind w;
w	headwind (kt); and
v_2	calibrated airspeed (kt) at altitude A_2.

The horizontal distance is calculated by:

$$S_d = \frac{A_1 - A_2}{\tan\gamma} \qquad \text{Eq. 3-40}$$

where

S_d	horizontal distance (ft) for the descent segment;

3.6.2.1.4.8 Deceleration-Sensitive Descend Step

A deceleration-sensitive descend step models descent at a specific angle to a target altitude and calibrated airspeed, adjusting one of the targets to preserve the deceleration that would have been observed in an ISA. For this type of step, 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. Although the inputs for this type of step are the same as for a standard descent step, this type of step (as well as the "Descend-Idle" step described in Section 3.6.2.1.4.9) is calculated in a way that preserves the acceleration value implied by its inputs.

In AEDT 2a, the initial altitude and speed appear to be user defined; 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 AEDT 2a is similar but not identical to the process described in Section B-10 of ECAC Doc 29. AEDT 2a 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:

$$a_{ISA} = \frac{\left(\sqrt{v_{T_{2_{ISA}}}^2 - w^2 \cdot \sin^2\gamma} - w \cdot \cos\gamma\right)^2 - \left(\sqrt{v_{T_{1_{ISA}}}^2 - w^2 \cdot \sin^2\gamma} - w \cdot \cos\gamma\right)^2}{2 \cdot S_d} \quad \text{Eq. 3-41}$$

where

a_{ISA} acceleration for ISA conditions (ft/s^2);

$v_{T_{1_{ISA}}}$ initial true airspeed (ft/s) for ISA conditions $\sigma_{1_{ISA}}$:

$$v_{T_{1_{ISA}}} = \left(\frac{101.2686}{60}\right) v_1 \,/\, \sqrt{\sigma_{1_{ISA}}}$$

where

v_1 input initial calibrated airspeed (kt);

$\sigma_{1_{ISA}}$ air density ratio at initial altitude A_1 (for ISA conditions);

$v_{T_{2_{ISA}}}$ final true airspeed (ft/s) for ISA conditions $\sigma_{2_{ISA}}$:

$$v_{T_{2_{ISA}}} = \left(\frac{101.2686}{60}\right) v_2 \,/\, \sqrt{\sigma_{2_{ISA}}}$$

where

v_2 input final calibrated airspeed (kt);

$\sigma_{2_{ISA}}$ 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 (ft) for the descent segment:

$$S_d = \frac{A_2 - A_1}{\sin\gamma}$$

where

A_1	initial altitude (ft) MSL; and
A_2	final altitude (ft) 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 or 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 (ft/s) is calculated as:

$$v'_{T_2} = \sqrt{\left(\sqrt{\left(\sqrt{v_{T_1}^2 - w^2\sin^2\gamma} - w\cdot\cos\gamma\right)^2 + 2s_d a_{ISA}} + w\cdot\cos\gamma\right)^2 + w^2\cdot\sin^2\gamma} \quad \text{Eq. 3-42}$$

where

v'_{T_2}	calculated final true airspeed for actual airport atmospheric conditions (ft/s); and
v_{T_1}	input initial true airspeed for actual airport atmospheric conditions (ft/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:

$$S'_l = \frac{\left(\sqrt{v_{T_2}^2 - w^2\cdot\sin^2\gamma} - w\cdot\cos\gamma\right)^2 - \left(\sqrt{v_{T_1}^2 - w^2\cdot\sin^2\gamma} - w\cdot\cos\gamma\right)^2}{2\cdot a_{ISA}} \quad \text{Eq. 3-43}$$

where

S'_l	segment length adjusted for non-ISA conditions (ft);
v_{T_1}	input initial true airspeed for actual airport atmospheric conditions (ft/s); and
v_{T_2}	input final true airspeed for actual airport atmospheric conditions (ft/s).

The segment's new final altitude A'_2 is calculated as:

$$A'_2 = A_1 - s'_l\cdot\sin\gamma \quad \text{Eq. 3-44}$$

where

A'_2	calculated final altitude (ft) MSL; and
A_1	input initial altitude (ft) MSL.

Descend-decel segment thrust values account for deceleration effects on thrust, unlike descent segments described in Section 3.6.2.1.4.7. Thrust is calculated with a force balance derived from SAE-AIR-1845 equation (A15) with an additional acceleration term:

$$\frac{F_n}{\delta} = \frac{W}{N \cdot \delta}\left(R \cdot \cos\gamma - \sin\gamma + \frac{a}{g}\right) \qquad \text{Eq. 3-45}$$

where

$\frac{F_n}{\delta}$	corrected net thrust per engine (lbf);
W	aircraft weight (lbf);
δ	pressure ratio at segment's altitude (dimensionless);
N	number of engines (dimensionless);
R	drag over lift coefficient that depends on flaps and gear setting (dimensionless);
a	aircraft acceleration along the velocity vector (ft/s^2);
g	gravitational acceleration of Earth (ft/s^2); and
γ	descent angle (positive by convention).

3.6.2.1.4.9 Idle Descend Step

An idle descend step models descent at a specific angle and idle thrust setting to a target altitude and calibrated airspeed, adjusting one of the targets to preserve the deceleration that would have been observed in an ISA. For this type of step, 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 AEDT 2a, 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 3.6.2.1.4.8 with the exception of thrust. Idle thrust is a rated thrust specification (see Section 3.6.2.1.1.2). The initial and final idle thrust values are calculated using the initial and final altitude and speed values as appropriate.

3.6.2.1.4.10 Level Step

A level step models level flight over a specific distance to a target calibrated airspeed, neglecting deceleration effects. For this type of step, 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 AEDT 2a creates a 1,000 ft transition segment so that the major portion of the level segment is flown at constant thrust.

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

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{\left(\frac{W}{\delta}\right) \cdot R_f}{N} \qquad \text{Eq. 3-46}$$

where

$\left(\frac{F_n}{\delta}\right)_2$	final corrected net thrust per engine (lbf) at altitude $A_1 = A_2$;
W	profile weight (lbf);
δ	pressure ratio at altitude $A_1 = A_2$ (dimensionless); and
R_f	drag-over-lift coefficient that depends on flaps and gear setting (dimensionless).

3.6.2.1.4.11 Deceleration-Sensitive Level Step

A deceleration-sensitive level step models level flight over a specific distance to a target calibrated airspeed, adjusting the target speed to preserve the deceleration that would have been observed in an ISA. For this type of step, the step length, initial true airspeed, and step 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-deceleration segment is calculated and then separated into two sub-segments. The first sub-segment is assigned a 1,000 ft 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 1,000 ft is set equal to the level-decel thrust. If the original horizontal distance is less than 2,000 ft, 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 1,000 ft sub-segment restores the thrust from the level-decel value to the appropriate initial thrust for the following segment. This sub-segment is created in the following segment.

AEDT 2a assumes that the procedural profile using the level-decel segment is 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:

$$a_{ISA} = \frac{\left(\left(\frac{v_2}{\sqrt{\sigma_{ISA}}} - w\right) \cdot \frac{101.2686}{60}\right)^2 - \left(\left(\frac{v_1}{\sqrt{\sigma_{ISA}}} - w\right) \cdot \frac{101.2686}{60}\right)^2}{2 \cdot S_d} \qquad \text{Eq. 3-47}$$

where

a_{ISA}	acceleration for ISA conditions (ft/s^2);
v_1	input initial calibrated airspeed (kt);
v_2	input final calibrated airspeed (kt);
σ_{ISA}	air density ratio at segment altitude (for ISA conditions);
w	headwind (kt); and
S_d	input horizontal distance (ft) 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:

$$s'_d = \frac{\left(\left(\frac{v_2}{\sqrt{\sigma}} - w\right) \cdot \frac{101.2686}{60}\right)^2 - \left(\left(\frac{v_1}{\sqrt{\sigma}} - w\right) \cdot \frac{101.2686}{60}\right)^2}{2 \cdot a_{ISA}} \quad \text{Eq. 3-48}$$

where

s'_d	segment length (ft); and
σ	air density ratio at segment altitude (for actual airport conditions).

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

$$\frac{F_n}{\delta} = \frac{W}{N \cdot \delta}\left(R + \frac{a}{g}\right) \quad \text{Eq. 3-49}$$

where

$\frac{F_n}{\delta}$	corrected net thrust per engine (lbf);
W	aircraft weight (lbf);
δ	pressure ratio at segment's altitude (dimensionless);
N	number of engines (dimensionless);
R	drag over lift coefficient that depends on flaps and gear setting (dimensionless);
a	aircraft acceleration along the velocity vector (ft/s^2); and
g	gravitational acceleration of Earth (ft/s^2).

3.6.2.1.4.12 Level-Idle Step

An idle level step models level flight at idle thrust over a specific distance to a target calibrated airspeed, adjusting the target speed to preserve the deceleration that would have been observed in an ISA. For this type of step, the step length, initial true airspeed, and step 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 separated into two sub-segments. The first sub-segment is assigned a 1,000 ft 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 1,000 ft is set equal to the calculated initial idle thrust value. If the original horizontal distance is less than 2,000 ft, 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 1,000 ft sub-segment restores the thrust from the final idle thrust value to the appropriate initial thrust for the following segment. This sub-segment is created in the following segment.

As for level-decel segments, AEDT 2a 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. 3-47 and Eq. 3-48 from Section 3.6.2.1.4.11.

Idle thrust is a rated thrust specification (see Section 3.6.2.1.1.2). The initial and final idle thrust values are calculated using the constant segment altitude and the initial and final speed values as appropriate.

3.6.2.1.4.13 Landing Ground Roll Step

A landing ground roll step models ground roll from touch down over a specific distance to a target calibrated airspeed and thrust setting. For this type of step, the initial and final altitudes are given (the elevation of the touch-down end of the runway), the initial (landing) speed is calculated, the final roll-out true speed is calculated from a 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):

$$v_1 = D_f \cdot \sqrt{W} \qquad \text{Eq. 3-50}$$

where

v_1	calibrated airspeed (kt) just before landing;
D_f	landing coefficient that depends on the flaps and gear setting (kt/$\sqrt{\text{lbf}}$); and
W	approach profile weight (lbf); weight is assumed to remain constant for the entire approach profile.

The initial and final true speeds are calculated by:

$$v_{T_1} = v_1 \,/\, \sqrt{\sigma} \qquad \text{Eq. 3-51}$$

$$v_{T_2} = v_2 \,/\, \sqrt{\sigma} \qquad \text{Eq. 3-52}$$

where

σ	density ratio at airport altitude (dimensionless).

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 3.6.2.1.4.7).

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

$$\left(\frac{F_n}{\delta}\right)_2 = F_s \cdot \left(\frac{P}{100}\right) \qquad \text{Eq. 3-53}$$

where

$\left(\frac{F_n}{\delta}\right)_2$	corrected net thrust per engine (lbf) at end of landing roll-out;
F_S	static corrected net thrust per engine (an input parameter) (lbf); and
P	percentage of thrust (an input parameter).

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

3.6.2.1.4.14 Decelerate Step

A decelerate segment models ground roll over a specific distance to a target calibrated airspeed and thrust. For this type of step, the initial and final altitudes are given (the elevation of the touch-down end of the runway), 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 3.6.2.1.4.13), and the ground-roll distance is user input.

3.6.2.2 Helicopter Trajectory

AEDT 2a 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 AEDT 2a, and are not modified by AEDT 2a 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 AEDT 2a references operational modes and not thrust values. Available operational modes for helicopters include the following:

Dynamic operational modes:

- Constant-velocity descent
- Constant-velocity climb
- Constant-velocity level
- Vertical ascent with ground effect
- Vertical ascent without ground effect
- Vertical descent with ground effect
- Vertical descent without ground effect
- Level deceleration
- Descending deceleration
- Level acceleration
- Ascending acceleration

Static operational modes:

- Idle with ground support
- Idle without ground support
- Hover with ground effect
- Hover without ground effect

Each helicopter operational mode can have 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 AEDT 2a. Note that AEDT does not require the existence of all modes. Thrust is not included in helicopter flight profiles.

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

- Horizontal coordinate (ft);
- Altitude of the helicopter above the helipad (ft);
- Helicopter true groundspeed at the point (kts);
- Helicopter operational mode; and
- Time spent at a location for static operational modes (sec).

3.6.2.2.1 Helicopter Procedure Steps

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 three types of helicopter flight operations (approach, departure, and overflight) are created by using 13 types of procedure steps:

- Start Altitude: This step is used to start a profile at a given altitude and speed. The starting altitude and speed are inputs.
- Constant-Velocity Level: 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.
- Constant-Velocity Descent: 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.
- Descending Deceleration: 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.
- Level Deceleration: 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.
- Vertical Descent: 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.
- 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.
- Idle With Ground Support: 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.
- Idle Without Ground Support: 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.
- Vertical Climb: 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.

- Level Acceleration: 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.
- Ascending Acceleration: 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.
- Constant-Velocity Climb: 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.

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, AEDT 2a calculates a ground effect altitude as follows:

$$A_{GE} = 1.5 \cdot D_{MR} \qquad \text{Eq. 3-54}$$

where

A_{GE} ground effect altitude (ft AFE); and
D_{MR} main rotor diameter (ft, an input parameter).

If the procedure step stays below the ground effect altitude, the resulting trajectory segment is assigned the corresponding flight operational mode with ground effect. If the step stays at or above the ground effect altitude, the resulting trajectory segment is assigned the corresponding flight operational mode without ground effect. If a given Vertical Climb or Vertical Descent procedure step crosses the ground effect altitude, AEDT 2a automatically divides the step into two at the ground effect altitude and assigns flight operational modes to the two steps as appropriate.

AEDT 2a 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.

3.6.2.3 Flight Path Calculation

3.6.2.3.1 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 (n ordered set of latitude, longitude points). Where there is a track point, a z-value is computed by interpolating between two points on the profile. Where 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:

$$z = z_1 + f \cdot (z_2 - z_1) \quad \text{Eq. 3-55}$$

$$v_t = v_{T_1} + f \cdot (v_{T_2} - v_{T_1}) \quad \text{Eq. 3-56}$$

$$\left(\frac{F_n}{\delta}\right) = \left(\frac{F_n}{\delta}\right)_1 + f \cdot \left[\left(\frac{F_n}{\delta}\right)_2 - \left(\frac{F_n}{\delta}\right)_1\right] \quad \text{Eq. 3-57}$$

$$\Delta v = v_{T_2} - v_{T_1} \quad \text{Eq. 3-58}$$

$$\Delta F = \left(\frac{F_n}{\delta}\right)_2 - \left(\frac{F_n}{\delta}\right)_1 \quad \text{Eq. 3-59}$$

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 (dimensionless);
z_1, z_2	initial and final profile altitudes (ft AFE);
v_t	speed at the interpolated point (kt);
v_{T_1}, v_{T_2}	initial and final profile point speeds (kt);
(F_n / δ)	corrected net thrust per engine (lbf) at the interpolated point;
$(F_n/\delta)_1$	initial profile point corrected net thrust per engine (lbf); and
$(F_n/\delta)_2$	final profile point corrected net thrust per engine (lbf).

3.6.2.3.2 Flight Path Length Adjustments

After AEDT 2a 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 ft, 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 100,000 ft-kts. The number of sub-segments is calculated by:

$$N = \text{int}\left(1 + \sqrt{\frac{(v_{T_2} - v_{T_1}) \cdot L}{100{,}000}}\right) \quad \text{Eq. 3-60}$$

where

N	number of equal-distance sub-vectors (dimensionless);
$\text{int}(x)$	function that returns the integer part of a number x; and
L	length of the vector (ft).

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.

3.6.2.4 Bank Angle Treatment

The AEDT 2a bank angle calculation methods are based on the guidance provided in the Doc 29[23] (B-8):

$$\varepsilon = \tan^{-1}\left(2.85\frac{v_g^2}{rg}\right) \qquad \text{Eq. 3-61}$$

where

ε	bank angle (radians, positive in a left turn and negative in a right turn);
v_g	ground speed (kts);
r	turn radius (ft); and
g	gravitational acceleration of Earth (ft/s^2).

Two important assumptions inherent in the equation are listed below:

1. The aircraft is in a coordinated turn where the velocity vector is always aligned with the aircraft roll axis.
2. 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.

3.6.2.4.1 Bank Angle Smoothing and Filtering

AEDT 2a attempts to remove fluctuations in the bank angle through a sequence of smoothing, filtering, and limiting steps. The process is as follows:

1. Interpolate to stations every 0.5 nmi along the track.
2. Apply exponential smoothing.
3. Filter out fluctuations about zero.
4. Interpolate back onto original stations.
5. Apply upper limit.

The process is illustrated in Figure 3-1.

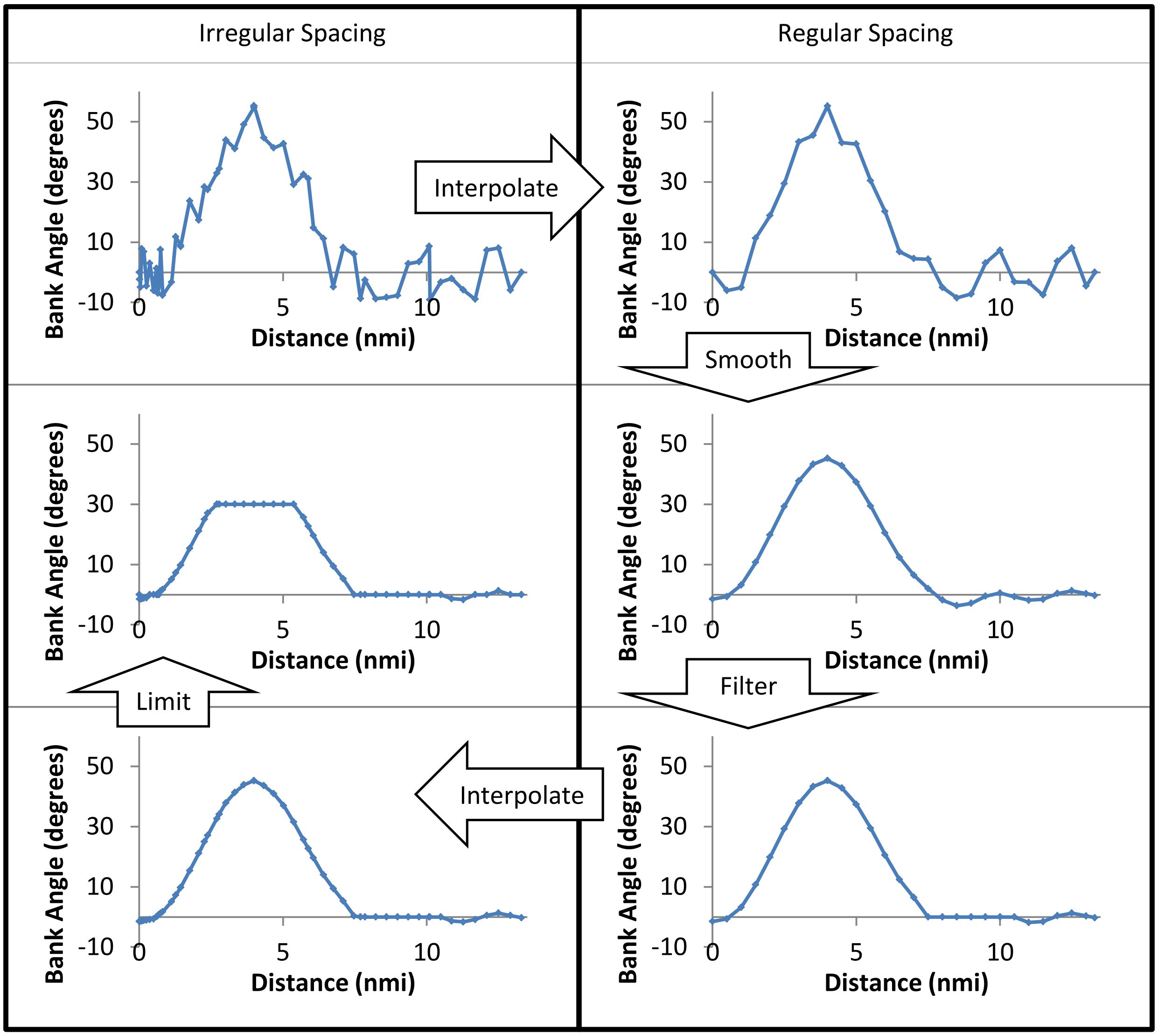

Figure 3-1 Example of bank angle smoothing, filtering, and limiting

Interpolation at every 0.5 nmi leads to a collection of n bank angle samples, ε_i. The first sample ε_0 is at a distance of zero and has the same value as the original first bank angle. The last sample ε_{n-1} is at the same distance as the original last bank angle, and has the same value (unlike the rest of the samples, the spacing between the last sample and its predecessor is not 0.5 nmi).

Exponential smoothing is similar to a moving average except that points are weighted exponentially. The smoothed value is calculated recursively as follows:

$$\varepsilon_{si} = (1 - b) \cdot \varepsilon_i + b \cdot \varepsilon_{si-1} \qquad \text{Eq. 3-62}$$

where

ε_{si} smoothed bank value at index i;
b smoothing parameter (dimensionless);

ε_i unsmoothed bank value at index i; and
ε_{si-1} smoothed value at index $i - 1$.

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. The parameter is selected automatically in AEDT 2a by using a variant of the signal to noise ratio on the calculated bank. The fluctuation magnitude N is defined as:

$$N = \frac{\text{median}(|\text{diff}(\varepsilon)|)}{\text{stdev}(\varepsilon)} \qquad \text{Eq. 3-63}$$

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

$$\text{diff}(\varepsilon_i) = \varepsilon_{i+1} - \varepsilon_i$$

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

$$b = \min(0.25 \cdot N, 0.5) \qquad \text{Eq. 3-64}$$

This step limits the smoothing value to be between 0 and 0.5 regardless of maximum fluctuation magnitude.

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 b value tends to reject high-frequency fluctuations more effectively than smoothing once with a higher b 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.

After the bank angles are interpolated back from the smoothed and filtered equally spaced samples to the original path points, the final step is to limit bank angle values. If a bank angle has a magnitude less than 1 degree, it is set to zero degrees. If a bank angle exceeds a limit (+/– 30 degrees), it is set to the limit value. Large bank angles may indicate a flight path with unrealistic combinations of turn radii and airspeed. If the flight path uses a points-type track, fluctuations in the track data may result in unrealistically fluctuating turning radii and extreme bank angle fluctuations. If the smoothing and filtering process fails to eliminate such fluctuations, users may improve their results by replacing the points-type track with a vector track. Turning radii in vector tracks are specified by the user, therefore all fluctuation can be removed.

3.6.2.4.2 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.

3.6.2.4.2.1 Common Elements

Regardless of operation type, the adjustment begins by calculating, for each segment, the drag to lift ratio and acceleration. Acceleration follows from initial and final segment speed along with segment length, according to uniform acceleration. Drag to lift ratio (dimensionless) comes from the force balance:

$$R_f = \frac{\left(\frac{F}{W} - \frac{a}{g} - \sin\gamma_A\right)}{\cos\gamma_A} \qquad \text{Eq. 3-65}$$

where

F	total net thrust (lbf);
W	aircraft weight (lbf);
a	acceleration along the flight path (ft/s^2);
g	gravitational acceleration of Earth (ft/s^2); and
γ_A	climb angle in the still-air frame of reference.

3.6.2.4.2.2 Approach

To account for the effects of bank angle on approach flight paths, AEDT 2a increases thrust so that forces (thrust, drag, lift, and weight) are still in balance with banking effects in place. The initial thrust for each flight path segment F_n/d_1 is recalculated using the following force balance equation:

$$F = \left(\frac{a}{g} + \frac{R_f}{\cos(\varepsilon)}\cos\gamma_A + \sin\gamma_A\right)W \qquad \text{Eq. 3-66}$$

where

R_f	drag to lift ratio (dimensionless); and
ε	bank angle.

3.6.2.4.2.3 Departure

To account for the effects of bank angle on departure flight paths, AEDT 2a reduces the climb angle and speed in order to balance the forces. Thrust and acceleration are not altered. Note that the reduced speed results in a reduced bank angle because bank is a function of speed, so it is recalculated. The climb angle with banking effects is calculated by solving:

$$R_f \cdot \frac{\cos\gamma_2}{\cos\varepsilon_1} + \sin\gamma_2 = R_f \cdot \cos\gamma_1 + \sin\gamma_1 \qquad \text{Eq. 3-67}$$

where

ε_1	aircraft bank angle at start of segment after smoothing and filtering;
γ_1	climb angle without banking effects; and
γ_2	climb angle with banking effects.

The new segment length L_{new} (ft) is calculated as follows:

$$L_{new} = L\frac{\cos\gamma_1}{\cos\gamma_2} \quad \text{Eq. 3-68}$$

where

L length (ft) without banking effects.

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

$$v_2^2 - v_1^2 = 2aL_{new} \quad \text{Eq. 3-69}$$

where

a aircraft acceleration along the velocity vector (ft/s^2);
v_1 aircraft true airspeed at start of vector (ft/s); and
v_2 aircraft true airspeed at end of vector (ft/s).

The vector speed along the horizontal plane v_g (ft/s) is then:

$$v_g = \frac{v_1 + v_2}{2}\cos\gamma_2 \quad \text{Eq. 3-70}$$

The segment speed can be used with Eq. 3-12 to calculate a new bank angle at the end of the segment, ε_2.

3.6.3 Trajectory Extension

The extension portions of profile-driven trajectories represent the performance of an aircraft between the airborne ends of explicit trajectories and study boundaries when the study boundary is invoked in processing. AEDT 2a processes these extensions one step at a time, starting at the explicit trajectory and ending at the study boundary. Thus, for extensions that describe flight from where the aircraft first enters the boundary to where an explicit approach or over-flight begins, the steps are processed in reverse temporal order.

3.6.3.1 Airplane Extension

Almost all extensions to profile-driven airplane performance are done according to the BADA performance model. For departures, the procedure consists of a climb out phase to cruise altitude, if necessary, followed by a level cruise phase to the boundary exit. For approach operations, the procedure ends with a descent phase from cruise altitude, preceded by a level cruise phase. For overflights, there are level cruise extensions to the boundary at both ends.

The following section introduces the BADA performance model with a discussion of its general philosophy and elements used throughout. This is followed by a description of how these elements are put to use for operational performance calculations.

3.6.3.1.1 BADA general discussion

This Section begins with an overview of the BADA performance model. This is followed by introductions to the fundamental elements of the BADA performance model.

3.6.3.1.1.1 Overview

BADA does not specify the overall structure of a flight (it could consist of any number of climb, cruise, and descent phases, arranged in any order). Instead, BADA provides performance calculation rules and modeling coefficients for each phase. For each phase type, a speed schedule is specified as a sequence of calibrated airspeeds with corresponding altitudes. Scheduled speeds increase with altitude. The maximum Mach number is also provided for each phase type. For the BADA weather model, each phase has a “Mach transition altitude” above which the maximum scheduled CAS is always limited by the maximum Mach number. BADA performance for a phase consists of any number (zero or greater) of constant-CAS steps below the Mach transition altitude, constant-Mach steps above Mach transition, and acceleration/deceleration steps.

Acceleration and deceleration steps below Mach transition serve to change CAS, whereas steps above Mach transition serve to change the Mach number. Since AEDT 2a uses the BADA model primarily for en-route phases of flight, only the CAS scheduled for the en-route phase is used. Transitions between scheduled CAS values are therefore not encountered. Acceleration/deceleration steps are only performed to transition between two BADA phases, or between a BADA phase and the Doc 29 model.

3.6.3.1.2 Mach Transition Altitude

Mach transition altitude for a phase is calculated for a given CAS and Mach number by the equation:

$$h_M = \left[1 - \left(\frac{\left[1 + \left(\frac{\gamma - 1}{2}\right)\left(\frac{V}{V_{S_{SL_{ISA}}}}\right)^2\right]^{\frac{\gamma}{\gamma-1}} - 1}{\left[1 + \frac{\gamma - 1}{2} M^2\right]^{\frac{\gamma}{\gamma-1}} - 1}\right)^{\frac{\alpha_{ISA} R}{g}}\right] \frac{T_{SL}}{\alpha_{ISA}} \qquad \text{Eq. 3-71}$$

where

γ	isentropic expansion coefficient for air 1.4 (dimensionless);
R	real gas constant for air $287.04\, m^2/K\,/s^2$;
V	calibrated airspeed (kt);
$V_{S_{SL_{ISA}}}$	atmospheric speed of sound at sea level in an ISA (kt);
M	aircraft Mach number (dimensionless);
α_{ISA}	ISA temperature lapse rate 0.0065 (K/m);
g	gravitational acceleration of Earth (m/s^2); and
T_{SL}	atmospheric temperature at sea level (K).

The tropopause altitude h_t (m) is calculated from:

$$h_t = h_{t_{ISA}} + \frac{\Delta T_{ISA_{SL}}}{\alpha_{ISA}} \qquad \text{Eq. 3-72}$$

where

$h_{t_{ISA}}$	ISA tropoause altitude (m); and
$\Delta T_{ISA_{SL}}$	sea-level temperature deviation from ISA (K).

Note that AEDT 2a calculates the sea-level temperature T_{SL} (K) by sampling the temperature at the associated airport and lapsing to sea-level:

$$T_{SL} = T_{airport} + \alpha_{ISA} h_{airport} \qquad \text{Eq. 3-73}$$

where

$h_{airport}$ airport elevation (m); and
$T_{airport}$ atmospheric temperature at the airport elevation (K).

The temperature deviation from ISA follows directly as discussed in Section 3.3.1.2.

Also note that the calculation of Mach transition altitude is based on a lapsed weather model, similar to those discussed in Section 3.3.2.1. Because of this simplification, the actual weather at Mach transition can differ from the assumed weather if high-fidelity weather module is in use. As a result of this, there can be a discontinuity of several knots in the speed profile at the Mach transition.

3.6.3.1.2.1 BADA Energy Share

BADA makes use of an energy share factor when climbing or descending. The energy share factor is used to dictate how much of the available thrust is used towards climbing or descending and how much is used for forward thrust. The energy share is determined by the altitude regime currently being modeled. Using constant CAS, below the Mach transition altitude and below the tropopause the energy share, $f\{M\}$, is calculated via:

$$f\{M\} = \left\{1 + \frac{\gamma \cdot R \cdot k_T}{2 \cdot g} \cdot M^2 + \left(1 + \frac{\gamma - 1}{2} \cdot M^2\right)^{\frac{-1}{\gamma-1}} \left\{\left(1 + \frac{\gamma - 1}{2} \cdot M^2\right)^{\frac{\gamma}{\gamma-1}} - 1\right\}\right\}^{-1} \qquad \text{Eq. 3-74}$$

where

k_T ISA temperature gradient with altitude, -0.0065 °K/m

When above the tropopause, but below the Mach transition altitude, and using constant CAS, a different equation is used, as follows.

$$f\{M\} = \left\{1 + \left(1 + \frac{\gamma - 1}{2} \cdot M^2\right)^{\frac{-1}{\gamma-1}} \left[\left(1 + \frac{\gamma - 1}{2} \cdot M^2\right)^{\frac{\gamma}{\gamma-1}} - 1\right]\right\}^{-1} \qquad \text{Eq. 3-75}$$

When below the tropopause at constant Mach, the equation below is used.

$$f\{M\} = \left[1 + \frac{\gamma \cdot R \cdot k_T}{2 \cdot g} M^2\right]^{-1} \qquad \text{Eq. 3-76}$$

Constant Mach above the tropopause uses the following equation:

$$f\{M\} = 1.0 \qquad \text{Eq. 3-77}$$

Finally, in cases where neither constant CAS nor constant Mach is used, the energy share factors are given by the following:

Acceleration in climb f{M} = 0.3
Deceleration in descent f{M} = 0.3
Deceleration in climb f{M} = 1.7
Acceleration in descent f{M} = 1.7

3.6.3.1.3 Drag

Drag D (N) is calculated from:

$$D = \left[C_{D0,CR} + C_{D2,CR} \left(\frac{mg}{\frac{1}{2}\rho V_T^2 S} \right)^2 \right] \frac{1}{2}\rho V_T^2 S \quad \text{Eq. 3-78}$$

where

$C_{D0,CR}$ parasitic drag coefficient in cruise configuration (dimensionless);
$C_{D2,CR}$ induced drag coefficient in cruise configuration (dimensionless);
S reference wing surface area (m^2);
m aircraft mass (kg);
ρ atmospheric density (kg/m^3); and
V_T aircraft true airspeed (m/s).

3.6.3.1.4 Thrust

With enough information, thrust can be calculated through an energy balance:

$$F = m\left(\frac{g}{V_T}\frac{dh}{dt} + a\right) + D \quad \text{Eq. 3-79}$$

or

$$F = \left[\frac{m \cdot g}{f\{M\} \cdot V_T}\right] \cdot \frac{dh}{dt} + D \quad \text{Eq. 3-80}$$

where

F aircraft total net thrust (N);
D aircraft drag (N);
a aircraft acceleration (m/s^2);
$\frac{dh}{dt}$ aircraft climb rate (m/s); and
$f\{M\}$ energy share.

Maximum total net thrust during climb in an ISA is given by:

$$F_{m_{C_{ISA}}} = \begin{cases} C_{Tc1} \times \left(1 - \frac{h}{C_{Tc2}} + C_{Tc3} \times h^2\right) (\text{jet}) \\ C_{Tc1} \times \left(1 - \frac{h}{C_{Tc2}}\right) / V_T + C_{Tc3} (\text{turboprop}) \; F_{m_{C_{ISA}}} \\ C_{Tc1} \times \left(1 - \frac{h}{C_{Tc2}}\right) + \frac{C_{Tc3}}{V_T} (\text{piston}) \end{cases} = \begin{cases} C_{Tc1} \times \left(1 - \frac{h}{C_{Tc2}} + C_{Tc3} \times h^2\right) (\text{jet}) \\ C_{Tc1} \times \left(1 - \frac{h}{C_{Tc2}}\right) / V_T + C_{Tc3} (\text{turboprop}) \\ C_{Tc1} \times \left(1 - \frac{h}{C_{Tc2}}\right) + \frac{C_{Tc3}}{V_T} (\text{piston}) \end{cases} \quad \text{Eq. 3-81}$$

where

h	aircraft altitude above mean sea level (ft);
$C_{Tc,1}$	1st max climb thrust coefficient (N for jet or piston, kN for turboprop);
$C_{Tc,2}$	2nd max climb thrust coefficient (ft); and
$C_{Tc,3}$	3rd max climb thrust coefficient (ft^{-2} for jet, N for turboprop, kN for piston).

The maximum total net thrust during climb F_{m_C} (N) for all weather contexts is given by:

$$F_{m_C} = \left(1 - C_{Tc5} \Delta T_{ISA_{eff}}\right) F_{m_{C_{ISA}}} \quad \text{Eq. 3-82}$$

with

$$\Delta T_{ISA_{eff}} = \Delta T_{ISA} - C_{Tc,4} \quad \text{Eq. 3-83}$$

and the limitations that

$$0.0 \leq C_{Tc5} \cdot \Delta T_{ISA_{eff}} \leq 0.4 \quad \text{Eq. 3-84}$$

and

$$C_{Tc5} \geq 0.0 \quad \text{Eq. 3-85}$$

where

ΔT_{ISA}	atmospheric temperature deviation from ISA (K);
$C_{Tc,4}$	1st thrust temperature coefficient (K); and
$C_{Tc,5}$	2nd thrust temperature coefficient (K^{-1}).

The standard reduced total climb thrust F_{r_C} (N) is:

$$F_{r_C} = D + \left(F_{m_C} - D\right)\left(1 - C_{red} \cdot \frac{m_{max} - m}{m_{max} - m_{min}}\right) \quad \text{Eq. 3-86}$$

where

m_{max}	aircraft's maximum mass (kg);
m_{min}	aircraft's minimum mass (kg);
C_{red}	reduction coefficient (dimensionless) determined by the BADA aircraft engine type:

$$C_{red} = \begin{cases} 0.15 (\text{jet}) \\ 0.25 (\text{turboprop}) \\ 0.0 (\text{piston}) \end{cases}$$

The maximum total net thrust during cruise F_{m_V} (N) is:

$$F_{m_V} = C_{Tcr} F_{m_C} \qquad \text{Eq. 3-87}$$

where

F_{m_C}	aircraft maximum total net thrust in climb (N) and
C_{Tcr}	maximum cruise thrust coefficient 0.95 (dimensionless).

The standard total net thrust during descent F_{m_D} (N) is:

$$F_{m_D} = \begin{cases} C_{T_{D_{hi}}} F_{m_C} (h > h_{des}) \\ C_{T_{D_{lo}}} F_{m_C} (h \leq h_{des}) \end{cases} \qquad \text{Eq. 3-88}$$

where

$C_{T_{D_{lo}}}$	low altitude descent thrust coefficient (dimensionless);
$C_{T_{D_{hi}}}$	high altitude descent thrust coefficient (dimensionless); and
h_{des}	transition altitude for calculation of descent thrust (ft).

3.6.3.1.5 Speed and Altitude Limits

The maximum altitude achievable by the aircraft h_m (ft) is given by:

$$h_m = \min\left[h_{MO}, h_{max_0} + \left(\Delta T_{ISA} - C_{Tc,4}\right) G_t + (m_{max} - m) G_w\right] \qquad \text{Eq. 3-89}$$

where

h_{max_0}	maximum altitude at MTOW under ISA conditions for maximum mass (allowing residual 300fpm ROC) (ft);
h_{MO}	maximum operational height above sea level (ft);
G_w	mass gradient on maximum altitude (ft/kg);
G_t	temperature gradient on maximum altitude (ft/K);
m_{max}	maximum mass (kg);
$C_{Tc,4}$	1st thrust temperature coefficient (K);
m	aircraft mass (kg); and
ΔT_{ISA}	atmospheric temperature deviation from ISA (K).

The minimum calibrated airspeed in cruise $V_{min_{CR}}$ (kt) is calculated from:

$$V_{min_{CR}} = C_{Vmin} \cdot V_{stall_{CR}} \qquad \text{Eq. 3-90}$$

where

$C_{V\,min}$	minimum speed coefficient in non-take-off configuration (dimensionless); and
$V_{stall_{CR}}$	aircraft's stall speed in cruise configuration (kt).

3.6.3.1.6 True Airspeed, Calibrated Airspeed and Mach Number

In the context of BADA, true airspeed V_T (m/s) is related to a given calibrated airspeed according to:

$$V_T = \sqrt{\frac{2}{\mu} \cdot \frac{P}{\rho} \left\{ \left(1 + \frac{P_{0_{ISA}}}{P} \cdot \left[\left(1 + \frac{\mu}{2} \cdot \frac{\rho_{0_{ISA}}}{P_{0_{ISA}}} \cdot V^2 \right)^{1/\mu} - 1 \right] \right)^{\mu} - 1 \right\}} \quad \text{Eq. 3-91}$$

where

ρ	atmospheric density (kg/m^3);
P	atmospheric pressure (N/m^2);
$P_{0_{ISA}}$	ISA sea-level pressure (N/m^2);
$\rho_{0_{ISA}}$	ISA sea-level density (kg/m^3);
V	aircraft calibrated airspeed (m/s); and
μ	ratio of gas constant to specific heat at constant pressure (dimensionless):

$$\mu = \frac{\gamma - 1}{\gamma}$$

where

γ Isentropic expansion coefficient for air, 1.4 (dimensionless).

Calibrated airspeed V (m/s) is therefore determined from true airspeed by:

$$V = \sqrt{\frac{2}{\mu} \cdot \frac{P_{0_{ISA}}}{\rho_{0_{ISA}}} \left\{ \left(1 + \frac{P}{P_{0_{ISA}}} \cdot \left[\left(1 + \frac{\mu}{2} \cdot \frac{\rho}{P} \cdot V_T^2 \right)^{1/\mu} - 1 \right] \right)^{\mu} - 1 \right\}} \quad \text{Eq. 3-92}$$

Mach number is related to true airspeed by:

$$V_T = M \cdot \sqrt{\gamma \cdot R \cdot T} \quad \text{Eq. 3-93}$$

where

V_T	aircraft true airspeed (m/s);
R	real gas constant for air $287.04\, m^2/K/s^2$;
T	atmospheric temperature (K); and
M	aircraft Mach number (dimensionless).

3.6.3.1.7 BADA Operational Calculations

Each climb-out phase consists of an acceleration to the speed schedule specified in BADA, if necessary, followed by a series of climbs at constant CAS or constant Mach number. Between the final explicit altitude and the cruise altitude, climb steps end and begin at each of the following altitudes:

- 10,000 ft AFE
- The Mach transition altitude (see Section 3.6.3.1.2)
- Every multiple of 1,000 ft above MSL.

Each descent phase consists of a deceleration from the speed schedule specified in BADA, if necessary, preceded by a series of descents at constant CAS or constant Mach number. Between the cruise altitude and the first explicit altitude, descent steps end and begin at the same altitudes enumerated above (note, however, that the Mach transition altitude is phase-specific).

Each cruise phase consists of a series of level steps connecting the latest calculated state to successive track nodes. If the altitude of the cruise phase is below 10,000 ft AFE, the steps are calculated according to the Doc 29 model as discussed in Section 3.6.2.1.4.10 with constant CAS. If the altitude of the cruise phase is above 10,000 ft AFE, a level cruise acceleration or deceleration step computes the change in speed to the BADA speed schedule, and the remaining level steps maintain that speed schedule.

The following Sections describe profile segment types, including constant-speed climb, accelerating climb, constant-speed descent, deceleration, and level cruise steps.

3.6.3.1.7.1 Constant-Speed Climb

The aircraft climbs at constant CAS (if below the Mach transition altitude) or Mach number (if above the Mach transition altitude) to a target altitude, using the BADA Total-Energy Model. The initial altitude, A_1, is equal to the final altitude from the previous segment and the final altitude is known. The initial and final speed values are set according to the scheduled speed. The initial thrust is set equal to the final thrust from the previous segment. The segment length S and final thrust T_2 are calculated.

The segment length S (ft) is calculated according to Eq. 3-36 with the average climb angle given by:

$$\gamma = \sin^{-1}\left(\frac{dh\ /\ dt}{\overline{V_T}}\right) \qquad \text{Eq. 3-94}$$

where

$dh\ /\ dt$ average climb rate (m/s) (see below);

$\overline{V_T}$ average true airspeed (m/s):

$$\overline{V_T} = \frac{1}{2}\cdot\left(V_{T_i} + V_{T_f}\right) \qquad \text{Eq. 3-95}$$

where

V_{T_i} initial true airspeed (m/s) calculated from the constant climb CAS using BADA equation 3.2-13 or the constant climb Mach number using BADA equation 3.2-17; and

V_{T_f} final true airspeed (m/s) calculated from the constant climb CAS using BADA equation 3.2-13 or the constant climb Mach number using BADA equation 3.2-17.

The average climb rate is calculated using the following equation based on BADA equation 3.1-4:

$$\frac{dh}{dt} = \left(\frac{(T_{mid} + D_{mid})\cdot\overline{V_T}\cdot C_{pow,red}}{m\cdot g}\right)\cdot f\{M\} \qquad \text{Eq. 3-96}$$

where

T_{mid} thrust (N) calculated at segment midpoint altitude A_{mid} using BADA equations 3.7-1 through 3.7-6;

A_{mid} segment midpoint altitude (ft):

$$A_{mid} = \frac{1}{2}\cdot(A_1 + A_2) \qquad \text{Eq. 3-97}$$

D_{mid} drag force (N) calculated at A_{mid} using BADA equations 3.6-1, 3.6-4 and 3.6-5,

$C_{pow,red}$ power reduction coefficient calculated using BADA equation 3.8-1;

m aircraft mass (kg);

g	gravitational acceleration of Earth (m/s^2); and
$f\{M\}$	energy share factor calculated using BADA equation 3.1-7 or 3.1-6, as appropriate, for altitude A_{mid}.

The final thrust T_2 (N) is calculated using the following equation:

$$T_2 = \left(T_{max,climb2} - D_2\right) \cdot C_{pow,red} + D_2 \qquad \text{Eq. 3-98}$$

where

$T_{max,climb2}$	maximum climb thrust (N) calculated at segment endpoint altitude A2 and segment endpoint true airspeed VT2 using BADA equations 3.7-1 through 3.7-6;
D_2	drag force (N) calculated at A2 using BADA equations 3.6-1, 3.6-4 and 3.6-5; and
$C_{pow,red}$	power reduction coefficient calculated using BADA equation 3.8-1.

3.6.3.1.7.2 Accelerating Climb from Doc 29 Speed

The initial altitude A_1, initial CAS, V_1, and initial thrust, $(F_n / \delta)_1$, are given from the end of the terminal departure profile. The final CAS V_2 is set equal to V_{cl_2}. Acceleration segments are forced to complete their acceleration before hitting a specified altitude. In this situation, the allowable change in altitude for the acceleration step, A_{limit}, is equal to the difference between the Mach transition altitude, h_{trans}, and A_1. This ensures that the final CAS V_{cl_2} will be reached prior to reaching the altitude h_{trans}. The final altitude A_2, final true airspeed V_{T_2}, final thrust $(F_n / \delta)_2$, and horizontal flying distance are calculated.

Final altitude, speed, thrust, and distance are calculated by using an iterative method. An altitude 100 ft above the initial altitude 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 tenth of a ft.

The horizontal distance S (ft) is calculated using the following equation based on SAE-AIR-1845[14] equation (A10):

$$S = \frac{0.95 \cdot k \cdot ({v_{T1}}^2 - {v_{T2}}^2)}{a} \qquad \text{Eq. 3-99}$$

where

S	current iteration horizontal distance (ft);
k	constant ½(101.2686 / 60)^2 / 32.17 (ft/kt2);
v_{T1}	initial true airspeed (kt) calculated from Vc1 using BADA equation 3.2-13;
v_{T2}	final true airspeed (kt) calculated from Vc2 using BADA equation 3.2-13;
a	acceleration as a fraction of Earth's gravitational acceleration:

$$a = a_{max} \cdot (1 - f\{M\})$$

where

a_{max}	maximum acceleration available (as a fraction of Earth's gravitational acceleration) for current iteration:

$$a_{max} = \frac{\left(N \cdot \left(\frac{F_n}{\delta}\right)_{avg} - D_{avg}\right) \cdot C_{pow,red}}{\frac{W}{\delta_{avg}}}$$

where

N	number of engines;
D_{avg}	drag (lbf) at average segment altitude A_{avg} = ½ * (A1 + A2) calculated using BADA equations 3.6-1, 3.6-4, and 3.6-5;
$\frac{W}{\delta_{avg}}$	corrected aircraft weight (lbf);
δ_{avg}	pressure ratio at altitude A_{avg}; and
$\left(\frac{F_n}{\delta}\right)_{avg}$	average corrected net thrust (lbf):

$$\left(\frac{F_n}{\delta}\right)_{avg} = \frac{1}{2} \cdot \left(\left(\frac{F_n}{\delta}\right)_1 + \left(\frac{F_n}{\delta}\right)_2\right)$$

where

$\left(\frac{F_n}{\delta}\right)_1$	input initial corrected net thrust (lbf);
$\left(\frac{F_n}{\delta}\right)_2$	final corrected net thrust (lbf):

$$\left(\frac{F_n}{\delta}\right)_2 = \frac{T_{\max climb2}}{\delta_2}$$

where

$T_{\max climb2}$	maximum climb thrust (lbf) at altitude A2 calculated using BADA equations 3.7-1 through 3.7-6; and
δ_2	pressure ratio at altitude A2.

The next iteration final altitude $A_2{}'$ is calculated using the following equation based on SAE-AIR-1845[14] equation (A11):

$$A_2{}' = A_1 + \frac{S \cdot G}{0.95} \qquad \text{Eq. 3-100}$$

where

S	current iteration horizontal distance (ft); and
G	climb gradient for the current iteration: $G = a_{max} - a$

If the final altitude, A_2, is calculated to be greater than A_1 by more than A_{limit}, the BADA energy share factor f{M} is set equal to zero so that all available thrust is used for acceleration and the iterative method is repeated. If the aircraft is incapable of completing the desired acceleration while also climbing using the BADA-defined energy share factor within the allowable altitude range, the aircraft is forced to achieve the desired acceleration over an overflight segment.

3.6.3.1.7.3 Constant-Speed Descent

The aircraft first descends at constant Mach (if above Mach transition altitude) or constant CAS (if below Mach transition altitude) to a target altitude. Constant Mach descent steps are calculated using the BADA Total Energy Model using a method similar to the one described in Section 3.6.3.1.2.1 for constant speed climb steps. The only differences between the climb and descent calculations are that thrusts are calculated in descent configuration as discussed in Section 3.6.3.1.4.

3.6.3.1.7.4 Deceleration to Doc 29 Schedule

The final speed for en-route descent profiles must match the initial CAS from the terminal approach profile. A deceleration segment is calculated from the BADA en-route CAS to the initial terminal-area approach profile CAS.

The process for calculating en-route deceleration steps is similar to the method used to calculate en-route acceleration segments, described above in Section 3.6.3.1.7.2. The only differences in the case of deceleration are that all thrusts are calculated in descent configuration as discussed in Section 3.6.3.1.4, and that a_{max} is calculated without the use of the BADA power reduction coefficient as follows (recall that a_{max} is the maximum possible acceleration, as a fraction of Earth's gravitational acceleration, that would result from level flight, not the actual acceleration that the aircraft will undergo):

$$a_{max} = \frac{\left(N \cdot \left(\frac{F_n}{\delta}\right)_{avg} - D_{avg}\right)}{\frac{W}{\delta_{avg}}} \qquad \text{Eq. 3-101}$$

where

$(F_n/\delta)_{avg}$	step average corrected net thrust per engine (lbf);
D_{avg}	step nominal drag (lbf);
W	aircraft weight (lbf); and
δ_{avg}	pressure ratio at step average altitude.

As with acceleration segments, deceleration segments are forced to complete their deceleration before reaching a specified altitude. In this situation, the allowable change in altitude for the deceleration step, A_{limit}, is equal to the difference between 10,000 ft AFE and the initial altitude defined for the terminal approach profile. It is possible that the terminal approach profile's initial altitude is 10,000 ft AFE and therefore, A_{limit}, is equal to zero.

If the deceleration segment's final altitude, A_2, is calculated to be less than its initial altitude, A_1 by more than A_{limit}, the BADA energy share factor, f{M}, is set equal to zero and the iterative method is repeated. If the aircraft is incapable of completing the desired deceleration while also descending using the BADA-defined energy share factor within the allowable altitude range, the aircraft is forced to achieve the desired deceleration over an overflight segment.

3.6.3.1.7.5 Level Cruise Step

Level cruise acceleration steps adopt their initial geographic location, altitude, speed, and thrust from the latest calculated state. The final altitude is set equal to the initial altitude. The final true airspeed, thrust, and drag are calculated according the aircraft's cruise speed schedule, using Eq. 3-78, Eq. 3-87, Eq. 3-91, and Eq. 3-93. The segment duration is then calculated from the following equation:

$$\Delta t = \frac{V_{T_f} - V_{T_i}}{\bar{F} - D} m \qquad \text{Eq. 3-102}$$

were

V_{T_f}	aircraft final true airspeed (speed in the still-air frame of reference) (m/s);

V_{T_i} aircraft initial true airspeed (speed in the still-air frame of reference) (m/s);
m aircraft mass (kg);
F aircraft total net thrust (N); and
D aircraft drag (N).

The segment length comes from the following equation:

$$\Delta s = \frac{1}{2}\frac{V_{T_f}^2 - V_{T_i}^2}{\bar{F} - D} m \qquad \text{Eq. 3-103}$$

Level cruise deceleration is calculated in the same way, except that the final point is known and the initial points are computed. Level steps at scheduled speed are calculated in the same way as acceleration or deceleration steps, except that the segment length is a known quantity, and segment duration is computed accordingly. The duration is calculated by the following formula:

$$\Delta t = \frac{\Delta s}{\overline{\overline{V_T}}} \qquad \text{Eq. 3-104}$$

3.6.3.2 Helicopter Extensions

Extensions for helicopter trajectories are simpler than for airplanes. The state at the airborne ends of the explicit helicopter trajectories are extended to the boundary without changes in speed or altitude. Only cumulative distance and time are adjusted to reflect their advancement.

3.7 Trajectory-Driven Flight Performance

Trajectory based flight performance is a subsection of aircraft performance in AEDT 2a that allows for deviation from standard AEDT profiles and allows for much more freedom in choosing how an aircraft should fly. It is particularly useful for modeling situations where standard profiles do not accurately represent actual routes taken by aircraft. By defining points along the trajectory that the aircraft must pass through, operations can be modeled to fly more meaningful routes.

AEDT 2a uses two models to simulate trajectory-based flight performance: SAE-AIR-1845 and the Base of Aircraft Data (BADA). SAE-AIR-1845 is used to model performance under 10,000 ft AFE and BADA is used above that altitude, with a few exceptions regarding overflight operations. Each follows different methodologies which are detailed in below (see Section 3.7.1.3 for SAE-AIR-1845 and 3.7.1.4 for BADA).

3.7.1 Altitude Controls

Altitude control codes are one of the primary ways AEDT 2a is capable of modeling trajectory-based flight performance. Altitude controls allow for specification of precise 3-dimensional trajectory points to be reached along the route. Control codes are attached to geographic latitude/longitude points at the beginning of each track segment along the track and are associated with an altitude. Null controls function as if no controls are present for the track segment to which they are attached. Non-null control codes do not have to be present at every track segment for valid codes to be followed. Note that, although the ASIF input schema supports associating a speed with a track node in the same way that control altitudes are associated, these speeds do not affect performance calculations.

Three different non-null controls are available. They are:

a. *At* controls require the route to hit a specific altitude at a specific latitude/longitude point exactly.
b. *AtOrBelow* controls specify that the route must be at an altitude equal to or less than the altitude specified in the altitude control.
c. *AtOrAbove* controls specify that the route must be at an altitude equal to or greater than the altitude specified in the altitude control.

Additional notes about altitude control codes include:

a. Control codes placed below 500 ft AFE are ignored by AEDT.
b. All tracks using control codes must be assigned to aircraft whose profiles are defined as procedure steps. Tracks that violate this generate an error.
c. Overflight tracks containing level flight events must have a minimum of two altitude controls above 500 ft AFE. Tracks that do not comply generate errors.
d. Approach tracks containing approach operations cannot have sequentially ascending altitude control codes.
e. Departure tracks containing departure operations cannot have sequentially descending altitude control codes.
f. Altitude control codes have a 300 ft altitude tolerance. If a route is able to meet the control within 300 ft, no error is generated, and the route is processed.
g. Altitude controls of type AtOrBelow are treated as though their target altitude is the lesser of their given target altitude and the aircraft's maximum BADA operating altitude.

Control codes which cannot be met within tolerance generate an error; the operation being modeled fails and is noted in an error log.

3.7.1.1 Track Extensions

When the option to truncate or extend tracks is activated, aircraft tracks are extended in a straight line in the same direction as the last track segment of the original, unaltered track to the study boundary, except in the case where no study boundary is present. Tracks are extended and subsequently modeled, before being truncated at the study boundary. The extension begins at the track point furthest from the arrival airport for approach operations and from the departure airport for departure operations. For overflights, tracks are extended in both directions of the original airport track. Aircraft tracks are extended a minimum of 1000 nmi. Extensions can be longer than 1000 nmi, but 1000 nmi is the baseline minimum extension for modeling. Post modeling, track segments are truncated to intersect the study boundary. Portions of the track modeled outside the study boundary are discarded once the performance trajectory is known.

In order to properly model trajectory-based flight performance, an altitude control is added at the end of the extended track. The altitude for this altitude control depends on the type of operation being modeled, as described below.

- Cruise altitude vs. last original altitude control – Each aircraft type has a default cruise altitude value. These altitudes serve as the altitude at which a specific aircraft will level off, unless directed otherwise by altitude controls. Cruise altitudes are user-configurable and reside in the AEDT 2a Fleet database.

- Approaches – Approach operations add an altitude control at the end of the extended track at either the aircraft's cruise altitude or the highest altitude control in the original, unaltered track. The higher value is used for the added altitude control.
- Departures – Departure operations, like approach operations, also add the higher value of either the cruise altitude or the highest original altitude control altitude.
- Overflights – Overflight operations do not examine an aircraft's cruise altitude, and simply extend track segments level with the first and last altitude controls onto the beginning and end of the track, respectively.

3.7.1.2 Trajectory Output

AEDT 2a trajectory-driven performance modeling based on altitude controls calculates a fixed profile point profile that describes the route taken by the aircraft. The profile consists of a list of fixed points that contain the following:

- Altitude – the altitude of the current point.
- Distance – the distance traveled along the track to reach the current point.
- Speed – the aircraft's true airspeed at the current point. This differs from ground speed by the magnitude of the headwind.
- Thrust – the amount of corrected net thrust per engine used at the current point. Used with units of pounds, percent, or other, and is dependent on aircraft type.
- Operation Mode – a sub-categorization of the phase of flight being modeled.

The profile and track are then processed as described in Section 3.6 to generate the full performance result.

3.7.1.3 SAE 1845 Implementation

SAE-AIR-1845 calculates aircraft performance using a series of procedure steps based on simplified aerodynamic and thrust equations. Each procedure step is of a specific type and has specific input parameters. Ordered lists of these steps are known as procedural profiles. Procedural profiles are required if altitude controls are present on the track, and can be of three operational types: approach, departure, or overflight. When altitude controls are introduced in a standard profile, the aircraft's trajectory is forced to either deviate from the standard profile, or extend beyond it, creating a custom profile.

Trajectory-based flight performance requires specific data input, some of which may not be required for other types of performance modeling. Some of these inputs can be validated before modeling begins. Approach procedural profiles must have an associated arrival airport and runway end. Departure procedural profiles must also have an associated departure airport and runway end. If a runway end is not associated with the operation, a default runway end is created at the location of the associated airport.

Modeling a procedure step requires specific inputs and calculations. Common to all procedure steps is retrieval of headwind information. Specifically, headwind is found by finding the heading of the current track segment and taking the projection of the headwind. The heading of the current track segment is found by converting the latitude and longitude of the endpoints of the track segment into a planar X-Y coordinate system via a geographic projection system. The X-Y coordinate system has its origin at the start point of the track segment, so finding the unit vector of the track segment is done by normalizing the X and Y components of the segment end point. That unit vector is then multiplied by the magnitude and vector of the headwind, resulting in the projection of the headwind vector onto the track segment vector.

In a few cases with trajectory-based performance, additional derivative steps are used. Specifically, decelerate, descend, and land steps may be calculated in reverse. These steps exist as their own step types: reverse decelerate, reverse descend, and reverse land, respectively. However, these steps mimic the calculations of their forward-moving counterparts exactly, excepting the reversal of direction. Reverse procedure steps are used on approach profiles only.

3.7.1.3.1 SAE 1845 Modeling Process

The process by which profile point trajectories may be calculated from a list of procedure steps, except for specific step calculations, is detailed below.

Procedure steps must be in the order in which they are to be modeled. Departure and overflight operation procedure steps are already in the appropriate order, but AEDT 2a reverses the list of procedure steps internally for approach operations. AEDT 2a models approach operations in reverse, from the ground up to cruising altitude.

AEDT 2a creates a list of target points, each with a distance and altitude. The target points correspond to the beginning of each track segment, and their distances are calculated by summing up the lengths of all preceding track segments. For each track segment, the following equation is used:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad \text{Eq. 3-105}$$

where

- D distance of the track segment (m);
- X_1 X coordinate of the track segment start (m);
- X_2 X coordinate of the track segment end (m);
- Y_1 Y coordinate of the track segment start (m); and
- Y_2 Y coordinate of the track segment end (m).

Note that the distances accumulated for target points are further modified to account for displaced thresholds and crossing heights as described in Section 3.6.2.1.3.

Altitudes of target points are determined by the presence of altitude controls on the track segments. Target points corresponding to track segments with altitude controls are assigned the altitude control's altitude. If the segment has a null altitude control, an altitude is not assigned.
The list of target points for approach operations is reversed because profile distances become magnitude of distance to the runway end from the current point, and as a result, approaches are modeled with negative distances that increase as they approach the runway end.

The approach list of target points is then modified by adding the sum of the ground roll distance, the runway offset, and the runway displacement to the distance of target points.

Next, mandatory procedure steps are calculated. For overflights, this consists of making a level step for the first target point. For approach and departure, takeoff, decelerate (ground roll), and land procedure steps are mandatory steps and are modeled.

Custom procedure steps encompass everything not calculated in the mandatory procedure step modeling phase. This includes standard profile steps on a standard profile. AEDT 2a follows the standard procedures for the aircraft used in the current operation until altitude controls require the aircraft to break away from those procedures. Once the aircraft state has been set to break away, AEDT 2a is capable of inserting, splitting, modifying or substituting procedure steps to reach the next altitude control. This process of using non-standard procedures is used to model the remainder of the operation once the aircraft has left the standard procedure and is described in the steps below. The number of procedure steps and the number of target points are not required to have a one-to-one correspondence, so it is possible that several procedure steps of varying type will be required to meet the next target point.

1. While there are target points remaining to be processed, AEDT 2a does the following:
    a. Checks if the next target point can be reached from the current position. This is done by comparing the target's associated distance against the distance of the calculated last profile point and by checking that the climb or descent angle to the next target's altitude is an acceptable value.
        i. If yes, then go to step 1.b.
        ii. If no, then go to step 1.c.
    b. Checks if the next target's altitude is within 300 ft and distance is within 250 ft of where the previous procedure step ended.
        i. If yes, then updates the target point index, and proceeds to 2.
        ii. If no, then saves the current state and proceeds to 2.
    c. Checks if the last saved state can be restored.
        i. If no, then logs an error.
        ii. If yes, then proceeds to step 2.
2. Checks if the aircraft has broken away from the standard profile or if all the standard procedure steps have been used.
    a. If yes to either condition, then proceeds to 2.c.
    b. If no, to both conditions, then proceeds to 3.
    c. Checks if a procedure step can be added that will reach the next target. This is determined by first looking at the operation type. If the operation type is an approach, AEDT 2a proceeds to 2.c.i. If the operation type is a departure or overflight, AEDT 2a proceeds to 2.c.ii. If the operation type is not listed or if a climb or descent step cannot be added, AEDT 2a proceeds to 2.c.iii.
        i. AEDT 2a checks if the difference in altitude between the next target altitude and the end of the previous procedure step is greater than 300 ft and if the difference in distance between the next target distance and the end of the previous procedure step is within 250 ft.
            1. If yes, then adds a descend step ending at the next target altitude with the greater of the calibrated airspeeds at the current and next target altitudes. Proceeds to 2.d.
            2. If no, then proceeds to 2.c.iii.
        ii. Checks if the difference in altitude between the next target altitude and the end of the previous procedure step is greater than 300 ft and if the difference in distance between next target distance and the end of the previous procedure step is within 250 ft.
            1. If yes and the differences are positive, then AEDT 2a adds a climb step ending at the next target altitude at the calibrated airspeed of the next target altitude. If the climb step fails due to insufficient thrust and the target control type allows the aircraft to fly below it, the climb is replaced by a level step. Proceeds to 2.d.
            2. If yes and the differences are negative, then adds a descent step to the next target altitude at the calibrated airspeed of the next target altitude. Proceeds to 2.d.
            3. If no, then proceeds to 2.c.iii.
        iii. Adds a level procedure step to the procedure step list and updates the step indices. Proceeds to 2.d.
    d. Computes difference in distance between next target point and distance reached with proposed procedure step. Then, AEDT 2a checks if the difference is less than 250 ft.
        i. If yes, then updates the target point index and proceeds to 1.
        ii. If no, then proceeds to 1.

3. While there are still more procedure steps to be processed, AEDT 2a does the following:
    a. If the aircraft has broken away from the standard profile and is attempting to use remaining accelerate steps and the procedure step is not an acceleration step, it is a condition known as AlmostAway. This procedure step is removed from the list and proceeds to the next step.
    b. Retrieves the first and last procedure points for the current procedure step.
    c. Processes the next procedure step.
    d. Checks if this procedure step goes beyond the next target point's distance.
        i. If yes, proceeds to 3.e.
        ii. If no, proceeds to 3.g.
    e. Computes the distance at which the aircraft passed the target point from the start of the procedure step and interpolates to find the altitude at that (crossing) point.
    f. Checks if the crossing altitude is within the parameters of the target point requirements, i.e. if the aircraft's altitude is within 300 ft of the target altitude when it reached the target point distance.
        i. If yes, then AEDT 2a checks if the crossing distance is within target point requirements, i.e. 250 ft.
            1. If yes, then the target is considered to be reached and its conditions satisfied. Proceeds to 3.f.iii.
            2. If no, then splits the current procedure step into two steps, both of the same type as the original step. With split steps, because the crossing height is within target point requirements, the first step will reach an acceptable altitude. This leaves the second step to resolve the discrepancy in distance. AEDT 2a proceeds to 3.f.iii.
        ii. If no, then adds a custom procedure step to reach the next target point. A custom procedure step is added by first examining the operation type. If the operation type is an approach, AEDT 2a proceeds to 3.f.ii.1. If the operation type is a departure or overflight, AEDT 2a proceeds to 3.f.ii.2. If the operation type is not listed, or if a climb or descend step cannot be added, AEDT 2a proceeds to 3.f.ii.3.
            1. Checks if the difference in altitude between the next target altitude and the end of the previous procedure step is greater than 300 ft and if the difference in distance between next target distance and the end of the previous procedure step is within 250 ft.
                a. If yes, then adds a descend step ending at the next target altitude with the greater of the calibrated airspeeds at the current and next target altitudes. Proceeds to 3.f.ii.4.
                b. If no, then proceeds to 3.f.ii.3.
            2. Checks if the difference in altitude between the next target altitude and the end of the previous procedure step is greater than 300 ft and if the difference in distance between next target distance and the end of the previous procedure step is within 250 ft.
                a. If yes and the differences are positive, then adds a climb step ending at the next target altitude at the calibrated airspeed of the next target altitude. Proceeds to 3.f.ii.4.
                b. If yes and the differences are negative, then adds a descent step to the next target altitude at the calibrated airspeed of the next target altitude. Proceeds to 3.f.ii.4.
                c. If no, then proceeds to 3.f.ii.3.

3. Adds a level procedure step to the procedure step list and updates the step indices. Proceeds to 3.f.ii.4.
4. If the current procedure step is not an accelerate step, deletes it from the list of remaining steps.
5. Sets the aircraft condition to be AlmostAway.
6. Sets the aircraft condition to broken away from the standard if the custom step operation mode is not the same as the profile operation type.
7. Proceeds to 3.f.iii.

iii. If the next target is reached, then updates to the next target point index.
iv. Proceeds to 1.

g. Is the next target reachable from the current procedure step?
   i. If no, then checks if the current procedure step can be modified to reach the target, and proceeds to 3.g.ii.1, or if a custom procedure step can be created to reach the target, proceeds to 3.g.ii.2.
      1. Checks to confirm that the current step does not start inside the target altitude window, and attempts to adjust its final altitude to match the target altitude.
         a. Checks if the step is one of the following step types: climb, descend, cruiseClimb, descendDecelerate, or descendIdle.
            i. If yes, proceeds to 3.g.i.1.b.
            ii. If no, proceeds to 3.g.i.2.
         b. Checks if the step starts within (but not at) the tolerance of the target altitude.
            i. If yes, proceeds to 3.g.i.1.c.
            ii. If no, proceeds to 3.g.i.2.
         c. Checks if the step starts below the target altitude.
            i. If yes, modifies the step, and proceeds to 3.
            ii. If no, proceeds to 3.g.i.2.
      2. Examines the operation type. If the operation type is an approach, AEDT 2a proceeds to 3.g.i.2.a. If the operation type is a departure or overflight, AEDT 2a proceeds to 3.g.i.2.b. If the operation type is not listed, or if a climb or descend step cannot be added, AEDT 2a proceeds to 3.g.i.2.c.
         a. Checks if the difference in altitude between the next target altitude and the end of the previous procedure step is greater than 300 ft and if the difference in distance between the next target distance and the end of the previous procedure step is within 250 ft.
            i. If yes, then adds a descend step ending at the next target altitude with the greater of the calibrated airspeeds at the current and next target altitudes. Proceeds to 3.g.i.2.d.
            ii. If no, then proceeds to 3.g.i.2.c.
         b. Checks if the difference in altitude between the next target altitude and the end of the previous procedure step is greater than 300 ft and if the difference in distance between the next target distance and the end of the previous procedure step is within 250 ft.
            i. If yes and the differences are positive, then adds a climb step ending at the next target altitude at the calibrated airspeed of the next target altitude. Proceeds to 3.g.i.2.d.

            ii. If yes and the differences are negative, then adds a descent step to the next target altitude at the calibrated airspeed of the next target altitude. Proceeds to 3.g.i.2.d.
            iii. If no, then proceeds to 3.g.i.2.c.
         c. Adds a level procedure step to the procedure step list and updates the step indices. Proceeds to 3.g.i.2.d.
         d. Computes the difference in distance between the next target point and distance reached within the proposed procedure step. Then checks if the difference is less than 250 ft.
            i. If yes, then updates the target point index and proceeds to 3.g.i.3.
            ii. If no, then proceeds to 3.g.i.3.
      3. Sets the aircraft condition to AlmostAway.
      4. AEDT 2a determines if the aircraft should leave the standard profile completely. To determine this, AEDT 2a does the following:
         a. Checks if the custom profile type is the same as the original profile type.
            i. If yes, then proceeds to 3.g.i.6.
            ii. If no, then proceeds to 3.g.i.5.
         b. Checks if the original profile mode is a departure and if the last procedure step type is descend, descendDecelerate, or descendIdle.
            i. If yes, then proceeds to 3.g.i.5.
            ii. If no, then proceeds to 3.g.i.6.
         c. Checks if the original profile mode is an approach and if the last procedure step type is climb, cruiseClimb, accelerate, or acceleratePercent.
            i. If yes, then proceeds to 3.g.i.5.
            ii. If no, then proceeds to 3.g.i.6.
      5. Sets the aircraft condition to broken away from the standard profile.
      6. Proceeds to 1.
   ii. If yes, then AEDT 2a determines if the aircraft has reached the target by checking if the end altitude and distance of the procedure step are within 300 ft and 250 ft of the target point's altitude and distance, respectively.
      1. If yes, then updates to the next target index.
      2. Proceeds to 1.
  h. Increments to the next procedure step.
  i. Proceeds to 3.
4. Removes any remaining procedure steps from the list.
5. Adjusts the thrust value for each level step if necessary.
  a. Checks if the step type is a level step.
     i. If yes, checks if the step is shorter than 1 nautical mile.
        1. If yes, checks if the step is the first or last step of the operation.
           a. If yes, proceeds to 5.a.i.4.
           b. If no, adjust the step's starting thrust value to match that of the end of the previous step (if the first step of the operation), or adjust the step's final thrust value to match that of the start of the next step (if the last step of the operation). Proceeds to 5.a.i.4.

2. If no, proceed to 5.a.i.4.
3. Proceed to the next procedure step. Go to 5.a.

ii. If no, proceed to the next procedure step. Go to 5.a.

Note that whenever AEDT detects that an aircraft cannot fly according to the SAE 1845 specification while satisfying the constraints of the altitude controls, it checks to see if the flight failure occurs outside of the terminal area. If so, it skips ahead to the post-processing phase of 1845 calculations (discussed in section 3.7.1.3.2) so that the calculations can be attempted according to the BADA performance specification (as discussed in section 3.7.1.4).

3.7.1.3.2 Post-Procedure Step Processing

After each target point has been met, all of the calculated procedure step points, which are just the start and end points of the procedure steps, are saved into a final profile. Because procedure steps have overlapping start/end points, points are duplicated, and duplicates that share the same distance, altitude, speed, and thrust are removed. Additionally, points that are less than 2,000 ft. apart are spread out by half of the distance that separated them initially. Altitude and speed are consequently interpolated to account for this shift in location.

The SAE-AIR-1845 model portion of AEDT 2a concludes by examining the altitudes of the final points calculated. If there are no procedure step points exactly at 10,000 ft, the model interpolates between the highest altitude under 10,000 ft. and the lowest above 10,000 ft, if such points exist. By doing this, the speed the aircraft travels at when crossing the 10,000 ft altitude level can be determined and saved for the transition to BADA, if it is needed. Finally, if any final points have an altitude higher than 10,000 ft., then AEDT 2a uses BADA to calculate the portion of the route above that altitude threshold.

3.7.1.4 BADA Implementation

BADA is used to simulate trajectories, or parts of trajectories, over 10,000 ft AFE. Trajectory points calculated with SAE 1845 that reside above 10,000 ft AFE are removed and recalculated with BADA.

Fundamentally, AEDT 2a uses BADA to model performance from one non-null altitude control to the next, regardless of the number of track segments in between those controls. As a result, AEDT 2a with BADA does not “plan ahead” for upcoming changes in altitude and has no mechanism to change previously calculated points, unlike the SAE-AIR-1845 portion of AEDT 2a which can adjust target points.

3.7.1.4.1 SAE 1845-BADA Transition

Bridging the transition between models smoothly requires several important steps. For approach and departure operations, the first step taken when transitioning to BADA is the removal of any points over 10,000 ft AFE from the list of calculated trajectory points. AEDT 2a goes through the following process to determine if a point should be deleted.

If the current point’s altitude is over 10,000 ft AFE, the next sequential point is examined. If the next sequential point’s altitude is also over 10,000 ft AFE or is equal to 10,000 ft AFE, the current point is removed and the process is repeated with the next sequential point taking the place of the current point. If the next sequential point is lower than 10,000 ft AFE, then a linear interpolation is performed between the current point’s and next point’s altitudes. This is done so that the proper track distance traveled at 10,000 ft. AFE may be calculated from the track distances of the current and next points. Like distance, thrust and speed are also interpolated from values at the current and next points. These calculated values are assigned to the current point, overwriting the existing values, and an altitude of 10,000 ft AFE is set at the current point. Thus, a transition point is set to begin BADA modeling.

3.7.1.4.2 En-Route Recalculation for Departure Operations

As discussed in section 3.7.1.4, the en-route portion of the trajectory calculated according to the SAE 1845 performance specification is discarded and replaced by a trajectory calculated according to the BADA specification. The calculation of the en-route portion of departures begins with determining what calibrated airspeed (CAS) and maximum Mach number should characterize the climbout phase. The climbout CAS is taken to be the larger of the aircraft's BADA en-route climbout CAS and the CAS at the SAE 1845-BADA transition point discussed in section 3.7.1.4.1. Likewise, the maximum Mach number is taken to be the larger of the aircraft's BADA en-route climbout maximum Mach number and the Mach number at the SAE 1845-BADA transition point.

Departure operations cannot have descending altitude control to altitude control steps, so AEDT 2a checks that all departure steps will be either climb or level steps. Recalculation of the en-route flight profile begins from the SAE 1845-BADA transition point and continues to each successive altitude control further along the track with an altitude greater than 10,000 ft. Each control constitutes a target altitude and distance, to be reached from the latest calculated state (distance, altitude, speed, thrust, etc.). For the performance calculations for each target, the headwind is fixed to its value at the latest calculated location and time, and the atmospheric thermodynamic profiles are fixed to the profiles at the latest calculated geographic coordinate and time. Under these conditions, a profile is calculated according to the BADA specification to the target distance, with adjustments made to energy share and thrust to come as close as possible to the target altitude. If the aircraft state at the target distance does not meet the constraint imposed by the altitude control, the flight fails and AEDT 2a issues a message accordingly.

The profile calculated to each target is comprised of one or more steps. The latest calculated state is compared to the en-route climb parameters to determine an appropriate step type and limiting values for clipping (by interpolation). If the latest CAS is less than the climbout CAS and the latest Mach number is less than the climbout maximum Mach number, a full BADA increasing-CAS climb step is calculated and clipped where it reaches the target distance and/or the maximum Mach number. If the latest CAS is not less than climbout CAS but the latest Mach number is less than the climbout maximum Mach number, a BADA constant-CAS step is calculated to the target distance and clipped where it reaches the maximum Mach number. The step evaluation and clipping provide a new latest calculated state, and the process is repeated until the latest state is at the target distance.

3.7.1.4.2.1 Full BADA Increasing-CAS Climb Step

In the case of increasing CAS during climb, the energy share is held at a constant value and a final CAS is targeted. With the final CAS constrained, the final true airspeed (TAS) is a function of the step height. The step height and final TAS are not directly calculable, but can be iteratively determined together by finding the root of the function:

$$F(h_f) = \frac{v_{T_f}^2(h_f) - v_{T_i}^2}{2g(h_f - h_i)} - \frac{1 - f\{M\}}{f\{M\}} \qquad \text{Eq. 3-106}$$

where

F	function whose root is the altitude where the target CAS is reached (dimensionless);
h_f	final altitude (m);
h_i	initial altitude (m);
$f\{M\}$	BADA standard climb energy share for increasing-CAS climb 0.3 (dimensionless);
g	Earth's gravitational acceleration (m/s^2);
v_{T_i}	initial true airspeed (m/s); and
v_{T_f}	final true airspeed (m/s).

This does not resolve the step length, however. The length of the step is related to the thrust through the climb angle equation Eq. 3-80. By solving this for step length the BADA maximum thrust setting at the final altitude, AEDT 2a determines the shortest step length (steepest climb angle and largest acceleration) supported there.

If the climb angle of the standard BADA increasing-CAS climb step exceeds the angle of a direct climb to the target, the angle could be reduced either by reducing thrust or by reducing energy share. Since it is not realistic to reduce thrust while attempting to accelerate, AEDT 2a calculates a reduced-angle increasing-CAS climb at full thrust, implicitly reducing the climb energy share below the standard value. With climb angle constrained, the geometry of the step is determined by iteratively finding the root of the function:

$$F(L) = \frac{T_m(L) - D(L)}{mg} - \sin\gamma - \frac{1}{g}\frac{\Delta v_T^2(L)}{2L} \qquad \text{Eq. 3-107}$$

where

F	function whose root is the step length where the target CAS is reached (dimensionless);
L	step length (m);
T_m	BADA maximum climb thrust (N);
D	BADA drag (N);
m	aircraft mass (kg);
g	Earth's gravitational acceleration (m/s^2);
γ	target climb angle (radians); and
Δv_T	final true airspeed (m/s).

3.7.1.4.2.2 Constant CAS or Constant Mach Climb

For constant-CAS and constant-Mach BADA climbs, a target altitude and target climb angle are provided, and one aspect of speed is held fixed. AEDT 2a begins by determining whether or not the target climb angle is supported at the target altitude by evaluating equation Eq. 3-80 for the climb angle using the target altitude and maximum climb thrust setting, using the appropriate energy share equation as discussed in section 3.6.3.1.2.1. If the climb angle supported by maximum thrust at the target altitude meets or exceeds the target climb angle, the target is reached, and equation Eq. 3-80 is evaluated for thrust using the target climb angle and altitude. If the target climb angle is not supported by the maximum thrust at the target altitude, the maximum achievable altitude is determined by iteratively finding the root of the function:

$$F(h_f) = \frac{\left(T_m(h_f) - D(h_f)\right)}{mg} f\{M\}(h_f) - \frac{(h_f - h_i)}{\sqrt{\Delta d^2 + (h_f - h_i)^2}}$$ Eq. 3-108

where

F	function whose root is the maximum achievable step height (dimensionless);
h_f	final altitude (m);
h_i	initial altitude (m);
T_m	BADA maximum climb thrust (N);
D	BADA drag (N);
m	aircraft mass (kg);
g	Earth's gravitational acceleration (m/s^2);
$f\{M\}$	BADA climb energy share for the given speed conditions; and
Δd	distance to target (m).

3.7.1.4.2.3 Departure Boundary Extensions

When the option to truncate or extend tracks is activated, AEDT 2a models all flights to the study boundary, unless no boundary is present within the study. A track extension is modeled, from the end of the original input track to either the study boundary or 1000 nmi, whichever is further away. If the study boundary is closer than 1000 nmi from the end of the original track, the excess track extension will be clipped post-modeling. For departure operations, if the cruise altitude is higher than the last altitude control on the un-extended track, then the aircraft will fly at max climb thrust until it reaches the cruise altitude. Upon reaching the cruise altitude, the aircraft will fly a level cruise step to the end of the track extension.

To climb at maximum thrust to cruise altitude over as much distance as needed, Eq. 3-80 must be rearranged. Its new form is:

$$\frac{dh}{dt} = \left[\frac{(F_{m_C} - D) \cdot V_T}{m \cdot g}\right] \cdot f\{M\}$$ Eq. 3-109

where

F_{m_C}	maximum climb thrust;
$dh\ /\ dt$	climb rate (m/s);
D	drag (N);
V_T	true airspeed;
m	aircraft mass (kg);
g	Earth gravitational acceleration (m/s^2); and
$f\{M\}$	energy share.

The track distance can then be calculated by:

$$d = \frac{(h_{cruise} - h_{start}) \cdot V_T}{\frac{dh}{dt}}$$ Eq. 3-110

where

d	track distance traveled during climb;
h_{cruise}	cruise altitude; and
h_{start}	starting altitude of climb.

If the climb to the cruise altitude crosses the Mach transition altitude, then the climb step will be split into two steps. The first step will use BADA CAS as the speed of the step and will travel from the step starting altitude to the Mach transition altitude. The second step will use BADA Mach as the speed of the step and will climb from the Mach transition altitude to the cruise altitude. Like other climbs, a fixed trajectory point is added to the final flight profile at the top of the climb.

Once the cruise altitude has been reached via a maximum thrust climb, a cruise step is modeled. Calculation details for cruise steps can be found in the Section 3.7.1.4.4.1.

3.7.1.4.3 Approach Operations

Approach operations cannot have ascending altitude control to altitude control steps, so AEDT 2a ensures that all steps will be either descend or level steps. Thus, AEDT 2a looks for the first altitude control with an altitude greater than 10,000 ft. Once it is determined which track segment to start modeling on, AEDT 2a loops through the rest of the track segments, modeling from track segment to track segment as presence of altitude controls dictate.

Once the index of the next track segment in the track segment list is identified, the track segment is considered the current segment. The next altitude control following the current segment is then located in the list of track segments. The current segment and the next segment bridge a descent step. For the first BADA step, a decelerating descent step is substituted for a pure descent step, as the aircraft must transition from scheduled BADA CAS to interpolated SAE 1845 speeds. If one decelerating descent step is unable to slow down enough, the decelerating descent step is used again, until the speeds can be smoothly transitioned. After a step has been modeled, the next track segment becomes the current segment and a new next track segment is identified. This loop is repeated until all track segments with altitude controls have been modeled.

Approaches are modeled in reverse, from a step to step perspective. That is, the order of descending steps begins with the descent to 10,000 ft AFE and ends with the descent from the cruise altitude.

3.7.1.4.3.1 Descend Steps

When calculating a descend step, first a determination must be made regarding which altitude region the step is taking place. If the descent will cross the Mach transition altitude, the step will be split into two pieces, one going from the starting step altitude dropping to the Mach transition altitude using the BADA Mach velocity, and one ranging from the transition altitude down to the final step altitude using the BADA CAS. The primary difference between those two steps is the velocity used. If the Mach transition altitude is not crossed during the step, then the step is not split.
For descent steps, the following is the methodology for how the step is calculated. First, based on if the step is starting above the Mach transition altitude or not, it is determined if BADA CAS or BADA constant Mach should be the speed used for the climb step. AEDT 2a then calculates the drag according to Eq. 3-78.

Next, the aircraft headwind is calculated. This is done by finding the heading of the current track segment and taking the projection of the headwind, which is altitude dependent. The heading of the current track segment is found by converting the latitude and longitude of the endpoints of the track segment into a planar X-Y coordinate system via a geographic projection system. The X-Y coordinate system has its origin at the start point of the track segment, so finding the unit vector of the track segment is done by normalizing the X and Y components of the segment end point. That unit vector is then multiplied by the magnitude and vector of the headwind, resulting in the projection of the headwind vector onto the track segment vector.

AEDT 2a calculates the *dh/dt* term of the force balance equation by dividing the change in altitude of the segment by the product of the segment length divided by the total segment speed (BADA speed – headwind).

Finally, AEDT 2a calculates the energy share factor for the altitude region in which the step takes place. Once all of the terms on the right-hand side of Eq. 3-80 are known, the thrust for the step is calculated.

3.7.1.4.3.2 Decelerating Descent Steps

Decelerating descent steps are used to bridge the speed differences between the SAE 1845 and BADA models. These steps both descend to the next altitude control as well as decrease the aircraft's speed. This is done by substituting different end speed values than those dictated by the BADA CAS schedule. Other than that, they act like normal descent steps.

Once the descent step has been modeled, a fixed trajectory point is populated with the final altitude, the thrust for the step, the speed traveled during the step, the horizontal track distance of the step, operation mode type, and point number.

The thrust is then converted from raw force units to corrected net thrust per engine. This process is the same as discussed in Section 3.7.1.4.2.3.

3.7.1.4.3.3 Approach Boundary Extensions

When the option to truncate or extend tracks is activated, AEDT 2a models all flights to the study boundary, unless no boundary is present within the study. A track extension is modeled, from the end of the original input track to either the study boundary or 1000 nmi, whichever is further away. If the study boundary is closer than 1000 nmi from the end of the original track, the excess track extension will be clipped post-modeling. For approach operations, if the cruise altitude is higher than the last altitude control on the un-extended track, then the aircraft will cruise with a level step from the far end of the extended track, until it is forced to descend to meet the outermost altitude control from the original un-extended track with a normal descent step. Like other descent steps, a fixed trajectory point is added to the final flight profile at the top of the climb.

3.7.1.4.4 Overflight Operations

Overflight operations in BADA are less restricted than approaches and departures in terms of the steps they can process. Specifically, overflights are able to model ascending or descending altitude controls by using climb and descend steps respectively. Additionally, overflights are able to model climb and descent steps in any order, provided they ultimately only cross the 10,000 ft AFE altitude once.

Due to the flexible nature of the trajectories overflights can be assigned to, overflights that start above or climb past 10,000 ft AFE will be modeled by BADA for all altitude controls sequentially after the one above 10,000 ft. This includes overflights that begin above 10,000 ft. and descend below the 10,000 ft. altitude.

Overflight modeling consists of a similar iterative process that approaches and departures perform. The next track segment with an altitude control is identified as the current segment, and the next altitude control following that segment is identified as the target. If the target altitude control altitude is higher than the current altitude by more than 100 ft, a climb step is called, as described below. If the next target is lower than the current altitude by more than 100 ft, a descend step is called as described in section 3.7.1.4.3.1. If neither of those step types are called, a cruise step is modeled.

3.7.1.4.4.1 Climb Steps

When calculating a climb step, first a determination must be made regarding which altitude region the step is taking place. If the step will cross the Mach transition altitude, the step will be split into two pieces, one going from the starting step altitude leading up to the Mach transition altitude, and one ranging from the transition altitude to the final step altitude. The primary difference between those two steps is the velocity used. If the Mach transition altitude is not crossed during the step, then the step is not split.

For climb steps, the following is the methodology for how the step is calculated. First, based on if the step is starting above the Mach transition altitude or not, it is determined if BADA CAS or BADA constant Mach should be the speed used for the climb step. The drag is then calculated according to Eq. 3-78.

Next, the aircraft headwind is calculated. This is done by finding the heading of the current track segment and taking the projection of the headwind, which is altitude dependent.

The heading of the current track segment is found by converting the latitude and longitude of the endpoints of the track segment into a planar X-Y coordinate system via a geographic projection system. The X-Y coordinate system has its origin at the start point of the track segment, so finding the unit vector of the track segment is done by normalizing the X and Y components of the segment end point. That unit vector is then multiplied by the magnitude and vector of the headwind returned by the Weather Module, resulting in the projection of the headwind vector onto the track segment vector.

The dh/dt term of the force balance equation is calculated by dividing the change in altitude of the segment by the product of the segment length divided by the total segment speed (BADA speed – headwind).

Finally, the energy share factor is calculated for the altitude region in which the step takes place. Once all of the terms on the right-hand side of Eq. 3-80 are known, the thrust for the climb step is calculated.

3.7.1.4.4.2 Climb Step Post-Processing

Once the climb step has been modeled, a fixed trajectory point is populated with the final altitude, the thrust for the step, the speed traveled during the step, the horizontal track distance of the step, operation mode type, and point number. The thrust is then converted from raw force units to corrected net thrust per engine via the following:

$$\frac{F_n}{\delta} = \frac{F/N}{\delta} \qquad \text{Eq. 3-111}$$

where

δ	atmospheric pressure ratio;
F	total thrust; and
N	number of engines.

If the thrust type is Percent, then the noise thrust is calculated as a percentage of static thrust, as discussed in 2.1.4.4.

Once the thrust has been converted, the trajectory point is then added to the end of the existing list of trajectory points.

3.7.1.4.4.3 BADA Thrust Limits

Once the thrust for the step has been determined, it is compared to the maximum achievable thrust the aircraft can produce at the altitude at which it is currently flying. Calculations for maximum available thrust are discussed in Section 3.6.3.1.4.

If the thrust needed to perform the climb step is greater than the maximum thrust the aircraft has available, the step is recalculated, with the aircraft flying at max thrust in an attempt to see how high it can climb over the course of track segment. The altitude achieved in this recalculation is then compared to the requirements of the altitude control.

To find the maximum achievable altitude, a convergence loop is established in which the end altitude is varied and the thrust calculated similarly to a normal climb step. The convergence is achieved when the calculated thrust is less than 1/1,000,000 Newtons less than maximum thrust. The altitude used on the iteration when that convergence criterion is achieved is the maximum achievable altitude.

If the maximum achievable altitude loop is unable to find a point of convergence, then a secondary backup loop is initiated, where in each iteration, the final altitude is lowered from the previous target in 100 ft increments, starting at the original altitude control altitude. This loop replicates the climb step, with the exception of the exit criteria, which remains the same as the convergence loop.

If neither the convergence loop nor the secondary backup loop are able to find a satisfactory maximum achievable altitude, an exception is generated.

Once an achievable maximum altitude is determined, that altitude is compared to the criteria set forth by the altitude control. Additionally, AEDT 2a allows for a 300 ft tolerance on either side of an altitude control altitude when checking if an altitude control has been satisfied. Specifically,

- If an achieved altitude is within 300 ft above or below an At type altitude control altitude, it is acceptable and within allowed tolerances.

- If an achieved altitude is below or within 300 ft above an AtOrBelow type altitude control altitude, it is acceptable and within allowed tolerances.
- If an achieved altitude is above or within 300 ft. below an AtOrAbove type altitude control altitude, it is acceptable and within allowed tolerances.

If the maximum achieved altitude is found to be within allowed tolerances, it is returned as the final altitude for the climb step.

3.7.1.4.4.4 Cruise Steps

Cruise steps follow the same force balance as the rest of the BADA steps, given in equation Eq. 3-80. However, the starting and ending altitudes of the step are equal, so thrust is equal to drag as given in Eq. 3-78. Cruise steps also have a slightly different limitation on thrust than climb steps. Specifically, maximum cruise thrust is set by BADA at 95% of maximum climb thrust.

For cruise segments longer than 10 nmi for which there is no change in altitude, a thrust transition segment is added after the first 1000 ft of the segment. The purpose of these segments is to allow for any thrust or speed transitioning that may occur between a previous climb or descend step and the current level step.

3.7.1.4.4.5 Overflight Boundary Extension and Post-Processing

Overflights are also extended to the study boundary, similar to approaches and departures. However, overflights just add a level segment on the beginning and end of the existing track, in the same direction as the first and last track segments, respectively. Level cruise steps are then modeled for those extensions. Aircraft cruise altitudes are ignored for overflight operations.

3.7.2 Speed Controls

Speed controls are not supported and are ignored in AEDT 2a.

3.7.3 Sensor Path Flights

AEDT 2a supports trajectory specification for runway-to-runway operations in the form of sensor path data. Each data sample specifies a location and groundspeed. The calculated performance result will tend to conform to these inputs, subject to the constraints of the performance model. The performance calculations for runway-to-runway operations proceed as follows:

- The input flight path is smoothed and filtered.
- The terminal-area departure portion of the operation is calculated.
- The en-route portion of the operation is calculated.
- The terminal-area approach portion of the operation is calculated.

Note that a sensor path may never reach 10,000 ft AFE, in which case the distance-weighted average altitude of the sensor path with respect to sea-level provides the dividing line at each end.

3.7.3.1 Preliminary Processing

First, before any preprocessing is performed on the original sensor path data, the horizontal length is calculated by integrating great circle path lengths between points. This is used to choose an appropriate standard profile by stage length for the terminal-area portion of the operation.

AEDT 2a smooths and applies filters to the altitude and speed profiles implied by provided sensor path data. All samples preceding the first sample above 500 ft AFE at the departure airport, and all samples following the last sample above 500 ft AFE at the arrival airport, are discarded. Sensor path samples are discarded where the magnitude of acceleration to or from an adjacent sample exceeds the global longitudinal acceleration limit imposed by BADA. Samples for which the change in climb angle exceeds the BADA normal acceleration limit are also discarded. Exponential smoothing is applied to the remaining altitude and speed profiles in the forward and reverse directions. This results in the "trusted" path.

Next, a cruise altitude is calculated from the trusted path. This is the average altitude of the path, weighted by distance. The trusted path is then divided into phases. The terminal-area departure phase is based on the trusted path from the beginning to the lesser of cruise altitude and 10,000 ft AFE. The terminal-area approach phase is based on the trusted path from the lesser of cruise altitude and 10,000 ft AFE to the end. If cruise is above 10,000 ft AFE for the departure airport, there is an en-route climb phase based on the trusted path from 10,000 ft AFE with respect to the departure airport to the cruise altitude. If cruise is above 10,000 ft AFE for the arrival airport, there is an en-route descent phase based on the trusted path from cruise altitude to 10,000 ft AFE with respect to the arrival airport. The en-route cruise phase is based on the portion of the trusted path that is at or above the cruise altitude.

A final filtering step is applied to each phase, in which the number of points is reduced to those for which acceleration is equal to the average acceleration for the phase, or for which climb angle is equal to 130% or 70% of the average climb angle in the phase. Terminal area departure and approach phases are also forced to be monotonically increasing or decreasing, as appropriate.

3.7.3.2 Terminal Area

Terminal-area operations are defined for the departure and approach phases. These operations contain pointwise ground tracks, where the surface coordinates and altitude controls reflect the locations of the pre-processed sensor path data of their respective phases. The controls are of type "At or below". The departure operation is processed first, followed by the en-route phases (described in the next section), and the approach operation is processed last. The final point in the result of each phase informs the initial point of the phase that follows, and all results are combined into a complete runway-to-runway result. Note that since the terminal area portion of sensor path analysis is performed using altitude controls, terminal area speeds are determined by the standard procedural profile, and sensor path speeds in the terminal area do not inform the performance results.

3.7.3.3 En-route

For each segment of an en-route phase, the initial point is taken from the final point of the previous segment. This includes the initial altitude, h_i. All calculations to determine the final point are based on the initial time and initial aircraft weight. The final geographic coordinate is known from the sensor path specification, and as a result, the segment's horizontal length is known.
The final point of a segment is first limited by BADA envelope considerations. First, the envelope-limited final altitude, $h_f^{(1)}$, is determined by limiting the final altitude, $h_f^{(0)}$, specified in the sensor path by the maximum final altitude, $h_{f_{max}}$, as calculated by Eq. 3-89, with the aircraft mass taken from the initial point, and the temperature deviation sampled at the initial time and final geographic coordinate, at sea level. AEDT 2a then determines the envelope-limited final groundspeed, $V_{G_f}^{(1)}$, by limiting the final

groundspeed, $V_{G_f}^{(0)}$, specified in the sensor path by the minimum final calibrated airspeed, V_{min}, given by Eq. 3-90, and by the BADA aircraft's maximum operating CAS, V_{MO}. Note that all comparisons between groundspeed, true airspeed, and calibrated airspeed are performed in the context of the envelope-limited final altitude, $h_f^{(1)}$.

Next, the BADA longitudinal acceleration limit is applied to the final groundspeed of the segment. The acceleration-limited final groundspeed, $V_{G_f}^{(2)}$, is initialized to the envelope-limited final groundspeed, $V_{G_f}^{(1)}$, and then limited by iteratively decrementing (or incrementing, as appropriate) by one foot per second until it satisfies:

$$\left|V_{G_f}^{(2)} - V_{G_i}\right| \leq \frac{a_{l,\max(civ)}\sqrt{L_h^2 + \left(h_f^{(1)} - h_i\right)^2}}{\frac{1}{2}\left(V_{G_f}^{(2)} + V_{G_i}\right)} \qquad \text{Eq. 3-112}$$

where

h_i	initial altitude (m);
$h_f^{(1)}$	envelope-limited final altitude (m);
$V_{G_f}^{(2)}$	acceleration-limited final groundspeed (m/s);
V_{G_i}	initial groundspeed (m/s);
L_h^2	segment horizontal length (m); and
$a_{l,\max(civ)}$	maximum longitudinal acceleration for civil flights.

The maximum allowed change in climb angle, $\Delta\gamma_{max}$, from the previous segment's climb angle is calculated by:

$$\Delta\gamma_{max} = \frac{a_{n,\max(civ)}\sqrt{L_h^2 + \left(h_f^{(1)} - h_i\right)^2}}{\left[\frac{1}{2}\left(V_{G_f}^{(2)} + V_{G_i}\right)\right]^2} \qquad \text{Eq. 3-113}$$

where

$a_{n,\max(civ)}$	maximum normal acceleration for civil flights;

The acceleration-limited final altitude, $h_f^{(2)}$, is adjusted such that the climb angle, γ, does not differ from the previous segment's climb angle by more than this amount.

After limiting is complete, segment duration Δt (s) is calculated from:

$$\Delta t = \frac{\sqrt{L_h^2 + \left(h_f^{(2)} - h_i\right)^2}}{\frac{1}{2}\left(V_{G_f}^{(2)} + V_{G_i}\right)} \qquad \text{Eq. 3-114}$$

where

$h_f^{(2)}$	acceleration-limited final altitude (m).

Acceleration a (m/s^2) is calculated from:

$$a = \frac{V_{G_f}^{(2)} - V_{G_i}}{\Delta t} \qquad \text{Eq. 3-115}$$

and the climb rate from:

$$\frac{dh}{dt} = \frac{h_f^{(2)} - h_i}{\Delta t} \qquad \text{Eq. 3-116}$$

Drag is calculated as outlined in Section 3.6.3.1.3 and total net thrust is calculated according to Eq. 3-79, with the appropriate speed and density choices (initial values for initial thrust, final values for final thrust).

If the final thrust exceeds the maximum climb thrust (as evaluated at the final location) by more than 20%, then thrust limiting is applied. Here, the final speed is iteratively decremented, one knot at a time. With each iteration, the final thrust is recalculated in the same manner as originally calculated. Iteration continues as necessary until the final thrust is within limits, or until the final speed falls below either the initial segment speed or the stall CAS. If the final thrust still exceeds the limit, the final altitude is iteratively decremented, one foot at a time. This continues until either the final thrust is within limits, or the final altitude falls below the initial altitude. If the final thrust still exceeds the limit, the air operation is rejected, and an error message is logged.

At this point, there is enough information available to calculate the segment fuel flow and fuel burn, along with the change in weight. Note that the initial thrust calculated for the segment overrides the final thrust calculated according to the previous segment.

3.8 Noise Mode

Performance calculations in AEDT include the determination of which Noise-Power-Distance (NPD) curve to use in noise calculations (discussed in section 4). This determination is made for each individual trajectory segment. For helicopters, there is an NPD curve associated with each type of procedure step. Thus, each trajectory segment is assigned the NPD curve that corresponds to the type of procedure step undergone during the segment. For airplanes, all trajectory segments outside of the terminal area are assigned departure mode. Airplane segments in the terminal area that originate from explicit fixed-point profiles are assigned the NPD curve that is assigned to the nearest fixed-point at or preceding the trajectory segment. Airplane segments in the terminal area that originated from any other treatment are assigned departure mode if they are climbing, accelerating at constant altitude, or applying reverse thrust during ground roll; approach mode is assigned otherwise.

4 Noise

AEDT 2a computes noise from a series of individual aircraft operations (known as single-event noise), and then accumulates these single-event noise levels across all of the events in an AEDT 2a study to accumulate noise levels for the study. This is done according to the steps below:

1. Accept aircraft-specific data (equipment, noise, position and operational data) and study-specific data (weather, terrain, boundary and ambient data) as input(see Sections 2.2 and 4.1);
2. Determine the unadjusted noise values at the receptors (see Sections 4.2.1 and 4.2.2);
3. Apply adjustments to account for environmental, meteorological, operational and position effects (see Sections 4.3, 4.4 and 4.5);
4. Compute the single-event base metrics at the receptors (see Sections 4.6.1, 4.6.2, 4.6.3 and 4.6.4);
5. Repeat steps one through five for each unique, single event in the AEDT 2a study;
6. Accumulate the noise output and compute the appropriate noise metrics (see Section 4.6.5); and
7. Annualize noise results (see Section 6).

Figure 4-16 and Figure 4-17 graphically summarize the acoustic computation process employed in AEDT 2a. Figure 4-18 graphically summarizes the accumulation of noise metric computation process.

4.1 Flight Path Segment Parameters

As a prerequisite to noise level computations, AEDT 2a 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 4.1.1:

- The closest point of approach on the flight path segment, or the extended flight path segment, to the receptor
- The slant range from the receptor location to the closest point of approach

Computation of the following flight-segment geometric and physical parameters is presented in Section 4.1.2:

- The speed along the flight path segment
- The altitude associated with the flight path segment
- The over-ground, sideline distance from the receptor location to the ground-projection of the closest point of approach
- The engine power associated with the flight path segment

Figure 4-1 through Figure 4-3 present, respectively, the receptor/flight-segment geometry for the three general AEDT 2a cases:

- The receptor is behind the flight path segment
- The receptor is astride the flight path segment
- The receptor is ahead of the flight path segment

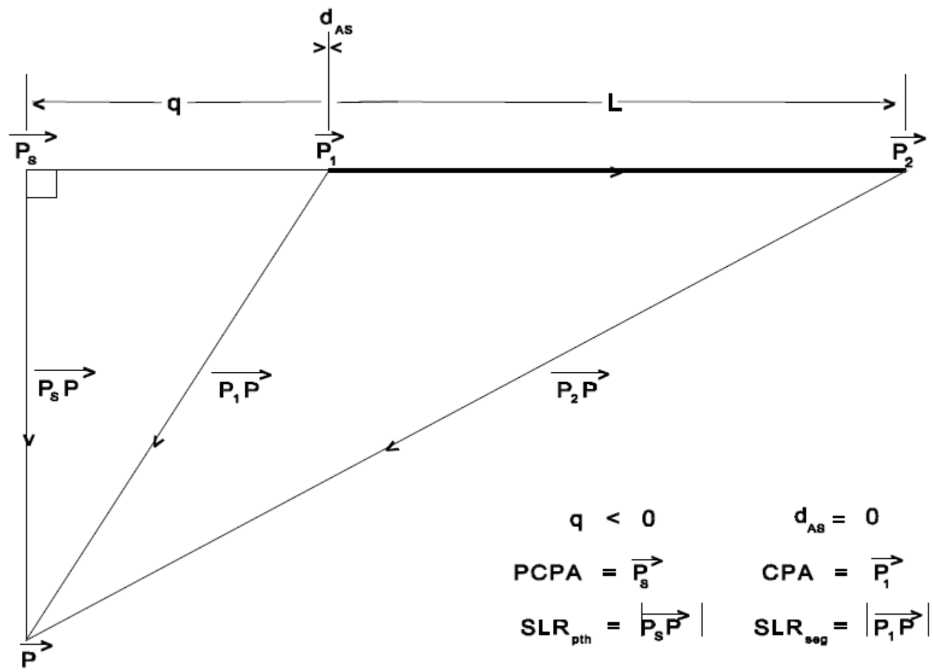

Figure 4-1 Flight-Segment Geometry when a Receptor is Behind a Segment

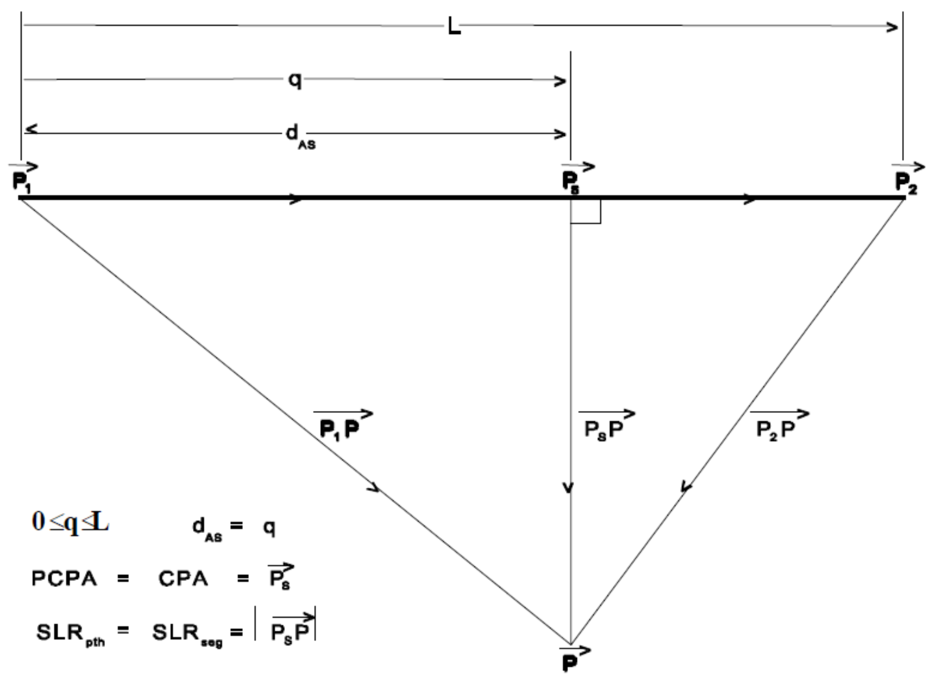

Figure 4-2 Flight-Segment Geometry when a Receptor is Astride a Segment

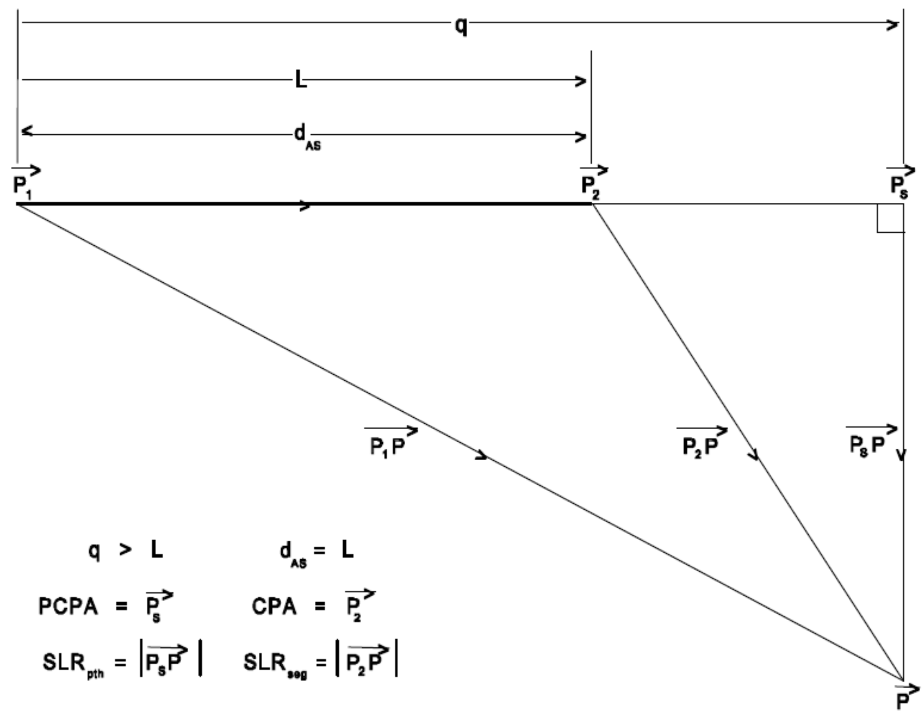

Figure 4-3 Flight-Segment Geometry when a Receptor is Ahead of a Segment

The variables shown in Figure 4-1 through Figure 4-3 are defined as follows:

P	Receptor point
P_1	Start-point of the flight path segment
P_2	End-point of the flight path segment
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 receptor, as defined in detail in Section 4.1.1, below. The specific definition depends on the position of the receptor relative to the flight path segment.
P_1P_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 ft.
P_1P	Vector from the start of the flight path segment to the receptor. It has a minimum length of 1 ft.
P_2P	Vector from the end of the flight path segment to the receptor. It has a minimum length of 1 ft.
P_sP	Perpendicular vector from the receptor to PCPA on the flight path segment, or the extended flight path segment, as defined in detail in Section 4.1.1. It has a minimum length of 1 ft.
SLR_{pth}	$\|P_sP\|$, the length of the perpendicular vector from the receptor to PCPA on the flight path segment, or the extended flight path segment as defined in detail in Section 4.1.1. It has a minimum length of 1 ft.
L	Length of the flight path segment. It has a minimum length of 1 ft.
CPA	Point on the flight path segment, not the extended flight path segment, which is the closest point of approach to the receptor, as defined in detail in Section 4.1.1.

	The specific definition depends on the position of the receptor relative to the flight path segment.
SLR_{seg}	Length of the vector from the receptor to CPA on the flight path segment, not the extended flight path segment, as defined in detail in Section 4.1.1. It has a minimum length of 1 ft.
q	Relative distance along the flight path segment, or the extended flight path segment, from P_1 to P_S (ft). The value of q is used to determine the position of the receptor relative to the flight path segment, as shown in Table 4-1.
d_{AS}	Distance along the flight path segment from the start of the segment at P_1 to CPA. Depending on the value of q, i.e., the relative geometry between the receptor and the flight path segment, d_{AS} takes on the values shown in Table 4-1.

Table 4-1 Position of the Receptor Relative to the Flight path Segment

Value of q	Value of d_{AS}	Position of receptor relative to flight path segment
q < 0	0	Receptor is behind segment
0 ≤ q ≤ L	q	Receptor is astride segment
q > L	L	Receptor is ahead of segment

4.1.1 Closest Point of Approach and Slant Range

The closest point of approach and slant range parameters are fundamental to AEDT 2a computations. The slant range is used for noise level interpolation of the NPD data (see Section 4.2.2). In addition, the computation of the closest point of approach and slant range parameters are a prerequisite to the noise fraction algorithm used for exposure-based metrics (see Section 4.3.3) and for lateral attenuation (see Section 4.3.5).

The slant range from the receptor 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 receptor. 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 AEDT 2a) and infinite flight paths significant. To obtain the noise exposure level due to an aircraft proceeding along a finite flight path segment in AEDT 2a, 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 receptor location relative to the flight path segment. If the receptor is behind or ahead of the flight path segment, then the PCPA is the intersection point of the perpendicular from the receptor to the extended segment. If the receptor is astride the flight path segment, then the PCPA is the intersection point of the perpendicular from the receptor to the segment.

The exceptions to the above definition for slant range occur:

- When the receptor is behind a takeoff ground-roll segment (see Section 4.4.2);
- During runup operations; and
- 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 receptor location to the closest point of approach on the flight path segment (CPA), not the extended flight path segment. The specific definition of the CPA depends on the position of the receptor location relative to the flight path segment. If the receptor is behind the flight path segment, the CPA is the start point of the segment. If the receptor is astride the flight path segment, the CPA is equivalent to the PCPA. If the receptor is ahead of the flight path segment, the CPA is the end point of the flight path segment.

4.1.2 Speed, Altitude, Distance, and Power

Computations of the following four parameters, associated with each flight path segment, are described in this Section.

- The speed at the CPA;
- The altitude at the CPA;
- The horizontal sideline distance from the receptor location to the vertical projection of the CPA; and
- The engine power setting (also known as thrust setting) at the 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 AEDT 2a. 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:

$$AS_{seg} = AS_{P1} + \left[\frac{d_{AS}}{L}\right] \cdot \Delta AS \qquad \text{Eq. 4-1}$$

where

AS_{P1}	speed at the start of the flight path segment (kts);
d_{AS}	distance along the flight path segment from the start of the segment at P_1 to CPA (ft), see Section 4.1;
L	length of the flight path segment (ft); and
ΔAS	change in speed along the flight path segment (kts).

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 ft at the CPA is computed via linear interpolation as follows:

$$d_{seg} = [P_1]_z + d_{AS}\left[\frac{(P_1P_2)_z}{L}\right] + h_{terr} - h_{airport} \qquad \text{Eq. 4-2}$$

where

$[P_1]_z$	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 (ft above field elevation);
$(P_1P_2)_z$	change in altitude along the flight path segment (ft);
h_{terr}	terrain elevation (ft MSL); when the terrain option is not invoked, $h_{terr} = h_{aprt}$; and
$h_{airport}$	airport elevation (ft MSL).

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

$$l_{seg} = \left(SLR_{seg}^2 - d_{seg}^2\right)^{1/2} \qquad \text{Eq. 4-3}$$

where

SLR_{seg} length of the vector (ft) from the receptor to CPA on the flight path segment, not the extended flight path segment; and

d_{seg} as computed above (Eq. 4-2).

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 the CPA is computed via linear interpolation:

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

where

P_{P1} engine power at the start of the flight path segment (see Section 2.1.4.1 for units[viii]); and

ΔP change in power along the flight path segment.

P_{seg} is used in performing noise level interpolation as presented in Section 4.2.2[ix].

4.2 Noise-Power-Distance (NPD) Data Computations

Noise propagation is represented in AEDT 2a with a database of noise-power-distance (NPD) data, which are specific according to aircraft type, aircraft operation type and noise metric (and, in the case of helicopters, directivity). The NPD data for a fixed-wing aircraft in AEDT 2a consist of a set of decibel levels for various combinations of aircraft operational modes (approach, departure, overflight), engine power states and slant distances from receptor to aircraft, as described in Section 2.1.4.1. Each NPD has noise levels at the following ten AEDT 2a distances: 200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, and 25000 ft. In addition, each set of NPDs include NPDs with the following base noise metrics: SEL, LAMAX, EPNL and PNLTM. When noise data are needed at thrust settings, distances and noise metrics not represented in the NPD data set, they are approximated for the existing NPD database. Section 4.2.1 discusses computations used to approximate base noise metrics, when they are not available in the AEDT 2a database. Section 4.2.2 discusses methods for determining noise levels from the NPD data sets using interpolation and extrapolation.

[viii] 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.

[ix] The engine power setting for helicopters is an arbitrarily assigned number in AEDT, because the helicopter NPDs are dependent on operational mode, instead of thrust setting. The helicopter engine power setting is determined by $P_{seg} = P_{p1}$.

4.2.1 Noise Metric Approximations

In order to compute all of the noise metrics in AEDT 2a from the NPDs in the Fleet database, several noise metric approximations must be made. Section 4.2.1.1 presents methods for computing maximum noise level approximations if the Fleet database does not include maximum noise level NPDs for a particular airframe-engine-engine modification combination. Section 4.2.1.2 presents methods for computing C-weighted noise level approximations from A-weighted NPDs in the Fleet database.

4.2.1.1 Maximum Noise Level Approximation

For several aircraft in the AEDT 2a Fleet 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 AEDT 2a database. The equations are as follows:

For civil aircraft:

$$L_{ASmx} = L_{AE} - 7.19 - 7.73 \cdot log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 4-5}$$

$$L_{PNTSmx} = L_{EPN} + 1.22 - 9.34 \cdot log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 4-6}$$

where

L_{AE}	A-weighted sound exposure level (dB);
L_{EPN}	effective perceived noise level (dB); and
SLR_{PTH}	the length (ft) of the perpendicular vector from the receptor to PCPA on the flight path segment, or the extended flight path segment.

For military aircraft:

$$L_{ASmx} = L_{AE} - 7.84 - 6.06 \cdot log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 4-7}$$

$$L_{PNTSmx} = L_{EPN} + 2.51 - 5.84 \cdot log_{10}\left[\frac{SLR_{pth}}{1000}\right] \qquad \text{Eq. 4-8}$$

4.2.1.2 C-Weighted Metric Approximation

C-weighted metrics are calculated using a simplified adjustment procedure, consistent with FAR Part 36[27], 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 ft reference) using SAE-AIR-1845[14]. These are the two weighted source spectra;
3. Each weighted source spectrum is corrected to the ten standard AEDT 2a NPD distances using the standard AEDT 2a atmosphere (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 AEDT 2a distance, yielding a distance-specific, weighted sound pressure level ($L_{A,\,d}$ and $L_{C,\,d}$). These

levels are then arithmetically subtracted for each AEDT 2a 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; and

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 AEDT 2a distance, resulting in a C-weighted NPD.

4.2.2 Noise Level Interpolation/Extrapolation ($L_{P,D}$)

Each aircraft in the modeling layer of the AEDT 2a fleet database is assigned to an NPD data set that represents the noise levels for a discrete number of operation modes, thrust values, distance values and metrics. 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.

The NPD data are used to either interpolate or extrapolate an associated noise level value. The interpolation/extrapolation is a piecewise 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 4.2.2.4).

4.2.2.1 Standard Noise Level Interpolation/Extrapolation

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, afterburner or overflight operations is performed using the NPD curves designated as approach, afterburner or overflight curves, respectively.

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-defined noise metric, or family of metrics to be computed at the receptor. The specific distance and power value used in the interpolation/extrapolation process is dependent on the type of base metric selected. This Section discusses the distance and power values for exposure-based noise-level metrics and maximum noise-level metrics, respectively.

Following is a generalized description of the noise interpolation for an engine power P[x] 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 at engine power, P_1, and distance, d, is given by:

[x] Several of the military aircraft contain NPD data for afterburner operations (NOISEMAP equivalent of "FIXED" interpolation). If a particular flight path segment is identified as an afterburner segment, interpolation or extrapolation is only performed with regard to distance, not power.

$$L_{P1,d} = L_{P1,d1} + \frac{\left(L_{P1,d2} - L_{P1,d1}\right) \cdot (log_{10}[d] - log_{10}[d_1])}{(log_{10}[d_2] - log_{10}[d_1])} \quad \text{Eq. 4-9}$$

where

P_1, P_2 engine power values for which noise data are available in the NPD database (dependent on aircraft);
d_1, d_2 distance values for which noise data are available in the NPD database (ft);
$L_{P1,d1}$ 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 at engine power, P_2, and distance, d, is given by:

$$L_{P2,d} = L_{P2,d1} + \frac{\left(L_{P2,d2} - L_{P2,d1}\right) \cdot (log_{10}[d] - log_{10}[d_1])}{(log_{10}[d_2] - log_{10}[d_1])} \quad \text{Eq. 4-10}$$

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

$$L_{P,d} = L_{P1,d} + \frac{\left(L_{P2,d} - L_{P1,d}\right) \cdot (P - P_1)}{(P_2 - P_1)} \quad \text{Eq. 4-11}$$

The above methodology is utilized when:

1. The engine power and/or distance associated with the receptor/segment pair lies between existing values in the NPD data (i.e., interpolation);
2. The power and/or distance associated with the receptor/segment pair is larger than existing values in the NPD data (i.e., extrapolation); or
3. The power associated with the receptor/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. The limit is included to prevent extrapolation to unrealistic noise levels.

The general noise interpolation/extrapolation process described in this Section is applicable for the four fundamental noise-level metrics, L_{AE}, L_{EPN}, L_{ASmx}, and L_{PNTSmx}. 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. In addition, another special noise extrapolation process is invoked when the distance associated with the receptor/segment pair is smaller than the smallest distance in the NPD data (i.e., 200 ft). These special cases are discussed separately for exposure-based noise-level metrics and maximum noise-level metrics (see Sections 4.2.2.2 and 4.2.2.3).

4.2.2.2 Additional Interpolation Information for Exposure-Based Noise Level Metrics

For exposure-based metrics, if the end points of a fixed 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 a receptor/segment pair, is given by:

$$L_{P,d} = \begin{cases} L_{P_{seg,d=SLR_{pth}}} & Observer\ behind\ or\ ahead\ of\ segment \\ L_{P_{seg,d=SLR_{seg}}} & Observer\ astride\ segment \end{cases} \qquad \text{Eq. 4-12}$$

where

$L_{P_{seg,d=SLR_{pth}}}$ interpolated noise level (dB) based upon engine power associated with the flight path segment, P_{seg}, as defined in Section 4.1.2, and the distance to the PCPA on the extended flight path segment; and

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

For the special case in which SLR_{pth} or SLR_{seg} is smaller than 200 ft, 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 ft and for a given power setting in the NPD data is 95.6 dB, the extrapolated L_{AE} at 100 ft and at the same power setting is 95.6 + 10 $\log_{10}[200/100]$ = 98.6 dB

4.2.2.3 Additional Interpolation Information for Maximum Noise Level Metrics

For maximum noise-level metrics, if the end points of a fixed 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 a receptor/segment pair, is given by:

$$L_{P,d} = \begin{cases} Max[L_{P,d,START}, L_{P,d,END}] & Observer\ behind\ or\ ahead\ of\ segment \\ Max[L_{P,d,START}, L_{P,d,PCPA}, L_{P,d,END}] & Observer\ astride\ segment \end{cases} \qquad \text{Eq. 4-13}$$

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 ft. 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 ft and for given power setting in the NPD database is 95.6 dB, then the extrapolated L_{ASmx} at 100 ft at the same power setting is 95.6 + 20 $\log_{10}[200/100]$ = 101.6 dB.

4.2.2.4 Noise Level Interpolation/Extrapolation for Helicopters

Interpolation or extrapolation of helicopter NPD data is slightly more involved than the standard aircraft NPD interpolation and extrapolation. Besides the three standard dynamic operational modes (approach, departure and overflight), there are also helicopter noise data for four static modes (ground idle, flight idle, hover-in-ground-effect, and hover-out-of-ground-effect).

Although interpolation and extrapolation on the Helicopter NPDs for the four static modes are performed in the same manner as standard aircraft interpolation and extrapolation presented in Section 4.2.2, interpolation and extrapolation for the three dynamic modes are handled differently, because the data set for each operational mode consists of three NPD curves, adding another dimension to the interpolation and extrapolation. The NPD curves for the dynamic modes also take into account in-flight directivity, and are labeled Left, Center and Right. For these dynamic modes, interpolations and extrapolations between distance values are handled according to Section 4.2.2, and interpolations and extrapolations between the Left, Center and Right NPDs are accounted for with the Lateral Directivity Adjustment (see Section 4.5.2).

4.3 General AEDT 2a Noise Adjustments

The sound level adjustments presented in Sections 4.3.1 through 4.3.6 are applicable to all aircraft in AEDT 2a. 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}).

4.3.1 Atmospheric Absorption Adjustment (AA_{ADJ})

The introduction of a spectral database into AEDT 2a 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 environments due to the increased atmospheric absorption associated with the lower humidity.

The spectral data in AEDT 2a has been corrected to reference day conditions, using the SAE-AIR-1845[14] standard atmosphere, at a distance of 305 m. The following steps, which are consistent with the simplified procedure of FAR Part 36[27], are used to correct the data to the user-defined 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 ft 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 AEDT 2a distances assuming two conditions: the AEDT 2a standard atmosphere based on SAE-AIR-1845 and a user-supplied atmosphere generated with SAE-ARP-866A[28]. These are $spectrum_{1845,\,d}$ and $spectrum_{866A,\,d}$ respectively.
3. The 24 one-third octave band values of each spectrum are logarithmically summed at each AEDT 2a 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 AEDT 2a 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 AEDT 2a distance.

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.

4.3.2 Acoustic Impedance Adjustment (AI_{ADJ})

Before the interpolated/extrapolated noise level data, $L_{P,d}$, are 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 AEDT 2a NPD database are corrected to reference-day conditions: temperature 77°F, pressure 29.92 inches of mercury, and altitude mean sea level. The noise levels can be adjusted to airport temperature and pressure by:

$$AI_{ADJ} = 10log_{10}\left[\frac{\rho \cdot c}{409.81}\right] \qquad \text{Eq. 4-14}$$

$$\rho \cdot c = 416.86 \cdot \left(\frac{\delta}{\theta^{1/2}}\right) \qquad \text{Eq. 4-15}$$

where

AI_{ADJ}	acoustic impedance adjustment to be added to noise level data in the AEDT 2a NPD database (dB);
$\rho \cdot c$	specific acoustic impedance at receptor altitude and pressure (N-s/m^3);
θ	ratio of absolute temperature at the receptor to standard-day absolute temperature at sea level; and
δ	ratio of atmospheric pressure at the receptor to standard-day pressure at sea level.

When terrain elevation is invoked, AI_{ADJ} is computed and applied to the NPD data on a receptor-by-receptor basis, according to the receptor altitude, temperature, and pressure. Otherwise, the airport elevation and the receptor 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 ft MSL, respectively, then AI_{ADJ} is zero.

4.3.3 Noise Fraction Adjustment for Exposure Metrics (NF_{ADJ})

The exposure-based noise level data interpolated/extrapolated from the AEDT 2a NPD data, $L_{P,d}$, represents the noise exposure level associated with a flight path of infinite length. However, the aircraft flight path is described by a set of finite-length segments, each contributing varying amounts of exposure to the overall noise metric computed at a receptor.

The noise fraction algorithm, used exclusively for computation of the exposure-based metrics (L_{AE}, L_{CE}, L_{EPN}), and indirectly for computation of the time-above metrics (TA_{LA}, TA_{LC}, TA_{PNT},), 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.

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 a receptor location due to an aircraft proceeding along a finite fixed path segment, the exposure-based noise-level data, interpolated/extrapolated from the AEDT 2a NPD data, must be adjusted by a fractional component, which is associated with the geometry of the receptor/flight-segment pair.

4.3.3.1 Noise Fraction Adjustment for Flight Path Segments

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

$$F_{12} = \left(\frac{1}{\pi}\right) \cdot \left[\frac{\alpha_2}{(1+\alpha_2^2)} + \tan^{-1}(\alpha_2) - \frac{\alpha_1}{(1+\alpha_1^2)} - \tan^{-1}(\alpha_1)\right] \qquad \text{Eq. 4-16}$$

where

$$\alpha_1 = \frac{q_1}{S_L} \qquad \text{Eq. 4-17}$$

$$\alpha_2 = \frac{(q_1 + L)}{S_L} \qquad \text{Eq. 4-18}$$

$$S_L = S_0 \cdot 10^{\frac{[L_{E,P,d} - L_{Smz,p,d}]}{10}} \qquad \text{Eq. 4-19}$$

and where

q_1	relative distance (ft) from the segment start point to point P_s;
L	length of segment (ft);
S_0	171.92 ft for L_{AE} and L_{CE}, or 1719.2 ft for L_{EPN};
$L_{E,P,d}$	unadjusted interpolated NPD noise exposure level (dB) at 160 kts (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 receptor to the perpendicular closest point of approach (PCPA) on the extended segment.

The noise fraction is then converted to a dB adjustment:

$$NF_{ADJ} = 10log_{10}[F_{12}] \qquad \text{Eq. 4-20}$$

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

For a receptor 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.

$$F_{12}' = \left(\frac{1}{\pi}\right) \cdot \left|\frac{\alpha_2}{(1+\alpha_2^2)} + \tan^{-1}(\alpha_2)\right| \quad \text{Eq. 4-21}$$

$$\alpha_2 = \left(\frac{L}{S_L}\right) \quad \text{Eq. 4-22}$$

where L and S_L are defined in Section 4.3.3.1. This adjustment is supplemented by the ground based directivity adjustment DIR_{ADJ}, see Section 4.4.2.

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

$$NF_{ADJ} = 10log_{10}[F_{12}'] \quad \text{Eq. 4-23}$$

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

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

For exposure-based metrics, consistent with SAE-AIR 1845[14], NPDs are derived for a reference speed of 160 kts for fixed-wing aircraft. For fixed-wing aircraft speeds other than 160 kts, the duration adjustment is applied to account for the effect of time-varying aircraft speed, 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 static 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 kts. For other aircraft speeds, the aircraft speed adjustment in dB, DUR_{ADJ}, is given by:

$$DUR_{ADJ} = 10log_{10}\left[\frac{AS_{ref}}{AS_{seg}}\right] \quad \text{Eq. 4-24}$$

where

AS_{ref} reference aircraft speed (160 kts for fixed-wing aircraft); and
AS_{seg} aircraft speed at the closest point for approach (CPA) for the segment).

Helicopters in the AEDT 2a 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 Eq. 4-24, when calculating the aircraft speed adjustment, DUR_{ADJ}, for helicopters.

4.3.5 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[xi]:

- Ground reflection effects
- Refraction effects
- Airplane shielding and engine installation effects

For the lateral attenuation adjustment in AEDT 2a, the ground beneath the receptor is defined by a flat plane, regardless of whether the terrain feature is invoked or not. The absorption of reflected noise as it propagates over this flat plane (or any surface) is known as ground effect. The ground effect component of the lateral attenuation adjustment assumes propagation over soft ground, which is considered acoustically absorptive. This effect is defined by equation Eq. 4-32. In AEDT 2a, the ground effect component of the lateral attenuation adjustment for helicopter and propeller aircraft (e.g. tour aircraft) can be turned off in order to model propagation over hard ground types. Since hard ground effects are most prominent close to the ground, jets are always modeled over soft ground in AEDT 2a.

The specific algorithms used for computing lateral attenuation in AEDT 2a are dependent on aircraft type, civil or military. Section 4.3.5.1 describes the lateral attenuation algorithms for civil aircraft, and Section 4.3.5.2 describes the lateral attenuation algorithms for military aircraft.

4.3.5.1 Civil Aircraft

The lateral attenuation adjustment for civil aircraft is based on SAE-AIR-5662[29]. SAE-AIR-5662 provides methods for combining multiple lateral attenuation effects, including those related to source configuration (recognizing different source effects among jet aircraft with fuselage-mounted engines and wing-mounted engines, as well as propeller-driven aircraft), and those related to propagation.

Computation of the lateral attenuation adjustment for aircraft in AEDT 2a depends upon the following parameters:

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

$$\beta = \sin^{-1}\left(\frac{d_{seg}}{SLR_{seg}}\right) \qquad \text{Eq. 4-25}$$

   where

   d_{seg} see Eq. 4-2 and

$$SLR_{seg} = \left(d_{seg}^2 + l_{seg}^2\right)^{1/2} \qquad \text{Eq. 4-26}$$

3. The aircraft bank angle, ε; and

[xi] The lateral attenuation adjustment in AEDT 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 AEDT could under predict the actual noise level.

4. The depression angle, φ, which is defined by β and ε in the following equation:

$$\varphi = \varepsilon + \beta \qquad \text{Eq. 4-27}$$

These parameters are presented in Figure 4-4 and Figure 4-5.

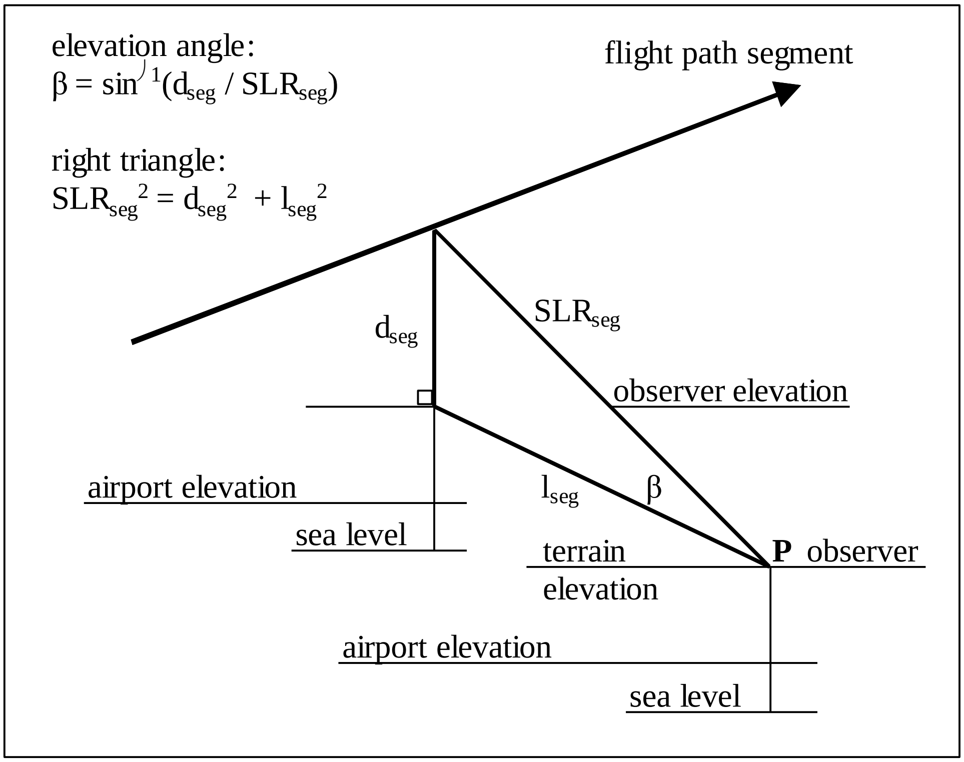

Figure 4-4 Lateral Attenuation Geometry

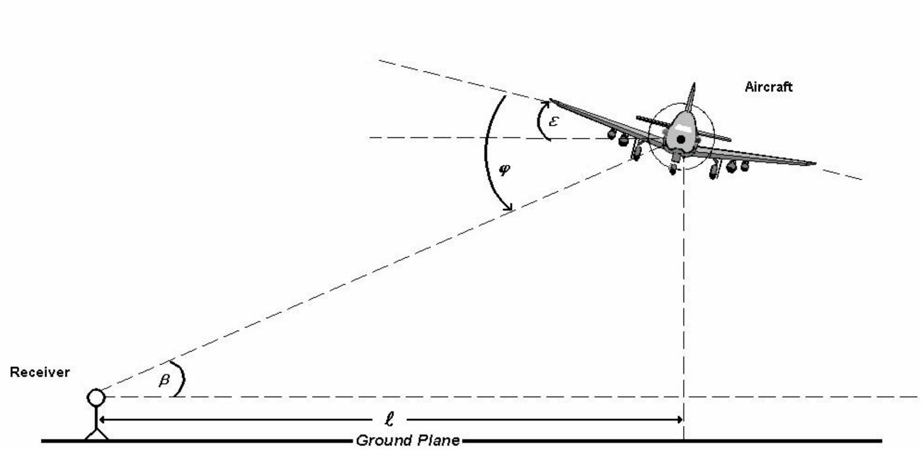

Figure 4-5 Bank Angle ε, Elevation Angle β, Depression Angle ϕ, and Lateral Distance ℓ[29]

The four parameters are applied to the following equations for calculating lateral attenuation for civil 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, Λ(β). 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°;
2. Aircraft is airborne, the elevation angle is greater than 0°, and the lateral (or sideline) distance is greater than 3000 ft (914 m); or
3. Aircraft airborne, the elevation angle is greater than 0°, and the lateral distance is less than or equal to 3000 ft (914 m).

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 dB) for an airplane with fuselage-mounted jets engine is:

$$E_{FUS}(\varphi) = 10log_{10}([0.1225 \cdot \cos^2(\varphi) + \sin^2(\varphi)]^{0.329} \qquad -180° \leq \varphi \leq 180° \qquad \text{Eq. 4-28}$$

where

φ depression angle (°).

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

$$E_{WING}(\varphi) = \begin{cases} 10log_{10}\left(\dfrac{[0.0039 \cdot \cos^2(\varphi) + \sin^2(\varphi)]^{0.062}}{[0.8786 \cdot \sin^2(2\varphi) + \cos^2(2\varphi)]}\right) & 0° \leq \varphi \leq 180° \\ -1.49 & 0° > \varphi > 180° \end{cases} \qquad \text{Eq. 4-29}$$

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

$$E_{PROP}(\varphi) = 0.00 \qquad \text{Eq. 4-30}$$

Since helicopter directional effects are represented by the left-center-right NPD curves and the directivity adjustments, see Section 4.4.2, their engine installation effects are already taken into account and therefore are represented by:

$$E_{HELI}(\varphi) = E_{PROP}(\varphi) = 0.00 \qquad \text{Eq. 4-31}$$

The engine installation effects for jet-powered airplanes are illustrated in Figure 4-6.

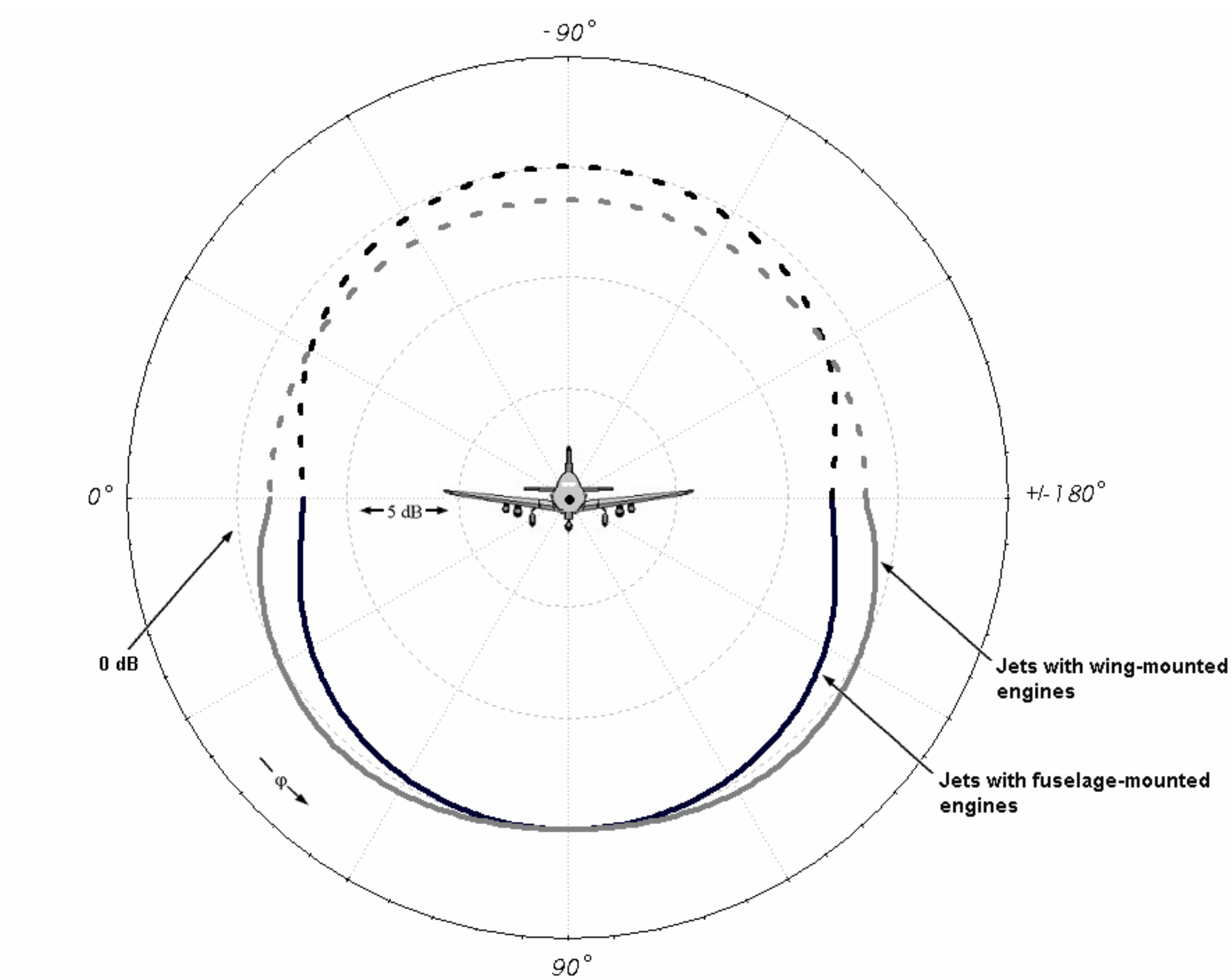

Figure 4-6 Illustration of Engine-Installation Effects for Jet-Powered Airplanes[29]

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

$$G(l_{seg}) = \begin{cases} 11.83 \cdot \left[1 - e^{-0.00274 \cdot l_{seg}}\right] & 0 \leq l_{seg} \leq 914\,m\ (3000\,ft) \\ 10.86 & l_{seg} > 914\,m\ (3000\,ft) \end{cases} \qquad \text{Eq. 4-32}$$

where

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

The ground-to ground component of the lateral attenuation adjustment is illustrated in Figure 4-7.

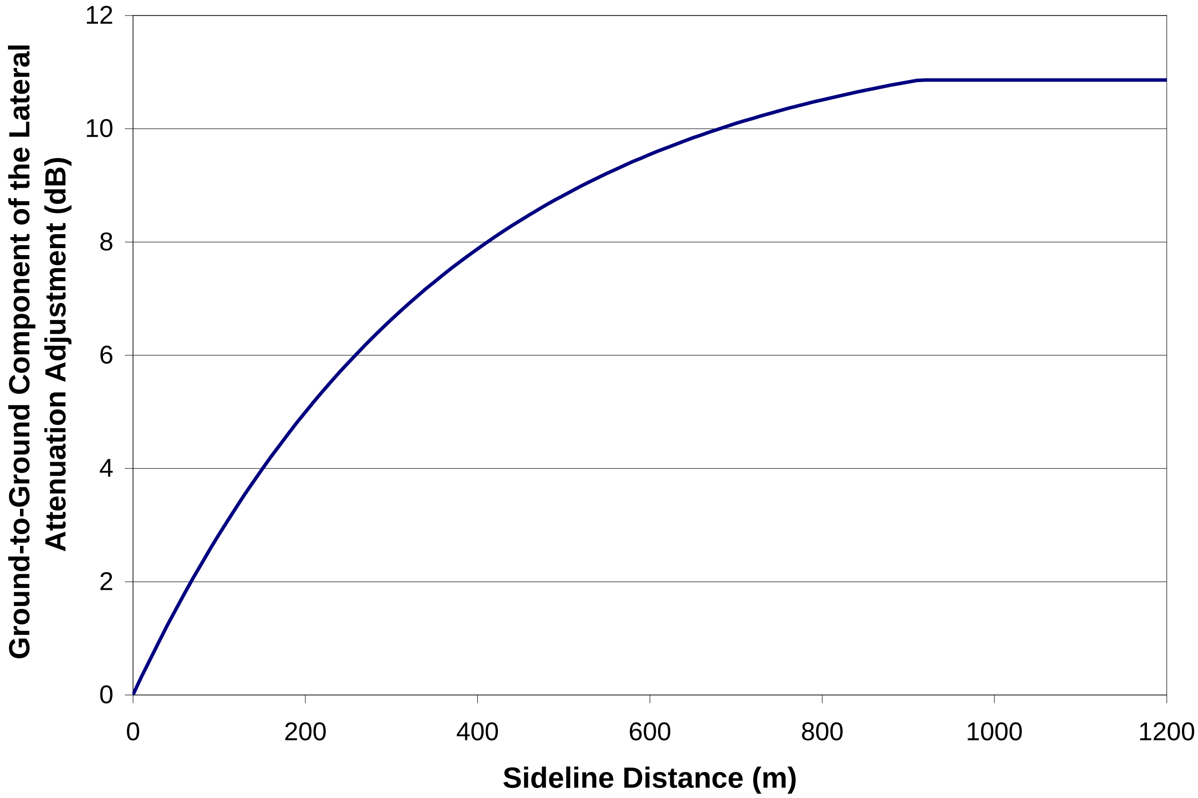

Figure 4-7 Illustration of Ground-to-Ground Component of Lateral Attenuation

The refraction-scattering, or air-to-ground, component of the lateral attenuation adjustment, Λ(β), is computed as follows:

$$\Lambda(\beta) = \begin{cases} 10.86 & \beta \leq 0° \\ 1.137 - 0.0229\beta + 9.72 \cdot e^{-0.142\beta} & 0° < \beta \leq 50° \\ 0.0 & 50° < \beta \leq 90° \end{cases} \qquad \text{Eq. 4-33}$$

where

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

The air-to-ground component of the lateral attenuation adjustment is illustrated in Figure 4-8.

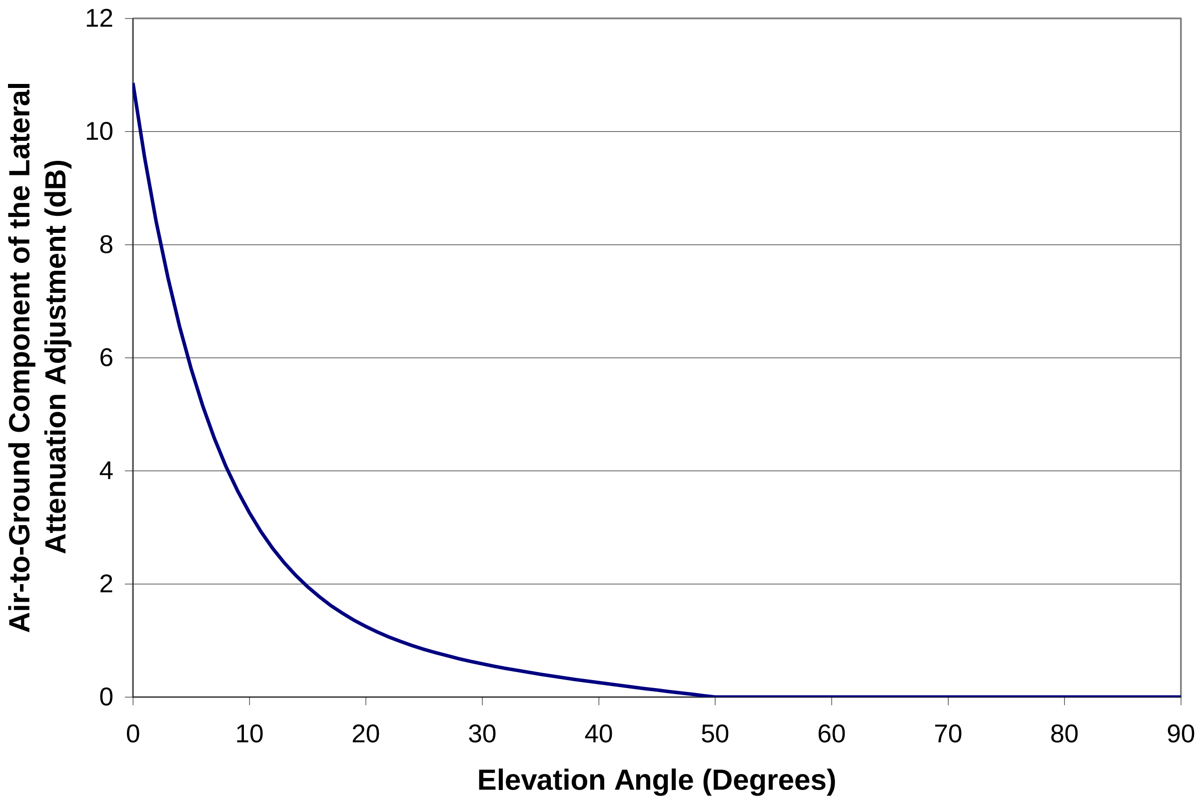

Figure 4-8 Illustration of Air-to-Ground Component of Lateral Attenuation

The overall lateral attenuation adjustment, LA_{ADJ} (in dB)[xii] 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:

$$LA_{ADJ(AEDT)} = -\left[E_{ENGINE}(\varphi) - \frac{G(l_{seg}) \cdot \Lambda(\beta)}{10.86}\right] \qquad \text{Eq. 4-34}$$

It is important to note that the depression angle in Figure 4-8 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.

4.3.5.2 Military Aircraft

The AEDT Fleet database includes all of the aircraft from the United States Air Force NOISEMAP suite of programs[30] as of March 2001. For military aircraft, computation of the lateral attenuation adjustment depends upon the elevation angle, β. If the elevation angle is less than 2 degrees, the adjustment has a

[xii] For AEDT 2a Aircraft, the sign of $LA_{ADJ\ (AEDT)}$ is made negative (see Eq. 4-34) in order to fit AEDT 2a calculation conventions.

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[xiii]:

$$G(l_{seg}) = \begin{cases} 15.09 \cdot \left[1 - e^{-0.00274 \cdot l_{seg}}\right] & 0 \leq l_{seg} \leq 401\, m\, (1316\, ft) \\ 10.06 & l_{seg} > 401\, m\, (1316\, ft) \end{cases} \qquad \text{Eq. 4-35}$$

where

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

The ground-to-ground component of the lateral attenuation adjustment for military aircraft is illustrated in Figure 4-9.

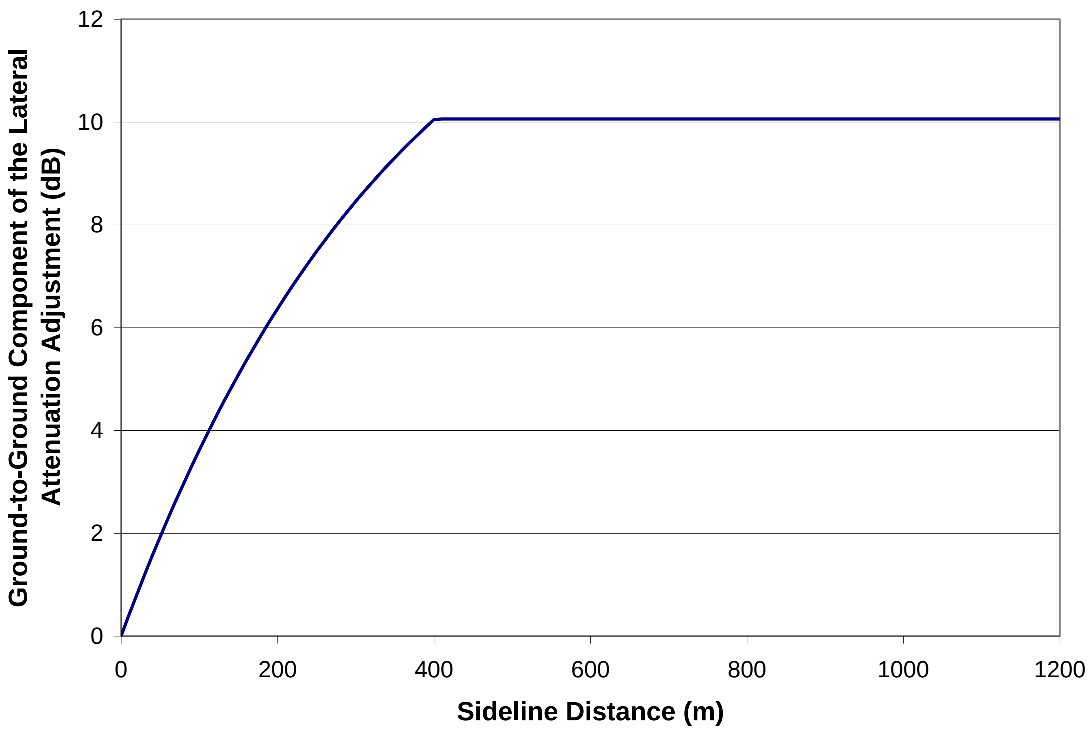

Figure 4-9 Illustration of Ground-to-Ground Component of Lateral Attenuation for Military Aircraft

[xiii] 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 AEDT 2a and NOISEMAP results directly, especially in the immediate vicinity of the airport runways.

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

$$\Lambda(\beta) = \begin{cases} \left(\dfrac{21.056}{\beta}\right) - 0.468 & 2° \leq \beta \leq 45° \\ 0 & 45° \leq \beta \leq 90° \end{cases} \qquad \text{Eq. 4-36}$$

where

β elevation angle (°); if $\beta > 0°$, β is set to 0°.

The air-to-ground component of the lateral attenuation adjustment for military aircraft is illustrated in Figure 4-10.

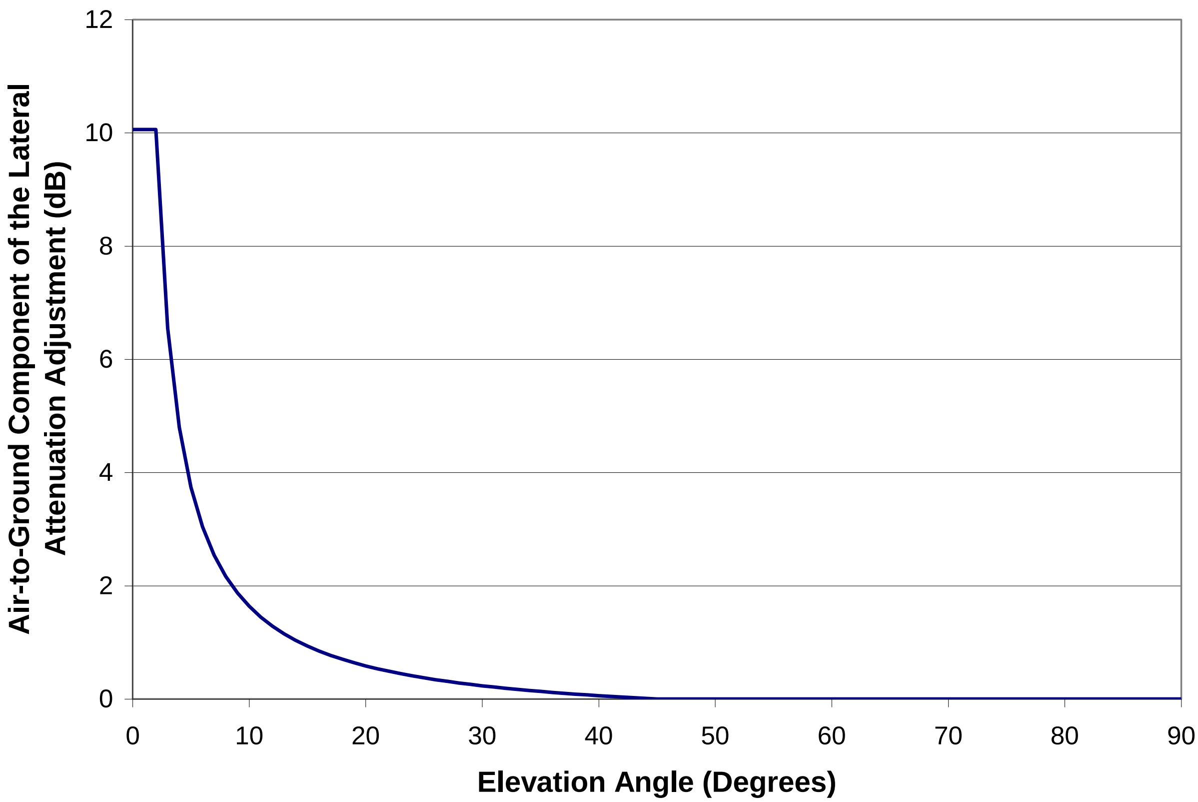

Figure 4-10 Illustration of Air-to-Ground Component of Lateral Attenuation for Military Aircraft

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

$$LA_{ADJ(Military)} = \frac{G(l_{seg}) \cdot \Lambda(\beta)}{10.06} \qquad \text{Eq. 4-37}$$

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

This adjustment 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 over the top of terrain features. The path length difference is used to compute the 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. Figure 4-11 illustrates LOS blockage from a terrain feature.

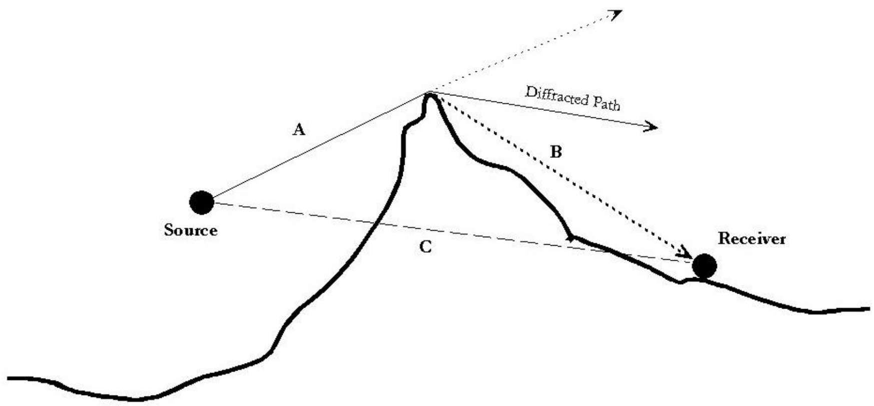

Figure 4-11 Line-of-Sight (LOS) Blockage Concept

The path length difference must be computed first using the following equation:

$$\delta_0 = (A + B) - C \qquad \text{Eq. 4-38}$$

where

A	distance between the source and the top of the barrier;
B	distance between the top of the barrier and the receiver; and
C	distance between the source and the receiver.

The LOS_{ADJ} is based on the theoretical, frequency-dependent barrier effect (assuming a barrier of infinite length), which is calculated with the following equation:

$$BE_i = \begin{cases} 5 + 20log_{10}\left(\dfrac{\sqrt{2\pi|N_{0,i}|}}{\tan\left(\sqrt{2\pi|N_{0,i}|}\right)}\right) & N_{0,i} < 0 \\ 5 + 20log_{10}\left(\dfrac{\sqrt{2\pi|N_{0,i}|}}{\tanh\left(\sqrt{2\pi|N_{0,i}|}\right)}\right) & N_{0,i} \geq 0 \end{cases} \qquad \text{Eq. 4-39}$$

where

BE_i	barrier effect for the i-th one-third octave band; and
$N_{0,i}$	Fresnel Number determined along the path defined by a particular source-barrier-receiver geometry for the i-th one-third octave band; computed as follows:

$$N_{0,I} = \pm 2\left(\frac{\delta_0}{\lambda_i}\right) = \pm 2\left(\frac{f_i \delta_0}{c}\right) \qquad \text{Eq. 4-40}$$

where

$\pm$	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, and =(A+B)-C (see Figure 4-11);
λ_i	wavelength of the sound radiated by the source (i-th one-third octave band);
f_i	frequency of the sound radiated by the source (i-th one-third octave band); and
c	speed of sound.

In AEDT 2a N_0 is limited to -0.1916 at the lower bound, and values of N_0 greater than 10 are set to 23.1[31].

Since LOS_{ADJ} is frequency dependent, the following adjustments are made to spectral classes in order to appropriately calculate LOS_{ADJ}:

1. The aircraft spectral class, SC, is corrected back to the source (from the 1000 ft reference), effectively removing the SAE-AIR-1845 reference atmosphere[14], using the following equation:

$$SC_{source,i} = SC_i - \left(\left(ac_{ref,i}\right) \cdot \left[-\frac{1000ft}{d_{ref}}\right]\right) \qquad \text{Eq. 4-41}$$

where

$ac_{ref,i}$	atmospheric absorption coefficient for the i-th third octave band for the reference atmosphere as presented in SAE-AIR-1845;
SC_i	i-th octave band of the spectral class;
$SC_{source,i}$	i-th octave band of the spectral class corrected back to the source; and
d_{ref}	1000 ft in AEDT 2a.

2. The source spectrum is then corrected to the receptor distance in the study atmosphere generated with SAE-ARP-866A[28], using the following equation:

$$SC_{LOS,i} = SC_{Source,i} - \left(\left(ac_{study,i}\right) \cdot \frac{SLR_{seg}}{d_{ref}}\right) \qquad \text{Eq. 4-42}$$

where

$ac_{study,i}$	atmospheric absorption coefficient for the i-th third octave band for the study-specific atmosphere as presented in SAE-AIR-1845;
$SC_{LOS,i}$	i-th octave band of the spectral class corrected back to the receptor;
SLR_{seg}	the slant range from the receptor to the start of the takeoff roll (ft); and
d_{ref}	1000 ft in AEDT 2a.

3. For each one-third octave band, the barrier effect is subtracted (in dB), BE_i, see Eq. 4-39, from SC_{LOS}, see Eq. 4-42. The result is referred to as $SC_{HPP,i}$.

$$SC_{HPP,i} = SC_{LOS,i} - BE_i \qquad \text{Eq. 4-43}$$

4. The energy is summed over $SC_{HPP,I}$ and converted to dB by the following equation:

$$HPP_{total} = 10log_{10}\left(\sum_{i=11}^{40} 10^{\frac{SC_{HPP,i}}{10}}\right) \qquad \text{Eq. 4-44}$$

5. The energy is summed over SC_{LOS} and converted to dB by the following equation:

$$LOS_{total} = 10log_{10}\left(\sum_{i=11}^{40} 10^{\frac{SC_{LOS,i}}{10}}\right) \qquad \text{Eq. 4-45}$$

6. Finally, LOS_{ADJ} can be computed using the following equation:

$$LOS_{ADJ} = HPP_{total} - LOS_{total} \qquad \text{Eq. 4-46}$$

If line-of-sight blockage is selected for the noise calculations, LOS_{ADJ} is compared to LA_{ADJ} on a point-by-point basis and the larger of the two values is applied to the calculations. For each segment-based noise calculation, either LOS_{ADJ} or AI_{ADJ} are implemented, but not both. This allows for a seamless transition between LOS_{ADJ} and 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”[32], 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 AEDT 2a, as a practical upper limit on barrier attenuation.

4.4 Fixed-Wing Aircraft Adjustments

The sound level adjustments presented in this Section are applicable only to fixed-wing aircraft, and not helicopters. These adjustments include thrust reverser (TR_{ADJ}) and ground-based directivity (DIR_{ADJ}).

4.4.1 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. The thrust reverser noise assumptions represent reverse thrust levels in typical aircraft operations, while maintaining agreement between measured and modeled noise generated during landing ground roll. This methodology is based on ECAC Doc 29[23] and “Thrust Reverser Analysis for Implementation in the Aviation Environmental Design Tool (AEDT 2a)”[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. These analyses were coordinated directly with the lead author of Doc 29 and are being considered for possible future enhancement of that document.

In the legacy noise tool (INM versions prior to version 7.0), thrust reverser was applied to all STANDARD approach profiles 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. These thrust values during landing ground roll were used to ensure good agreement between measured and modeled noise levels, but are not necessarily representative of actual thrust levels during thrust reverser deployment. Since the aircraft performance model is common to noise and emissions computations in AEDT 2a, the high thrust assumption is inappropriate when computing fuel burn and emissions. To appropriately model fuel burn and emissions, AEDT 2a 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[xiv]. In order to account for a higher noise level due to thrust reverser deployment than those due to a typical approach operation at a given thrust level, a 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:

$$TR_{ADJ} = \begin{cases} L_{unadj_{seg}} - L_{narrow_{seg}} & narrowbody\ aircraft \\ L_{unadj_{seg}} - L_{wide_{seg}} & widebody\ aircraft \\ 0 & propeller\ and\ military\ aircraft \end{cases} \quad \text{Eq. 4-47}$$

where

L_{unadj_seg}	noise level at P_{unadj_seg} based on Departure NPDs when $P_{unadj\_seg} \geq P_{final}$; noise level at P_{unadj_seg} based on Approach NPDs when $P_{unadj\_seg} < P_{final}$;
P_{final}	the last power setting before thrust reverser is applied;
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 the following equations:

$$P_{unadj\_seg} = \left[\frac{d_{rev\_seg}}{d_{rev}} \cdot (P_{60\%} - P_{10\%})\right] + P_{10\%} \quad \text{Eq. 4-48}$$

$$P_{narrow\_seg} = \left[\frac{d_{rev\_seg}}{d_{rev}} \cdot (P_{40\%} - P_{10\%})\right] + P_{10\%} \quad \text{Eq. 4-49}$$

$$P_{wide\_seg} = \left[\frac{d_{rev\_seg}}{d_{rev}} \cdot (P_{10\%} - P_{10\%})\right] + P_{10\%} = P_{10\%} \quad \text{Eq. 4-50}$$

where

$P_{60\%}$	60% Max Thrust, which is the legacy reverse thrust implementation;
$P_{40\%}$	40% Max Thrust, which is the current reverse thrust implementation for narrowbody aircraft;

[xiv] There is no thrust reverser adjustment for propeller-driven aircraft in AEDT 2a.

$P_{10\%}$	10% Max Thrust, which is the current reverse thrust implementation for widebody aircraft;
d_{rev}	the distance along the runway from the point of thrust reverser deployment to the end of the landing ground roll, where: $d_{rev} = -0.9 \cdot s_{stop}$;
s_{stop}	the location on the runway where the landing ground roll ends; and
d_{rev_seg}	the distance along the runway from the aircraft position to the end of the landing ground roll, where: $d_{rev\_seg} = -(300 + s_{stop} - d)$

where

d   aircraft distance down the runway

Engine power, aircraft speed, and reverse thrust levels for a standard landing ground roll are presented in Figure 4-12. In Figure 4-12 P_{rev} is 10% max thrust for widebody aircraft, and P_{rev} is 40% max thrust for narrowbody aircraft. In both cases, the ending engine power setting is 10%.

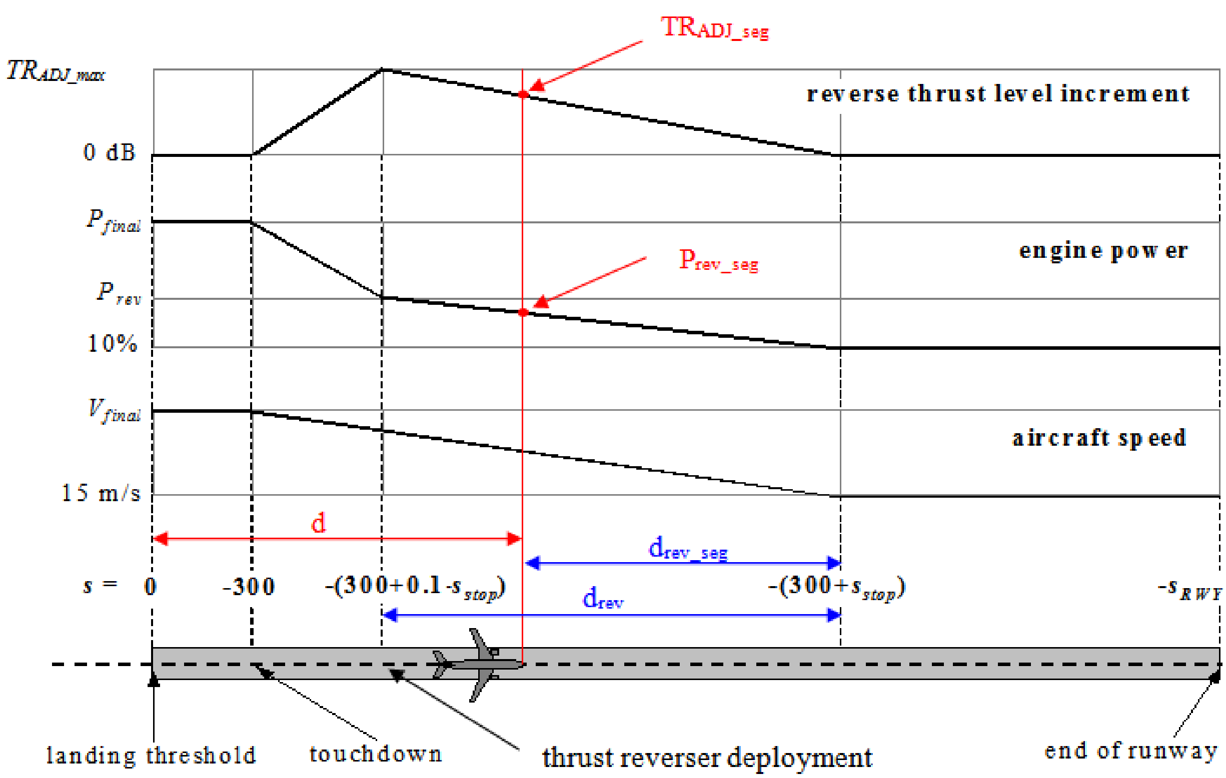

Figure 4-12 Modeling of Thrust Reverser Deployment During Landing Ground Roll

The thrust reverser adjustment in AEDT 2a represents the most up-to-date method to model thrust reverser engine power levels used in the derivation of noise levels in an integrated model. Additional data collection and research efforts are on-going and may result in future refinements.

4.4.2 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 receptor.

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 receptor location to the aircraft, is also applied.

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

$$\theta = \cos^{-1}\left(\frac{q}{r_1}\right) \qquad \text{Eq. 4-51}$$

where

q relative distance between points P_1 and P_s (ft) (by definition, the value of q is negative); and

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

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 receptor is behind start of takeoff.

The directivity adjustment, DIR_{ADJ} is computed as a function of azimuth angle:

For θ between 90° and 148.4°,

$$DIR_{ADJ} = 51.44 - (1.553 \cdot \theta) - (0.015147 \cdot \theta^2) + (0.000047173 \cdot \theta^3) \qquad \text{Eq. 4-52}$$

For θ between 148.4° and 180°,

$$DIR_{ADJ} = 339.18 - (2.5802 \cdot \theta) - (0.0045545 \cdot \theta^2) + (0.000044193 \cdot \theta^3) \qquad \text{Eq. 4-53}$$

Eq. 4-52 and Eq. 4-53 are plotted in Figure 4-13. The directivity adjustment is symmetric along the longitudinal axis of the aircraft in AEDT 2a. This adjustment supplements the noise fraction adjustment for modeling noise from the start-of-takeoff ground roll, NF_{ADJ}, see Section 4.3.3.2.

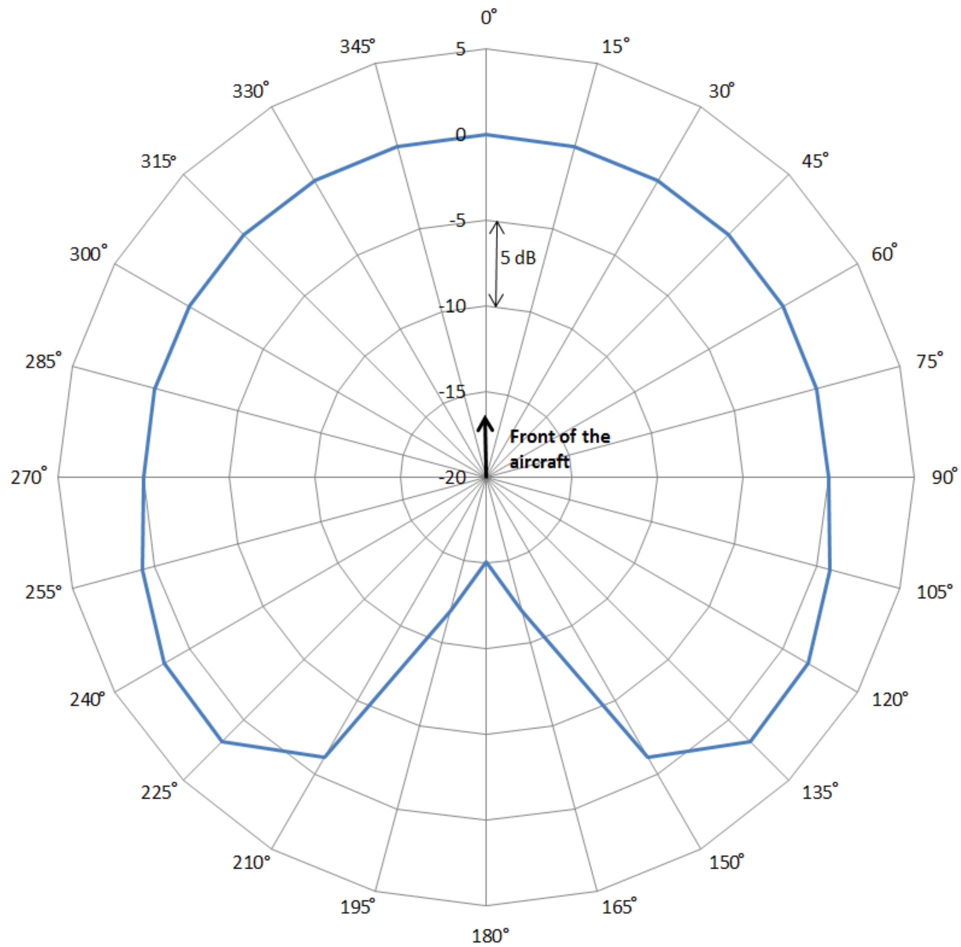

Figure 4-13 Ground-Based Directivity Adjustment

The directivity adjustment, DIR_{ADJ}, is modified by a smoothing equation that is computed as a function of slant range from the receptor location to start of takeoff, SLR_{seg}. The smoothing function is activated when SLR_{seg} is greater than 2,500 ft. The function, which reduces the directivity by a factor of 50% per doubling of distance, is given by:

$$DIR_{ADJ} = DIR_{ADJ} \cdot \left(\frac{2500}{SLR_{seg}}\right) \qquad SLR_{seg} > 2{,}500\ feet \qquad \text{Eq. 4-54}$$

4.5 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}).

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

This adjustment is necessary when the airspeed, temperature or rotor RPM deviates from the reference values. The adjustment is calculated using stored constants from a polynomial regression using the following equation:

$$MN_{ADJ} = B_0 + B_1 \cdot \left(M_{ADV_T} - M_{ADV_R}\right) + B_2 \cdot (M_{ADV_T} - M_{ADV_R})^2 \quad \text{Eq. 4-55}$$

where

B_0,B_1,B_2	helicopter specific coefficients;
V_T	operational airspeed (kts);
V_R	reference airspeed for the noise curve (kts); and
M_{ADV}	advancing tip Mach number, as defined by:

$$M_{ADV} = \frac{(1.688 \cdot V) + \left(\frac{\pi \cdot D \cdot RPM}{60}\right)}{c} \quad \text{Eq. 4-56}$$

where

V	airspeed (kts);
D	blade diameter (ft);
RPM	blade rotations per minute; and
c	speed of sound in air (ft/s), as defined by:

$$c = 49.018 \cdot (459.63 + T)^{1/2} \quad \text{Eq. 4-57}$$

where

T	temperature (F).

An example of the derivation of advancing tip Mach number adjustment from measured data can be found in the 1993 report "Noise Measurement Flight Test of Five Light Helicopters"[35].

4.5.2 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 Section 4.2.2.4). 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:

$$LD_{ADJ} = (L_{Left\ or\ Right} - L_{Center}) \cdot \left(\frac{|\beta| - 90}{45 - 90}\right) \quad \text{Eq. 4-58}$$

where

L_{Left}, L_{Center}, L_{Right}	left, center, or right NPD data and
β	observed elevation angle between 90° and 45°on either side of the helicopter (see Figure 4-14).

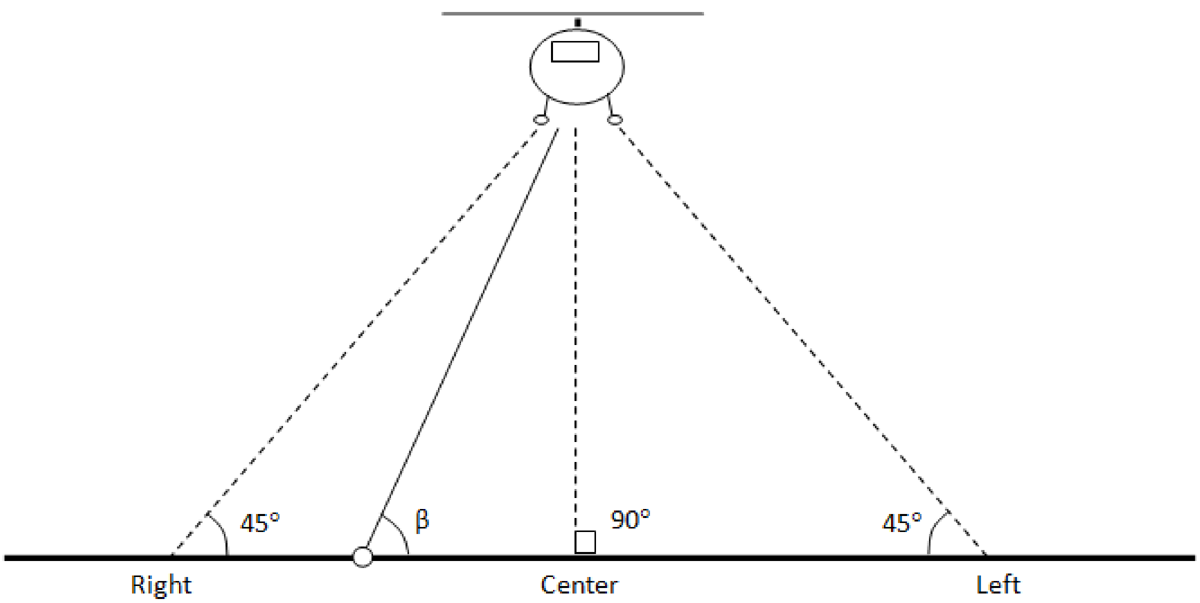

Figure 4-14 Elevation Angle for Helicopter Lateral Directivity Adjustment

For observed elevation angle less than 45° 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 4-14 for a dynamic operational mode, see Section 3.6.2.2 for a list of helicopter operational modes. An example of helicopter sound pressure levels according to elevation angle for a dynamic operational mode is shown in Figure 4-15.

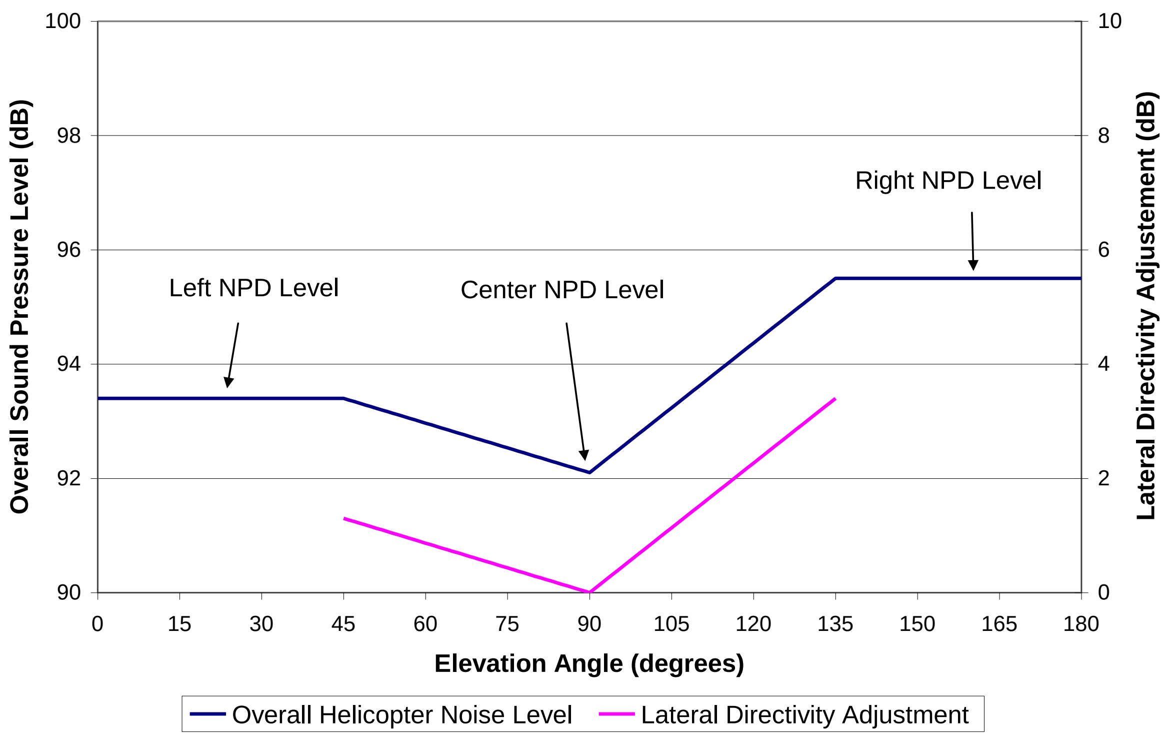

Figure 4-15 Example Helicopter Sound Pressure Levels According to Elevation Angle (Including Helicopter Lateral Directivity Adjustment)

4.5.3 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 2.1.4.3. 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).

4.5.4 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 cannot 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 4.6.2.3).

4.6 Noise Computation

The single-event noise data described in Section 4.2 and the noise level adjustments described in Sections 4.3, 4.4, and 4.5 are used to compute the single-event noise values at the receptors. This includes the application of system (or study-wide) adjustments to interpolated NPD data (see Section 4.6.1), the computation of the single-event noise for the nine base metrics in the following categories:

exposure-based noise level metrics L_{AE}, L_{CE} and L_{EPN} (see Section 4.6.2), the maximum noise level metrics L_{ASmx}, L_{CSmx} and L_{PNTSmx} (see Section 4.6.3), and the time-based metrics TA_{LA}, TA_{LC}, and TA_{PNL} (see Section 4.6.4). The noise computations are run iteratively when additional base metrics are desired. Once all of the single-events for an analysis have been computed for the applicable base metrics, then the single event results are accumulated across all of the events in the analysis and the appropriate noise metrics are computed (see Section 4.6.5).

Figure 4-16 graphically summarizes the acoustic computation process employed in AEDT 2a for a computing noise from a single flight path segment (or runup or static operation) at a single receptor, when terrain processing is not selected. Figure 4-17 summarizes the same computation process, when terrain processing is selected.

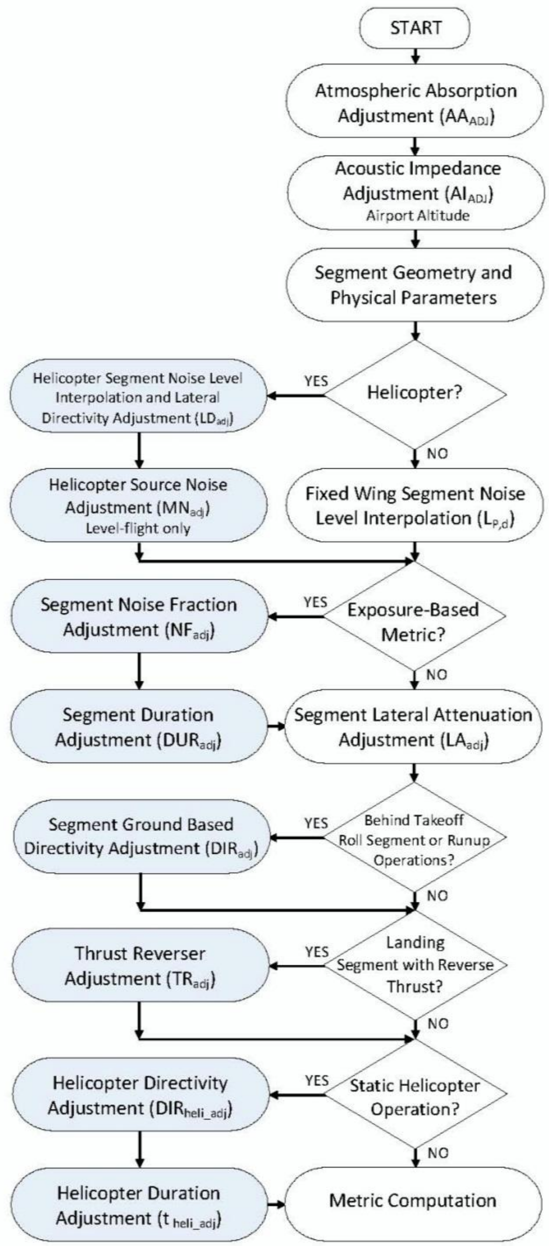

Figure 4-16 AEDT 2a Acoustic Computation Process without Terrain for a Single Flight Segment

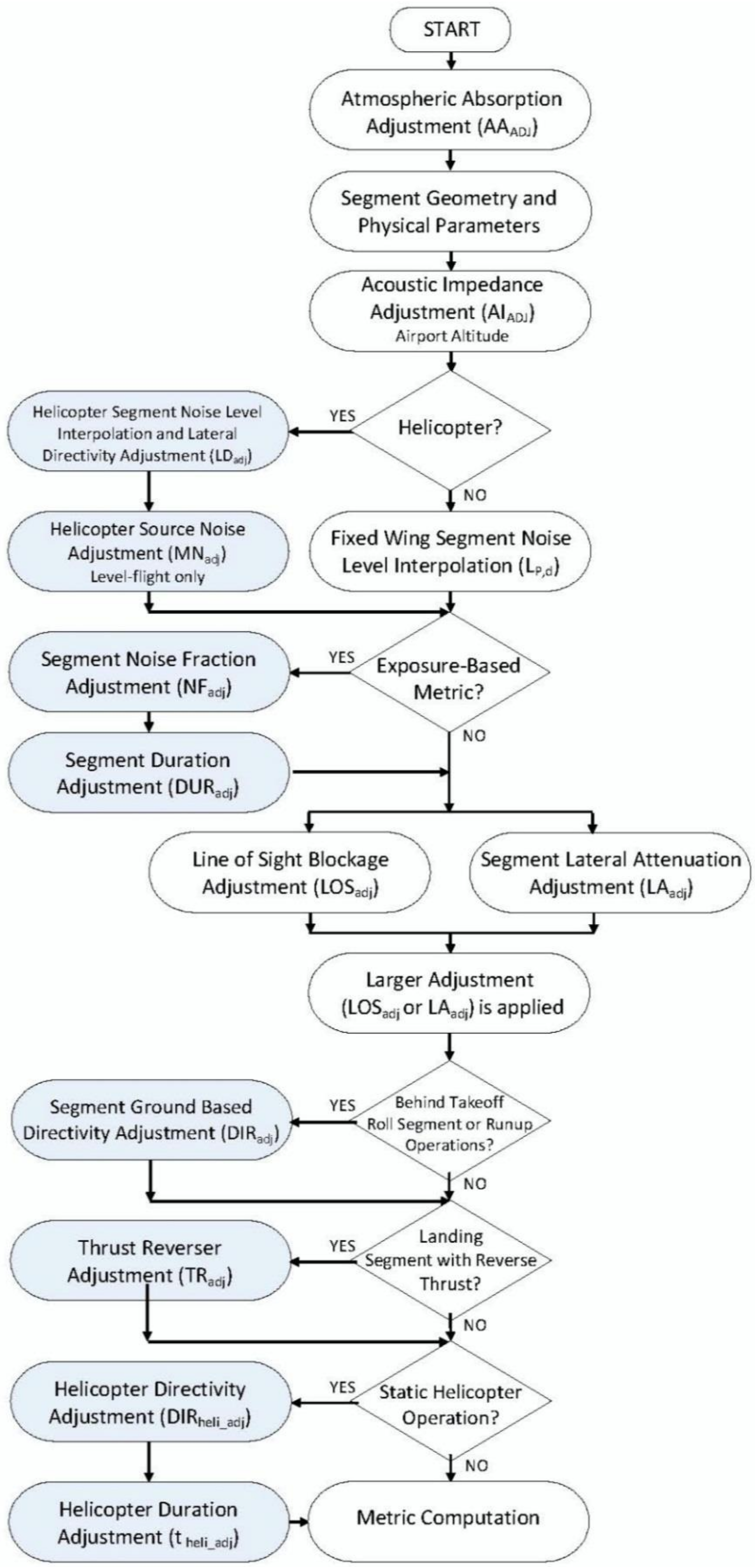

Figure 4-17 AEDT 2a Acoustic Computation Process with Terrain for a Single Flight Segment

4.6.1 System Adjustments

AEDT 2a applies study-wide adjustments to the interpolated NPD data. These adjustments include atmospheric absorption (AA_{ADJ}, Section 4.3.1) and acoustic impedance (AI_{ADJ}, Section 4.3.2). When terrain processing is not utilized in analysis, both study-wide atmospheric absorption (AA_{ADJ}) and acoustic impedance (AI_{ADJ}) adjustments are applied to the NPD according to the following equations:

$$L_{E,P,d-ADJ} = L_{E,P,d} + \left[AA_{ADJ} + AI_{ADJ}\right]_{study-wide} \quad \text{Eq. 4-59}$$

$$L_{Smx,P,d-ADJ} = L_{Smx,P,d} + \left[AA_{ADJ} + AI_{ADJ}\right]_{study-wide} \quad \text{Eq. 4-60}$$

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 (see Section 4.2.2) and atmospheric absorption and acoustic impedance (see Sections 4.3.1 and 4.3.2);
- $L_{E,P,d}$ — exposure NPD level; and
- $L_{Smx,P,d}$ — unadjusted, L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process (see Section 4.2.2), where the maximum noise level is computed at each segment end and the CPA, and the maximum of the three levels is used; and
- $L_{Smx,P,d}$ — maximum NPD level.

When terrain processing is utilized in an analysis, the acoustic impedance adjustment (AI_{ADJ}) is applied separately for each receptor, using the terrain elevation at the receptor's location instead of the airport elevation. For studies with terrain elevation processing, noise level interpolation is undertaken by first adjusting NPD curves using the study-wide atmospheric absorption adjustment (AA_{ADJ}), and then the receptor location-specific acoustic impedance adjustment is added to the sound levels after noise level interpolation:

$$L_{E,P,d-ADJ} = L_{E,P,d} + \left[AA_{ADJ}\right]_{study-wide} + \left[AI_{ADJ}\right]_{study-wide} \quad \text{Eq. 4-61}$$

$$L_{Smx,P,d-ADJ} = L_{Smx,P,d} + \left[AA_{ADJ}\right]_{study-wide} + \left[AI_{ADJ}\right]_{study-wide} \quad \text{Eq. 4-62}$$

4.6.2 Computation of Exposure-Based Noise Level Metrics

The exposure-based metrics represent the total sound exposure for a given time period, often 24 hours, at a receptor location based upon average annual day conditions at an airport. AEDT 2a standard sound exposure base 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).

This Section presents the computation of exposure-based noise level metrics for both fixed wing aircraft flight operations (Section 4.6.2.1), including runup operations (Section 4.6.2.2), and helicopter flight operations (Section 4.6.2.3), including static operations (Section 4.6.2.4). To obtain the total noise exposure at a receptor location, the contributions from all the operations in an analysis (fixed wing flight operations and runup operations, and helicopter flight and static operations) are combined (Section 4.6.5).

4.6.2.1 Fixed-Wing Aircraft Flight Operations

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

$$E_{Seg} = 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} + DUR_{ADJ} - LA_{ADJ} + TR_{ADJ} + DIR_{ADJ}]}{10}} \qquad \text{Eq. 4-63}$$

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 (see Section 4.2.2) and atmospheric absorption and acoustic impedance adjustments (see Section 4.3 and 4.6.1);
- NF_{ADJ} — noise fraction adjustment, in dB (see Section 4.3.3);
- DUR_{ADJ} — aircraft speed duration adjustment, in dB (see Section 4.3.4);
- LA_{ADJ} — lateral attenuation adjustment, in dB (see Section 4.3.5);
- TR_{ADJ} — thrust reverser adjustment, in dB, which is applied only if the fixed path segment is part of the landing ground roll during thrust reverser deployment (see Section 4.4.1); and
- DIR_{ADJ} — directivity adjustment, in dB, which is applied only if the fixed path segment is part of takeoff ground roll (see Section 4.4.2)

If line-of-sight blockage is invoked, LA_{ADJ} is compared to line-of-sight blockage adjustment (LOS_{ADJ}, see Section 4.3.6) 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 Eq. 4-63 can be rewritten as:

$$E_{Seg} = 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} + DUR_{ADJ} - (max[LOS_{ADJ}, LA_{ADJ}]) + TR_{ADJ} + DIR_{ADJ}]}{10}} \qquad \text{Eq. 4-64}$$

where

- LOS_{ADJ} — line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The sound exposure ratio associated with each path segment in a flight operation is computed iteratively and preserved.

4.6.2.2 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:

$$P_{runup} = 10^{\frac{[L_{Smx,P,d-ADJ} - LA_{ADJ} + DIR_{ADJ}]}{10}} \qquad \text{Eq. 4-65}$$

where

- $L_{Smx,P,d\text{-}ADJ}$ — L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process using NPD data (see Section 4.2.2) and atmospheric absorption and acoustic impedance adjustments (see Section 4.3 and 4.6.1);
- DIR_{ADJ} — directivity adjustment, in dB (see Section 4.4.2); and
- LA_{ADJ} — lateral attenuation adjustment, in dB (see Section 4.3.5).

If line-of-sight blockage is invoked, 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:

$$P_{runup} = 10^{\frac{[L_{Smx,P,d-ADJ} - (max[LOS_{ADJ}, LA_{ADJ}]) + DIR_{ADJ}]}{10}} \quad \text{Eq. 4-66}$$

where

LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The sound exposure ratio due to a single runup operation for a fixed-wing aircraft, E_{runup}, takes into account time duration of the runup operation. The sound exposure ratio is computed as follows:

$$E_{runup} = \left(\frac{t_{runup}}{t_0}\right) \cdot P_{runup} \quad \text{Eq. 4-67}$$

where

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

The sound exposure ratio associated with each runup operation is computed iteratively and preserved.

4.6.2.3 Helicopter Flight Operations

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

$$E_{seg\_HELI} = 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} + DUR_{ADJ} - LA_{ADJ} + MN_{ADJ} + LD_{ADJ}]}{10}} \quad \text{Eq. 4-68}$$

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 (see Section 4.2.2) and atmospheric absorption and acoustic impedance adjustments (see Section 4.3 and 4.6.1);
NF_{ADJ} noise fraction adjustment, in dB (see Section 4.3.3);
DUR_{ADJ} aircraft speed duration adjustment, in dB (see Section 4.3.4);
LA_{ADJ} lateral attenuation adjustment, in dB (see Section 4.3.5);
MN_{ADJ} helicopter source noise adjustment, in dB (see Section 4.5.1); and
LD_{ADJ} lateral directivity adjustment for helicopters, in dB (see Section 4.5.2).

If line-of-sight blockage is invoked, 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:

$$E_{seg\_HELI} = 10^{\frac{[L_{E,P,d-ADJ} + NF_{ADJ} + DUR_{ADJ} - (max[LOS_{ADJ}, LA_{ADJ}]) + MN_{ADJ} + LD_{ADJ}]}{10}} \quad \text{Eq. 4-69}$$

where

LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The sound exposure ratio associated with each path segment in a helicopter flight operation is computed iteratively and preserved.

4.6.2.4 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:

$$E_{seg\_HELI} = t_{HELI\_static} \cdot 10^{\frac{\left[L_{E,P,d-ADJ} + NF_{ADJ} - LA_{ADJ} + DIR_{HELI\_ADJ}\right]}{10}} \qquad \text{Eq. 4-70}$$

where

- t_{HELI_static} helicopter duration adjustment for static operations, in dB (see Section 4.5.4)
- $L_{E,P,d\text{-}ADJ}$ L_{AE},L_{CE}, or L_{EPN}, in DB, resulting from the noise interpolation process using NPD data (see Section 4.2.2) and atmospheric absorption and acoustic impedance adjustments (see Section 4.3 and 4.6.1);
- NF_{ADJ} noise fraction adjustment, in dB (see Section 4.3.3);
- LA_{ADJ} lateral attenuation adjustment, in dB (see Section 4.3.5); and
- DIR_{HELI_ADJ} helicopter directivity adjustment for static operations, in dB (see Section 4.5.3).

If line-of-sight blockage is invoked, 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:

$$E_{seg\_HELI} = t_{HELI\_static} \cdot 10^{\frac{\left[L_{E,P,d-ADJ} + NF_{ADJ} - \left(max\left[LOS_{ADJ}, LA_{ADJ}\right]\right) + DIR_{HELI\_ADJ}\right]}{10}} \qquad \text{Eq. 4-71}$$

where

- LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The sound exposure ratio associated with each static helicopter operation is computed iteratively and preserved.

4.6.3 Computation of Maximum Noise Level Metrics

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

AEDT 2a standard maximum noise level base 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).

This Section presents separately the computation of maximum noise level metrics for aircraft flight operations (Section 4.6.3.1), including runup operations (Section 4.6.3.2), and helicopter flight operations (Section 4.6.3.3), including static operations (Section 4.6.3.4). To obtain the maximum noise level at a receptor location, the contributions from all the operations in an analysis (fixed wing flight operations and runup operations, and helicopter flight and static operations) are combined (Section 4.6.5).

4.6.3.1 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:

$$L_{Smx,seg} = L_{Smx,P,d-ADJ} - LA_{ADJ} + TR_{ADJ} + DIR_{ADJ} \qquad \text{Eq. 4-72}$$

where

$L_{Smx,P,d\text{-}ADJ}$ L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process (see Section 4.2.2), where the maximum noise level is computed at each segment end and the CPA, and the maximum of the three levels is used, along with atmospheric absorption and acoustic impedance adjustments (see Section 4.3 and 4.6.1);
LA_{ADJ} lateral attenuation adjustment, in dB (see Section 4.3.5);
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 4.4.1); and
DIR_{ADJ} directivity adjustment, in dB, which is applied only if the flight path segment is part of takeoff ground roll (see Section 4.4.2).

If line-of-sight blockage is invoked, 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 (in place of LA_{ADJ}). Therefore, if line-of-sight blockage is invoked, Eq. 4-72 can be rewritten as:

$$L_{Smx,seg} = L_{Smx,P,d-ADJ} - max[LA_{ADJ}, LOS_{ADJ}] + TR_{ADJ} + DIR_{ADJ} \qquad \text{Eq. 4-73}$$

where
LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The maximum noise level associated with each path segment in a flight operation is computed iteratively and preserved.

4.6.3.2 Fixed-Wing Aircraft Runup Operations

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

$$L_{Smx,runup} = L_{Smx,P,d-ADJ} - LA_{ADJ} + DIR_{ADJ} \qquad \text{Eq. 4-74}$$

where
$L_{Smx,P,d\text{-}ADJ}$ L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process (see Section 4.2.2), where the maximum noise level is computed at each segment end and the CPA, and the maximum of the three levels is used, along with atmospheric absorption and acoustic impedance adjustments (see Section 4.3 and 4.6.1);
LA_{ADJ} lateral attenuation adjustment, in dB (see Section 4.3.5); and
DIR_{ADJ} directivity adjustment, in dB, which is applied only if the flight path segment is part of takeoff ground roll (see Section 4.4.2).

If line-of-sight blockage is invoked, 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:

$$L_{Smx,runup} = L_{Smx,P,d-ADJ} - max[LA_{ADJ}, LOS_{ADJ}] + DIR_{ADJ} \qquad \text{Eq. 4-75}$$

where
LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The maximum noise level associated with each runup operation is computed iteratively and preserved.

4.6.3.3 Helicopter Flight Operations

The maximum noise level due to a single flight path segment for a helicopter, $L_{Smx.seg\_HELI}$, is computed as follows:

$$L_{Smx,seg\_HELI} = L_{Smx,P,d-ADJ} - LA_{ADJ} + MN_{ADJ} + LD_{ADJ} \qquad \text{Eq. 4-76}$$

where

$L_{Smx,P,d\text{-}ADJ}$ L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process (see Section 4.2.2), where the maximum noise level is computed at each segment end and the CPA. and the maximum of the three levels is used along with atmospheric absorption and acoustic impedance adjustments (see Section 4.3.1 and 4.6.1);

LA_{ADJ} lateral attenuation adjustment, in dB (see Section 4.3.5);

MN_{ADJ} helicopter source noise adjustment (see Section 4.5.1); and

LD_{ADJ} lateral directivity adjustment for helicopters, in dB, (see Section 4.5.2).

If line-of-sight blockage is invoked, 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:

$$L_{Smx,seg\_HELI} = L_{Smx,P,d-ADJ} - max[LA_{ADJ}, LOS_{ADJ}] + MN_{ADJ} + LD_{ADJ} \qquad \text{Eq. 4-77}$$

where

LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The maximum noise level associated with each path segment of a helicopter flight operation is computed iteratively and preserved.

4.6.3.4 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:

$$L_{Smx,HELI\_static} = L_{Smx,P,d-ADJ} - LA_{ADJ} + DIR_{HELI\_ADJ} \qquad \text{Eq. 4-78}$$

where

$L_{Smx,P,d\text{-}ADJ}$ L_{ASmx}, L_{CSmx}, or L_{PNTSmx}, in dB, resulting from the noise interpolation process (see Section 4.2.2), where the maximum noise level is computed at each segment end and the CPA. and the maximum of the three levels is used along with atmospheric absorption and acoustic impedance adjustments (see Section 4.3 and 4.6.1);

LA_{ADJ} lateral attenuation adjustment, in dB (see Section 4.3.5);

DIR_{HELI_ADJ} helicopter directivity adjustment for static operations, in dB (see Section 4.6.2.4)

If line-of-sight blockage is invoked, 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:

$$L_{Smx,HELI\_static} = L_{Smx,P,d-ADJ} - max[LA_{ADJ}, LOS_{ADJ}] + DIR_{HELI\_ADJ} \qquad \text{Eq. 4-79}$$

where

LOS_{ADJ} line-of-sight blockage adjustment, in dB (see Section 4.3.6).

The maximum noise level associated with each helicopter static operation is computed iteratively and preserved.

4.6.4 Computation of 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). The AEDT 2a standard time-based base metrics are:

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

In addition to standard time-based metrics, user-defined metrics are available in AEDT 2a. A user specifies the time period for determining the metric value.

This Section presents the computation of the time-based metrics for flight operations for fixed wing aircraft and helicopters (Section 4.6.4.1), as well as for ground operations (Section 4.6.4.2); which include both runup operations for fixed wing aircraft and static operations for helicopters. To obtain time-based metrics at a receptor location, the contribution from both flight operations and ground operations are combined.

4.6.4.1 Flight Operations

The time-above metric (TA_{flt}, in minutes) 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 (A-weighted, C-weighted, or the tone-corrected perceived metric family). TA is expressed in minutes and is computed on a per flight basis. TA due to a single flight operation (for both fixed wing aircraft and helicopters) is computed by the equation:

$$TA_{flt} = \begin{cases} \left(\frac{4}{\pi}\right) \cdot t_0 \cdot \left[10^{\frac{\left[L_{E,flt} - L_{Smx,flt}\right]}{10}}\right] \cdot \left[10^{\frac{\left[L_{Smx,flt} - L_0\right]}{20}} - 1\right]^{1/2} \cdot \frac{1}{60} & L_{Smx,flt} > L_0 \\ 0 & L_{Smx,flt} \leq L_0 \end{cases} \quad \text{Eq. 4-80}$$

where

- t_0 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 4.6.2);
- $L_{Smx,flt}$ adjusted maximum noise level for the flight (dB), L_{ASmx}, L_{CSmx}, L_{PNTSmx} (where $L_{Smx.flt}$ must be larger than L_0) (Section 4.6.3); and
- L_0 user-defined noise-level threshold (dB), expressed as A-weighted noise level, C-weighted noise level, or tone-corrected perceived noise level.

TA for each path segment of a flight operation is computed iteratively and preserved.

4.6.4.2 Ground Operations

The time-above metric for 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-defined noise level threshold is exceeded by the ground operation noise. The time-above for a ground operation is computed as follows:

$$TA_{ground} = \begin{cases} T_{ground} & L_{Smx} > L_0 \\ 0 & L_{Smx} \leq L_0 \end{cases} \qquad \text{Eq. 4-81}$$

where

T_{ground}	the time-above duration (minutes) of the ground operation event;
L_{Smx}	one of the tree types of adjusted maximum noise levels for ground operation (Section 4.6.3.2 for fixed wing aircraft and Section 4.6.3.4 for helicopters); and
L_0	the time-above noise threshold level.

TA for each runup operation is computed iteratively and preserved.

4.6.5 Accumulation of Noise Metric Computations

Once all of the noise is computed for each unique aircraft operation and flight path segment at each receptor in an AEDT 2a analysis, the noise results are accumulated and the final noise results and the appropriate analysis metrics are computed. The weighting and averaging factors used to compute the 16 different noise metrics in AEDT 2a, as well user-defined noise metrics, are discussed in Section 4.6.5.1. The process for accumulating exposure-based noise level metrics from all the aircraft operations at all the receptors in an AEDT 2a analysis is presented in Section 4.6.5.2. The process for accumulating maximum noise level metrics from all the aircraft operations at all the receptors in an AEDT 2a analysis is presented in Section 4.6.5.3. The process for accumulating time-based noise metrics from all the aircraft operations at all the receptors in an AEDT 2a analysis is presented in Section 4.6.5.4.

Figure 4-18 graphically summarizes the acoustic computation process employed in AEDT 2a for accumulating noise from all the aircraft operations at all the receptors in an analysis.

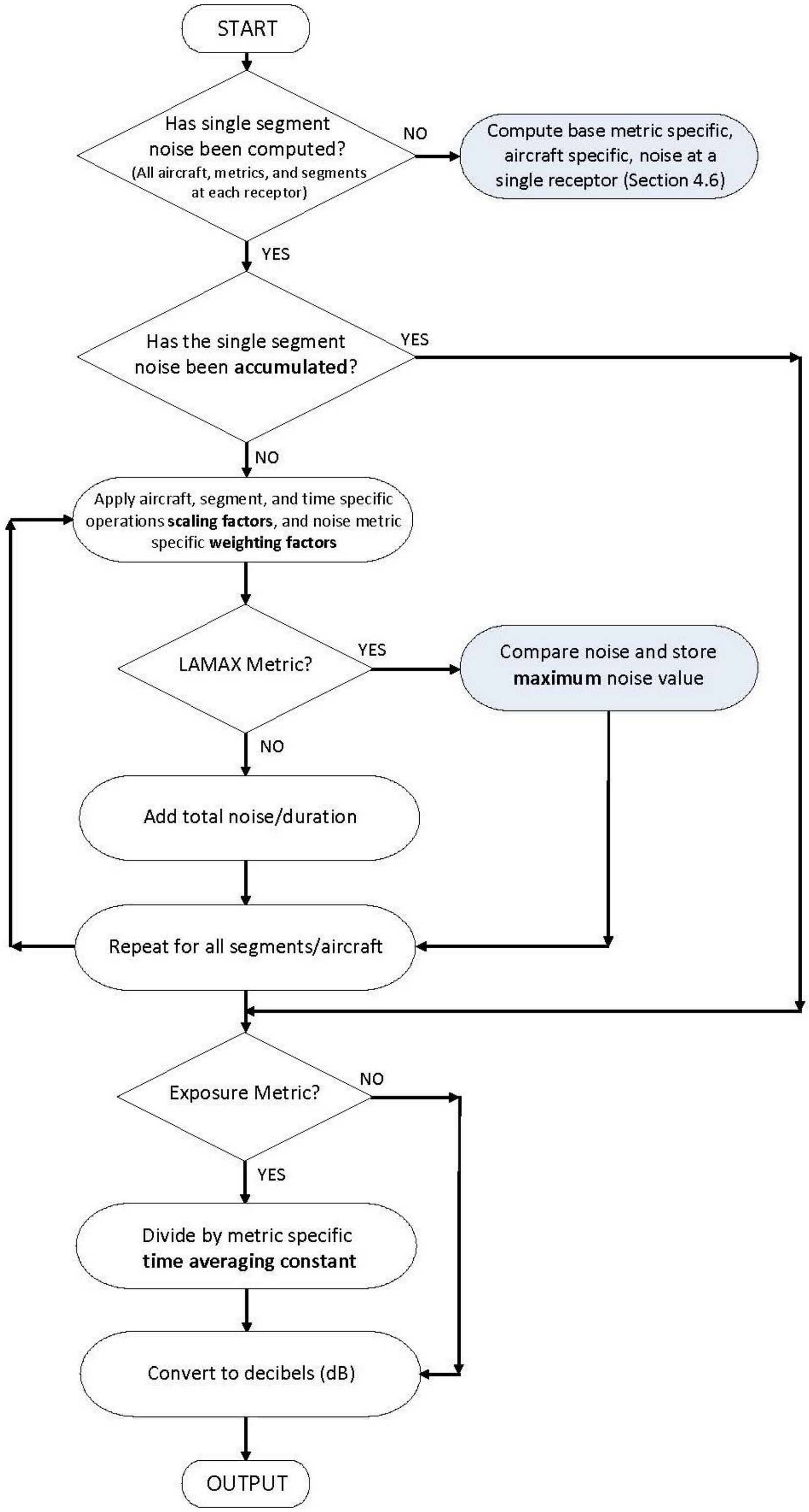

Figure 4-18 AEDT 2a Accumulation of Acoustic Computation Process

4.6.5.1 Noise Metric Weighting and Averaging Factors

As discussed in Section 2.2.1.2, there are four base noise level metrics: L_{AE}, L_{ASmx}, L_{EPN}, and L_{PNTSmx}. From those base metrics, AEDT 2a can compute 16 different noise metrics and user-defined metrics. The metrics that can be computed in AEDT 2a can be organized into three categories:

1. Exposure-based metrics, including change in exposure;
2. Maximum noise level metrics; and
3. Time-based metrics.

These 16 noise metrics are computed in AEDT 2a by applying metric-specific, time-averaging constants and/or day, evening, and night-time weighting factors to the base metrics. The time-averaging constant applies a metric-specific duration factor to the noise metric. For exposure metrics, the weighting factor applies time-period-specific weightings (or penalties) to events that occur during those time periods. 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.

In addition to AEDT 2a standard 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.

Table 4-2 summarizes associated weightings and averaging times.

Table 4-2 AEDT 2a Noise Metric-Specific Weighting and Averaging Factors

Noise Family	Metric Type	Noise Metric	Weighting Factors			Averaging Time (hr)	Time-Averaging Constant (N_T)
			Day (W_{day})	Evening (W_{eve})	Night (W_{ngt})		
A-Weighted	Exposure Based	SEL	1	1	1	-	1
		DNL	1	1	10	24	86400
		CNEL	1	3[xv]	10	24	86400
		LAEQ	1	1	1	24	86400
		LAEQD	1	1	0	15	54000
		LAEQN	0	0	1	9	32400
		User-defined	A	B	C	T	T*3600
	Maximum Level	LAMAX	1	1	1	-	-
		User-defined	A	B	C	-	-

[xv] In accordance with the technical definition, a 5 dB penalty is added to evening operations when computing the Lden 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 Lden metric, it was decided that AEDT 2a would be consistent with state law, rather than the traditional technical definition. The evening weighting factor in the LWECPN metric was changed to 3 for consistency. It is anticipated that this small difference will be of no practical consequence in the computations.

	Time-Based	TALA	1	1	1	-	-
		User-defined	A	B	C	-	-
C-Weighted	Exposure Based	CEXP	1	1	1	-	-
		User-defined	A	B	C	T	T*3600
	Maximum Level	LCMAC	1	1	1	-	-
		User-defined	A	B	C	-	-
	Time-Based	TALC	1	1	1	-	-
		User-defined	A	B	C	-	-
Tone-Corrected Perceived	Exposure Based	EPNL	1	1	1	-	1
		NEF	1	1	16.7	24	630957345[xvi]
		WECPNL	1	3[xvii]	10	24	8640[xviii]
		User-defined	A	B	C	T	T*3600
	Maximum Level	PNLTM	1	1	1	-	-
		User-defined	A	B	C	-	-
	Time-Based	TAPNL	1	1	1	-	-
		User-defined	1	1	1	-	-

A, B, C, and T represent user-defined variables.

The metric-specific time-averaging constants and weighting factors are used to accumulate the noise metrics from all the aircraft operations at all the receptors in an AEDT 2a analysis (Sections 4.6.5.2, 4.6.5.3, and 4.6.5.4).

4.6.5.2 Accumulation of Exposure-based Noise Level Metrics

This Section presents the accumulation of exposure-based noise level metrics for an AEDT 2a analysis. Once the exposure-based noise level from each flight path segment due to fixed-wing aircraft operations (Section 4.6.2.1 and 4.6.2.2) and helicopter operations (Section 4.6.2.3 and 4.6.2.4) are computed, the total noise exposure at a receptor location can be computed through the combination of all the individual flight path segment noise contributions at a receptor in an AEDT 2a study.

[xvi] The 630957345 value (88 dB = 10*$\log_{10}$(630957345)) is a scaling constant inherent in the definition of the L_{NEF} metric. A 24-hour period is used to compute the metric.

[xvii] In accordance with the technical definition, a 5 dB penalty is added to evening operations when computing the Lden 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 Lden metric, it was decided that AEDT 2a would be consistent with state law, rather than the traditional technical definition. The evening weighting factor in the LWECPN metric was changed to 3 for consistency. It is anticipated that this small difference will be of no practical consequence in the computations.

[xviii] 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.

Each flight in the case has an associated 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, are summarized in Table 4-2, which also includes user-defined weighting factors and averaging constants.

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.

$$E_{wt,seg} = \left[W_{day} \cdot N_{day} + W_{eve} \cdot N_{eve} + W_{ngt} \cdot N_{ngt}\right] \cdot E_{seg} \qquad \text{Eq. 4-82}$$

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 4-2 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 a receptor location due to a single flight path segment of a flight operation.

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 aircraft 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:

$$E_{wt,flt} = \sum_{i=1}^{n_{seg}} E_{wt,seg(i)} \qquad \text{Eq. 4-83}$$

where

n_{seg}	number of segments in the three dimensional flight path; and
$E_{wt,seg\,(i)}$	weighted sound exposure ratio for the operation on the i-th segment of a flight path.

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:

$$E_{wt,arpt} = \sum_{k=1}^{n_{flt}} E_{wt,flt(k)} \qquad \text{Eq. 4-84}$$

where

n_{flt}	number of flight operations in the study case; and
$E_{wt,flt\,(k)}$	ratio of each flight operation.

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-defined. The time-averaging constants for the standard exposure-based metrics are summarized in Table 4-2. 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 (the time-averaging constant is equal to1).The average or equivalent mean-square sound-pressure ratio, P, associated with an exposure-based metric, is given by:

$$P_{wt,arpt} = \frac{E_{wt,arpt}}{N_T} \qquad \text{Eq. 4-85}$$

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

$$L_{E,wt,arpt} = 10 \cdot \log_{10}\left[P_{wt,arpt}\right] \qquad \text{Eq. 4-86}$$

$L_{E.wt.arpt}$ 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 4.6.5.4).

$$L_{E,flt} = 10 \cdot \log_{10}\left[\sum_{i=1}^{n_{seg}} E_{seg(i)}\right] \qquad \text{Eq. 4-87}$$

4.6.5.3 Accumulation of Maximum Noise Level Metrics

This Section presents the accumulation of maximum noise level metrics for an AEDT 2a analysis. Once the maximum noise level from each flight path segment due to fixed-wing aircraft operations (Section 4.6.3.1 and 4.6.3.2), and helicopter operations (Section 4.6.3.3 and 4.6.3.4) are computed, the maximum noise level at a receptor location can be computed through the analysis of all the individual flight path segment noise contributions at a receptor in an AEDT 2a study.

The maximum noise level associated with each flight operation, $L_{Smx.flt}$, is 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:

$$L_{Smx,flt} = \underset{i=1}{\overset{n_{seg}}{Max}}\left[L_{Smx,seg(i)}\right] \qquad \text{Eq. 4-88}$$

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:

$$L_{Smx(t)} = \underset{k=1}{\overset{n_{flt(t)}}{Max}}\left[L_{Smx,\,flt(k)}\right] \qquad \text{Eq. 4-89}$$

where

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

L_{Smx} is computed for three time periods (day, evening and night). The maximum noise level equation is as follows:

$$L_{Smx} = max\left[L_{Smx(day)} \cdot W_{day},\ L_{Smx(eve)} \cdot W_{eve},\ L_{Smx(ngt)} \cdot W_{ngt}\right] \qquad \text{Eq. 4-90}$$

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 is 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.

4.6.5.4 Accumulation of Time-based Noise Metrics

This Section presents the accumulation of time-based noise metrics for an AEDT 2a analysis. Once the time-based noise from each flight path due to fixed-wing aircraft and helicopter operations (Sections 4.6.4.1 and 4.6.4.2) are computed, the time-based noise at a receptor location can be computed through the analysis of all the individual flight path noise contributions at a receptor in an AEDT 2a study.

Each flight in the case has an associated 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 and their assigned weighting factors are used to compute the weighted time-above value associated with a specific flight operation:

$$TA_{wt,flt} = \left[W_{day} \cdot N_{day} + W_{eve} \cdot N_{eve} + W_{ngt} \cdot N_{ngt}\right] \cdot TA_{flt} \qquad \text{Eq. 4-91}$$

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 is 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:

$$TA_{wt,arpt} = \sum_{k=1}^{n_{flt}} TA_{wt,flt(k)} \qquad \text{Eq. 4-92}$$

where

- n_{flt} 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.

4.7 Terrain

The use of terrain data in an AEDT 2a analysis affects the noise calculations through the following adjustments:

- Acoustic impedance adjustment (Section 4.3.2)
- Line-of-sight blockage adjustment (Section 4.3.6)

Accepted data formats for terrain are defined in Section 2.2.2.2.

4.8 Weather

Average annual weather included in AEDT 2a is used in all noise calculations. The use of weather data in an AEDT 2a analysis affects the noise calculations through the following adjustments:

- Atmospheric absorption adjustment (Section 4.3.1)
- Acoustic impedance adjustment (Section 4.3.2)
- Duration adjustment for exposure-based metrics (Section 4.3.4)
- Source Noise Adjustment Due to Advancing Tip Mach Number (Section 4.5.1)

In addition, weather can change aircraft thrust, speed, position, and other performance attributes which may in turn have an effect on noise.

5 Emissions

5.1 Overview

AEDT 2a computes emissions related to aircraft operation (taxi / idle portions of an operation are not considered). The following pollutants are modeled runway-to-runway based on phases of flight: nitrogen oxides (NO_x), total hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), carbon dioxide (CO_2), water (H_2O), sulfur oxides (SO_x), total organic gases (TOG), non-methane hydrocarbons (NMHC), volatile organic compounds (VOC), and speciated organic gases (OG), including hazardous air pollutants (HAPs).

In AEDT 2a, there are two broad flight regimes: terminal area and en-route. The term "terminal area" refers to portions of an aircraft's flight trajectory below 10,000 ft Above Field Elevation (AFE), while the term "en-route" refers to portions of flight above 10,000 ft AFE. A runway-to-runway flight path covers both terminal area and en-route regimes. AEDT 2a assigns the trajectory mode on each segment of the flight trajectory across both flight regimes.

The terminal-area trajectory modes in AEDT 2a are takeoff ground roll, takeoff airborne, terminal climb, approach, landing ground roll, and landing ground roll with reverse thrust. En-route trajectory modes are enroute climb, cruise, and enroute descent.

5.2 Aircraft-Related Emissions

The four methods used to compute aircraft-related emissions in AEDT 2a are described below:

- The Boeing Fuel Flow Method 2 (BFFM2)[36] is used to compute NO_x, HC, and CO;
- A First Order Approximation (FOA) is used to compute particulate matter below the mixing height (both FOA 3.0 and FOA 3.0a[37]);
- Fuel composition-based factors are used to compute SO_x, CO_2, and H_2O in addition to particulate matter above the mixing height; and
- Derivative factors are used to compute NMHC, VOC, TOG, and speciated organic gases.

These methods are publicly available and internationally recognized as adequate for aircraft emissions modeling. In AEDT 2a, 3000 feet (AFE) is assumed for mixing height at all times[7].

5.2.1 Boeing Fuel Flow Method 2

Of the four methods employed within AEDT 2a, the most complex is the Boeing Fuel Flow Method 2 (BFFM2). This method requires various atmospheric parameters including engine emissions certification-type data and fuel flow/fuel burn at flight conditions. Since this method relies on fuel flow as a direct input rather than power settings, it is called a "fuel flow method." The BFFM2[36] documentation also provides guidance for anomalous cases, e.g. when certification data do not behave according to the prescribed methodology.

BFFM2 is currently only used to model NO_x, HC, and CO because these are the only pollutants (in addition to particulates) for which data are available in the International Civil Aviation Organization's (ICAO)[38, 39] jet engine emissions certification databank (EEDB). Similarly, the emissions database within

AEDT relies on data derived for the Emissions and Dispersion Modeling System (EDMS)[40]. These data are a superset of the ICAO EEDB database, primarily due to the addition of data for turboprop and piston engines, as well as engines associated with more recent aircraft (e.g., the A380). Generally these additional data are provided directly from manufacturers; the AEDT Fleet database provides a complete record of these engine data and their origins. For each engine listed, the Fleet database contains an inventory of emissions produced per fuel consumed (henceforth referred to as an emission index (EI)) and fuel flow values corresponding to the standard landing-and-takeoff (LTO) cycle modes. The four standard modes are takeoff, climbout, approach, and idle which correspond to power settings of 100%, 85%, 30%, and 7%, respectively.

The steps in the BFFM2 Model as used in AEDT 2a are listed below:

1. The four ICAO reference fuel flows are adjusted for installation effects, that is, each of these fuel flows is multiplied by a modal-specific adjustment factor defined in BFFM2[36]. These adjustment factors are shown in the table below.

Table 5-1 Adjustment Factors for Installation Effects

Mode	Power Setting (%)	Adjustment Factor
Takeoff	100	1.010
Climb-out	85	1.013
Approach	30	1.020
Idle	7	1.100

2. Using the adjusted fuel flows from step 1 and the reference EI values from the Fleet database, Log-Log relationships between EI and fuel flow values are developed that allow predictions of reference EI values for reference fuel flow values. For NO_x, a point-to-point relationship is developed. For HC and CO, a bilinear fit is established between the two lower power setting points and the two higher power setting points.
3. A non-reference fuel flow value is determined within AEDT. The fuel flow corresponds to at-altitude atmospheric conditions for a specific flight segment or mode.
4. The non-reference fuel flow from step 3 is converted to reference conditions using the following equation:

$$RWf = \frac{Wf}{\delta}\theta^{3.8}e^{0.2M^2} \qquad \text{Eq. 5-1}$$

where

RWf fuel flow at reference conditions (kg/s);
Wf fuel flow at non-reference conditions (kg/s);
M Mach number;
θ temperature ratio (ambient to sea level); and
δ pressure ratio (ambient to sea level).

5. Using the Log-Log relationships from step 2 and the reference fuel flow from step 4, reference EI values for NO_x, HC, and CO are obtained.
6. The reference EI values from step 5 are converted to non-reference (at altitude) conditions using the following equations:

$$NO_X EI = NO_X REI e^H \left[\frac{\delta^{1.02}}{\theta^{3.3}}\right]^{1/2} \quad \text{Eq. 5-2}$$

$$HCEI = HCREI \frac{\theta^{3.3}}{\delta^{1.02}} \quad \text{Eq. 5-3}$$

$$COEI = COREI \frac{\theta^{3.3}}{\delta^{1.02}} \quad \text{Eq. 5-4}$$

$$H = -19.0 \left[\frac{0.62197058 \phi P_v}{(0.01P) - \phi P_v} - 0.00634\right] \quad \text{Eq. 5-5}$$

where

NOxEI	NOx EI at non-reference conditions (g/kg);
NOxREI	NOx EI at reference conditions (g/kg);
HCEI	HC EI at non-reference conditions (g/kg);
HCREI	HC EI at reference conditions (g/kg);
COEI	CO EI at non-reference conditions (g/kg);
COREI	CO EI at reference conditions (g/kg);
M	Mach number;
θ	temperature ratio (ambient to sea level);
δ	pressure ratio (ambient to sea level);
H	humidity coefficient;
ϕ	relative humidity; and
P_v	saturation vapor pressure (millibars).

7. The non-reference fuel burn corresponding to the fuel flow in step 3 is obtained.
8. Using the non-reference EI values from step 6 and the non-reference fuel burn from step 7, the non-reference emissions of NO_x, HC, and CO are computed. These represent the final emissions for the flight segment.

5.2.2 First Order Approximation 3.0 and 3.0a Methods

The First Order Approximation 3.0 (FOA 3.0) and First Order Approximation 3.0a (FOA 3.0a) methods are used solely for computing PM below the mixing height in AEDT 2a[37,41] for jet aircraft. The FOA methodology makes use of the current engine mode and properties, as well as fuel characteristics while fuel composition-based factors and derivative factors methodologies are based on applying constant factors to either the fuel burn or to other pollutant emissions. BFFM2 is used to model NO_x, HC, and CO. FOA 3.0 or 3.0a is used to model PM below the mixing height. While AEDT 2a supports both FOA 3.0 and 3.0a methods, the default configuration is set to use FOA 3.0. The default configuration is set by the *UseEPActApproximationForParticulateMatter* parameter of the AEDT 2a configuration file (C:\AEDT\FAA.AEE.AEDT.AEDTApp.exe.config).

In order to estimate PM emissions (both volatile and non-volatile components) for commercial aircraft engines within the vicinity of the airport (i.e. during the LTO cycle), a working group within ICAO CAEP adopted and further developed the FOA 3.0 methodology[37]. The FOA 3.0a methodology is an FAA/EPA-modified version of CAEP's FOA 3.0 methodology, and is intended to produce conservative PM emission estimates for U.S. domestic regulatory compliance purposes. The specific elements of these two methodologies are described below.

FOA 3.0 and 3.0a account for the formation of volatile PM components from fuel sulfur content (FSC) and hydrocarbon (fuel) organics, each component with its own modeling assumptions. FOA 3.0a adds additional computations to account for volatile organic-driven PM from the loss of lubrication oil, for only the takeoff and climb out modes.

FOA 3.0 and 3.0a PM EI (whether volatile or non-volatile) calculations are not directly based upon specific chord-based performance (as was the case in BFFM2), but rather, the current mode (i.e., idle, takeoff). These modes are clearly defined by ICAO, and are based upon approximate power settings (idle condition is assumed to be 7% of maximum thrust, approach 30%, climb-out 85%, and takeoff 100%).

The contributing modeled species to the volatile PM component are volatile sulfates, fuel organics, and in the case of FOA 3.0a only, lubrication oil. For each contributing species, an EI value is calculated, and all EI values are summed to provide a complete estimation for the volatile PM EI.

The FSC, a mass fraction of sulfur present in the fuel, must be input to the study. For the FOA methodology, the FSC is directly related to volatile sulfate PM emissions. It is assumed that a portion of the SO_x gaseous emissions will be converted to either: the compound sulfate (SO_4) in the case of FOA 3.0; or sulfuric acid (H_2SO_4) in the case of FOA 3.0a. Both sulfate and sulfuric acid are considered volatile sulfate PM species. The term "conversion efficiency" is used to describe the percentage of sulfur in the fuel that will be converted to a volatile sulfate PM species. Thus, the mass ratio of the volatile sulfate PM species to the amount of fuel consumed (the EI value) is found according to Eq. 5-6.

Typically, the FSC is expressed as the mass of sulfur per mass of fuel, i.e. mass fraction. To derive the volatile PM EI value, defined as grams of pollutant per kilograms of fuel, the mass of the sulfur present in the fuel is calculated as the FSC multiplied by 1000 to allow for units of kilograms of fuel. As stated earlier, the amount of sulfur converted to sulfate/sulfuric acid is known as the conversion efficiency, and may be defined as a percentage or fraction. The molecular weight of sulfur is 32, sulfate is 96, and sulfuric acid is 98. The final approximation for the volatile sulfur PM is provided in the equation below.

$$PM_{Vols\ FSC\ EI} = 1000 \cdot FSC \cdot \varepsilon \cdot \frac{M_a}{32} \qquad \text{Eq. 5-6}$$

where

$PM_{Vols\ FSC\ EI}$	is expressed in (g/kg);
FSC	fuel sulfur content (g / g);
Ɛ	conversion efficiency (%); and
M_a	molecular weight of sulfate (96) for FOA 3.0 or sulfuric acid (98) for FOA 3.0a.

Both FSC and the conversion efficiency can be user-defined. However, if no values are provided, the emissions model will use a default value of 0.0006 (grams of sulfur per gram of fuel) for fuel sulfur content, and 0.024 (fraction) for conversion efficiency. These values are being used by standards bodies such as ICAO-CAEP when implementing FOA 3.0, and appear in the FOA 3.0 guidance document[37].

The volatile fuel organics content of PM is based on testing and measurements from the APEX1 study[37]. This particular APEX study measured volatile organic PM from one engine (the CFM56-2-C1) for the four distinct LTO modes. Using the CFM56-2-5C as a surrogate (a close approximation, as the CFM56-2-C1 does not appear in the ICAO databank), the FOA methodology calculates the volatile organic PM according to Eq. 5-7. For the FOA methodology, it is assumed that volatile organic PM emissions are directly related to the mode-specific HC EI values, and that the relationship between ICAO HC EI values and the volatile organic PM emissions measured for the CFM56 is roughly the same for all engines. Additionally, FOA 3.0a uses a true mass balance in computing the volatile organic PM EI value from the APEX data, as well as applying a conservative factor (the standard deviation of the measured fuel organics EI is added to the average measure fuel organics EI).

Table 5-2 provides the volatile organic PM values from the APEX study used in FOA 3.0, as well as the CFM56-2-5C HC EI values from the ICAO databank. Table 5-3 provides the same information for FOA 3.0a. The equation below provides the formula used to calculate the mode-specific volatile organic PM EI (for both FOA 3.0 and FOA 3.0a).

$$PM_{Vols\ Org\ EI} = \left(\frac{EI_{PMVol-orgCFM56}}{EI_{HCCFM56}}\right) \cdot \frac{HC_{EI}}{1000} \qquad \text{Eq. 5-7}$$

where

PM Vols Org EI	is expressed in (g/kg);
$EI_{PMVol\text{-}orgCFM56}$	APEX1-determined fuel organics PM (from Table 5-2 or Table 5-3);
$EI_{HCCFM56}$	mode-specific HC EI from ICAO Databank (for the CFM56); and
HC_{EI}	mode-specific HC EI for engine observed.

Table 5-2 Mode Specific Values for Eq. 5-7 (FOA 3.0)

LTO Mode	$EI_{PMVol\text{-}orgCFM56}$ (mg/kg fuel) APEX1	$EI_{HCCFM56}$ (g/kg fuel) ICAO Databank
Takeoff	4.6	0.04
Climb-out	3.8	0.05
Approach	4.5	0.08
Idle	11.3	1.83

Table 5-3 Mode Specific Values for Eq. 5-7 (FOA 3.0a)

LTO Mode	$EI_{PMVol\text{-}orgCFM56}$ (mg/kg fuel) APEX1	$EI_{HCCFM56}$ (g/kg fuel) ICAO Databank
Takeoff	(1.2 + 19)	0.04
Climb-out	(2.9 + 16)	0.05
Approach	(4.5 + 10)	0.08
Idle	(11.3 + 25)	1.83

FOA 3.0 does not have a distinct calculation for the engine lubrication oil content of volatile PM. Conversely, FOA 3.0a performs an approximation for lubrication oil PM by assuming 1.4 grams are

emitted during takeoff and climbout (and none during approach and idle procedures). To adapt the 1.4 grams approximation to a segment-level pollutant mass, the following steps are performed:

- It is assumed that the 1.4 grams of lubrication oil PM is evenly distributed over the duration of the takeoff and climbout portions of the flight;
- The total time elapsed during the takeoff and climbout portions, as well as times for each flight chord, are provided within AEDT 2a. Specifically, there is always a flight segment break at the mixing height in order to ensure the correct application of the FOA to segments below the mixing height only; and
- The time for the individual chord is divided by the total time for the takeoff /climbout portions, and then this value is multiplied by 1.4.

Both FOA 3.0 and FOA 3.0a approximate non-volatile PM by multiplying the concentration index (CI) of non-volatile PM by the exhaust volumetric flow rate. Both CI and the exhaust volumetric flow rate are modal dependent. In addition, for mixed turbofan engines, the exhaust volumetric flow rate includes the bypass air which can be determined by the provided ICAO bypass ratio.

All equations for both FOA 3.0 and 3.0a computation of CI make use of modal-dependent smoke number (SN), specific to each engine considered. Thus, across a distinct mode, the SN and the CI will remain constant. When possible, the SN is retrieved from certification, manufacturer, or derived data from within the Fleet database, which may include a different SN for each of the four modes. For some engines, there is no SN for any or all of the modes and a value of 0.0 is used [42].

The FOA methodology (both FOA 3.0 and 3.0a) uses the one of the following two equations as appropriate to calculate CI:

- When the SN is at or below 30, Eq. 5-8 is used
- When the SN is above 30, Eq. 5-9 is used.

$$CI = 0.0694 \cdot SN^{1.234} \qquad SN \leq 30 \qquad \text{Eq. 5-8}$$

$$CI = 0.0297 \cdot SN^{2} - 1.802 \cdot SN + 31.94 \qquad SN > 30 \qquad \text{Eq. 5-9}$$

where

CI	concentration index; and
SN	smoke number.

The FOA methodology (both FOA 3.0 and FOA 3.0a) uses one of two equations as appropriate to calculate the exhaust volumetric fuel rate:

- Eq. 5-10 is used when the engine being observed is indicated as an internally mixed turbofan.
- Eq. 5-11 is used when the engine is not an internally mixed turbofan, thus the bypass ratio is ignored.

$$Q = AFR \cdot 0.776 \cdot (1 + B) + 0.877 \qquad Mixed\ Flow\ Turbofan\ Engines \qquad \text{Eq. 5-10}$$

$$Q = AFR \cdot 0.776 + 0.877 \qquad Non-Mixed\ Flow\ Turbofan\ Engines \qquad \text{Eq. 5-11}$$

where

Q	exhaust volumetric fuel rate in m^3/kg;

AFR air-to-fuel ratio; and
B bypass ratio.

The air-to-fuel ratio (AFR) was statistically estimated for each mode. As part of the FOA development, these values were reviewed by engine manufacturers and considered reasonable. The AFR is unit-less, and provided in Table 5-4.

Table 5-4 Mode Specific Values of AFR

Mode	AFR
Takeoff	45
Climbout	51
Approach	83
Idle	106

The final approximation for the non-volatile PM EI is provided in Eq. 5-12.

$$PM_{NonVols\ EI} = Q \cdot \frac{CI}{1000} \quad \text{Eq. 5-12}$$

where

$PM_{NonVols\ EI}$ is expressed in (g/kg);
Q exhaust volumetric fuel rate (m^3/kg fuel) (from Eq. 5-10 or Eq. 5-11); and
CI concentration index (mg/m^3) (from Eq. 5-8 or Eq. 5-9).

For all PM calculations above the mixing height, constant EI values across all aircraft and engine types are employed for sulfur, fuel organics, and non-volatile species. EI values are defined in the configuration file (C:\AEDT\FAA.AEE.AEDT.AEDTApp.exe.config). The default EI values are shown in Table 5-5, but can be modified based on user input.

Table 5-5 Default Constant PM EI Values above the Mixing Height

PM Species	EI (g/kg)
Sulfur	0.07
Fuel Organic	0.8
Non-Volatile	0.2

5.2.3 Sulfur Approximation

Sulfur which does not convert to the sulfur component of PM (sulfuric acid) is assumed to convert in to SO_x. Therefore, the SO_x EI approximation will use the FSC and conversion efficiency, and is linked to the FOA methodology. The process for calculating SO_x is presented in Eq. 5-13.

$$SO_X EI = 1000 \cdot FSC \cdot (1 - \varepsilon) \cdot \left(\frac{64}{32}\right) \quad \text{Eq. 5-13}$$

where

SO_xEI is expressed in (g/kg);
FSC fuel sulfur content (g / g);

ε conversion efficiency (%); and
64 molecular weight of SO_2.

When the default values of fuel sulfur content (0.0006 by mass fraction) and conversion efficiency (0.024 also a fraction) are used, the SO_x EI value will be 1.1712 g / kg. Note that for above the mixing height, the sulfur component of PM is not dependent upon the conversion efficiency; instead, it is a constant factor applied to fuel consumption. The sulfur component is not speciated into SO_X and volatile sulfur PM (based on the conversion efficiency) above the mixing height; therefore the mass of sulfur in the input fuel will not equal the mass of sulfur in the output emissions.

5.2.4 CO_2 and H_2O Approximations

Emissions of CO_2 and H_2O are modeled based on Jet Fuel A composition. Boeing conducted a review of the available fuel composition data and developed EI values that could be used to predict emissions solely based on fuel burn[43,44]. The values are shown in Table 5-6.

Table 5-6 Constant CO_2 and H_2O EI Values

Pollutant	EI (g/kg)
CO_2	3155
H_2O	1237

Since these EI values were derived based on average fuel compositions, they are constants used for all modes and all atmospheric conditions. Alternative values for the CO_2 and H_2O EI values may be provided as input, replacing the values presented in Table 5-6.

5.2.5 Derivative Factors for Modeling VOC, NMHC, and TOG

Three pollutants, VOC, NMHC, and TOG, are calculated by applying various factors to the HC amount (HC being calculated from the BFFM2 methodology noted above)[45,46]. The factors used to calculate VOC, NMHC, and TOG are known as derivative factors. AEDT 2a applies the derivative factors based on the engine type (turbine, piston).

The HC calculated in the BFFM2 is presented in terms of methane equivalency. TOG and NMHC are presented in terms of their own mass (TOG as TOG and NMHC as NMHC, respectively). For turbine engines, a derivative factor ($TOG_{ConversionFactor}$) is applied to the calculated HC to compute TOG. NMHC is computed by applying a conversion factor ($NMHC_{ConversionFactor}$) to the mass of TOG. And finally, VOC is computed by subtracting the mass of ethane from TOG. Therefore, to obtain VOC in terms of its own mass (VOC as VOC), TOG is multiplied by (1 – the mass fraction of ethane in TOG). For the sake of simplicity, AEDT 2a uses a derivative factor ($VOC_{ConversionFactor}$) to convert TOG to VOC. The application of the derivative factors to calculate TOG, NMHC, and VOC for turbine engines is demonstrated in Figure 5-1 and Eq. 5-14 through Eq. 5-16.

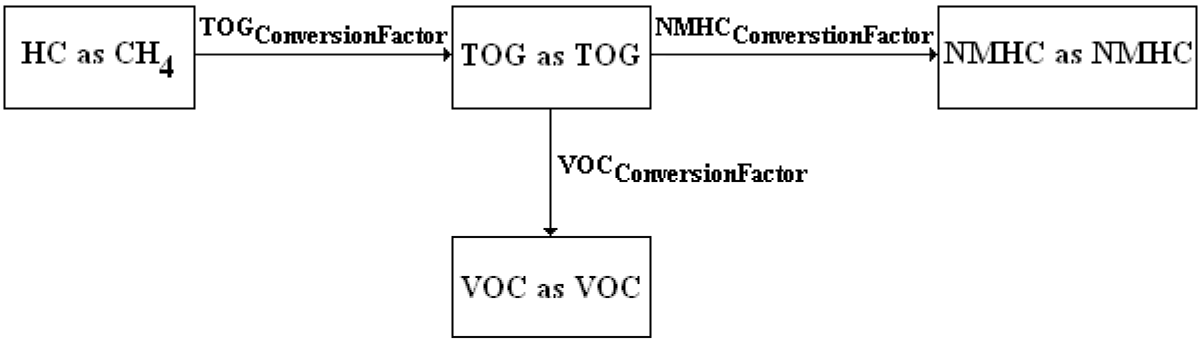

Figure 5-1 TOG, NMHC, and VOC Calculations for Turbine Engines

The equations for TOG, NMHC, and VOC for turbine engines are below:

$$TOG_{TOG} = HC_{CH4} \cdot TOG_{ConversionFactor} \quad \text{Eq. 5-14}$$

$$NMHC_{NMHG} = TOG_{TOG} \cdot NMHC_{ConversionFactor} \quad \text{Eq. 5-15}$$

$$VOC_{VOC} = TOG_{TOG} \cdot VOC_{ConversionFactor} \quad \text{Eq. 5-16}$$

where

TOG_{TOG}	TOG emissions as TOG (g);
HC_{CH4}	HC emissions using BFFM2 (in terms of methane equivalency) (g);
$NMHC_{NMHC}$	NMHC emissions as NMHC (g); and
VOC_{VOC}	VOC emissions as VOC (g).

$TOG_{ConversionFactor}$, $VOC_{ConversionFactor}$, and $NMHC_{ConversionFactor}$ are all inputs used to compute TOG, VOC, and NMHC emissions respectively. For aircraft with turbine engines, the default values of 1.156234049 ($TOG_{ConversionFactor}$), 0.9947855 ($VOC_{ConversionFactor}$), and 1.000 ($NMHC_{ConversionFactor}$) are set in the configuration file (C:\AEDT\FAA.AEE.AEDT.AEDTApp.exe.config). The default 0.9947855 value for $VOC_{ConversionFactor}$, assumes a 0.0052145 value for the ethane content in TOG. The default 1.000 value for $NMHC_{ConversionFactor}$, assumes that no methane is produced; therefore, NMHC is equal to TOG.

For piston aircraft, TOG, NMHC, and VOC calculations differ from the calculations done for aircraft with turbine engines. As for turbine engines, derivative factors are applied to the computed mass of HC in methane equivalency. However, a derivative factor ($VOC_{ConversionFactor}$) is multiplied by HC to calculate VOC as VOC. Next, a derivative factor ($TOG_{ConversionFactor}$) is multiplied by VOC as VOC to calculate TOG as TOG. And finally, for piston engines, methane may be present in TOG; therefore, there is a third derivative factor ($NMHC_{ConversionFactor}$), which is multiplied by TOG as TOG to calculate NMHC as NMHC. The application of the derivative factors to calculate TOG, NMHC, and VOC for piston engines is demonstrated in Figure 5-2 and Eq. 5-17 through Eq. 5-19.

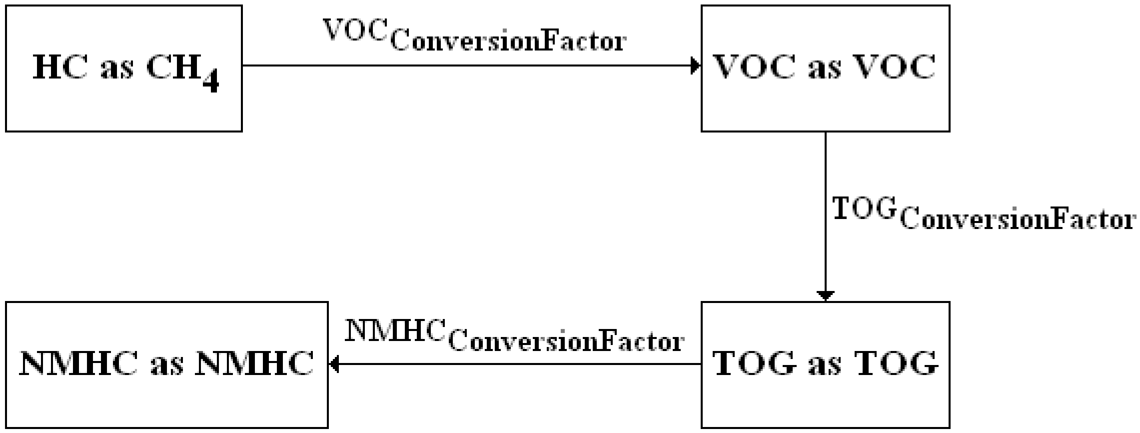

Figure 5-2 TOG, NMHC, and VOC Calculations for Piston Engines

Additionally, the equations for TOG, NMHC, and VOC (for piston engines) are below:

$$TOG_{TOG} = VOC_{VOC} \cdot TOG_{ConversionFactor} \quad \text{Eq. 5-17}$$

$$NMHC_{NMHC} = TOG_{TOG} \cdot NMHC_{ConversionFactor} \quad \text{Eq. 5-18}$$

$$VOC_{VOC} = TOG_{TOG} \cdot VOC_{ConversionFactor} \quad \text{Eq. 5-19}$$

where

TOG_{TOG}	TOG emissions as TOG (g);
HC_{CH4}	HC emissions using BFFM2 (in terms of methane equivalency) (g);
$NMHC_{NMHC}$	NMHC emissions as NMHC (g); and
VOC_{VOC}	VOC emissions as VOC (g).

$TOG_{ConversionFactor}$, $VOC_{ConversionFactor}$, and $NMHC_{ConversionFactor}$ are all inputs used to compute TOG, VOC, and NMHC emissions respectively. For aircraft with piston engines, the default values of 1.17371 ($TOG_{ConversionFactor}$), 0.83471 ($VOC_{ConversionFactor}$), and 0.8905 ($NMHC_{ConversionFactor}$) are set in the configuration file (C:\AEDT\FAA.AEE.AEDT.AEDTApp.exe.config).

5.2.6 Derivative Factors for Speciated Organic Gases

Speciated organic gases (including any known HAPs) are not implemented in AEDT 2a. Instead, a list of speciated organic gases and their mass fraction to the TOG amount can be defined as user input. The total mass for each speciated organic gas is computed by multiplying its mass fraction to the TOG_{TOG} emissions[23]. By definition, the summation of all individual speciated organic gas mass fractions should be 1.000.

Once the TOG_{TOG} amount is calculated (from Eq. 5-14 or Eq. 5-17 above), the mass for every speciated organic gas component in its own mass is computed by multiplying its respective mass fraction by the TOG amount, as in Eq. 5-20.

$$OG_i = TOG_{TOG} \cdot MF_i \qquad \text{Eq. 5-20}$$

where

OG_i	Organic gas emissions (g);
TOG_{TOG}	TOG emissions as TOG (g); and
MF_i	Mass fraction of speciated organic gas.

6 Annualization

Annualization is the process of performing a weighted aggregation over the noise and emissions results from some or all of the cases within a scenario in order to create results that represent noise and emissions exposures over the time period of interest. Depending on the data represented by the cases and the time period of the results, annualized results can be computed by applying a user defined weighting scheme. AEDT 2a allows the user the flexibility to define annualization hierarchies either through an ASIF or graphically in the user interface. The user must identify each case referenced for annualization and specify annualization weighting factors for each case. For information on how to setup annualizations refer to the AEDT 2a User Guide[1].

Central to the weighting scheme are two multipliers – the annualization weight and the optional scale factor. The annualization weight is a multiplication factor that is typically between zero and one representing percentage use. Annualization weights are applied to individual cases as well as groupings of cases. Individual groups represent a collection of cases or sub-groups that represent a portion of the total annual operations. For example, if an annualization consists of three groups – A, B, and C with annualization weights of 0.5, 0.25 and 0.25 respectively, then these weights indicate that group A occurs 50% of the year and groups B and C occur 25% of the year each. For NEPA related studies, the annualization weights needs to be consistent with the input data so that it represents an average annual day.

In addition to the annualization weight, an additional multiplier called the scale factor may be defined at the case or group level. This scale factor is an additional multiplier that may be used by the user to modify the number of operations and therefore the impact on resultant noise or emissions. For example, the user may apply a scale factor of 2.0 to an individual case to model a scenario where the number of operations in that case may double in a future scenario. The scale factor can be defined for any number greater than zero. See the AEDT 2a User Guide[1] Section 6.1 for a diagram and description of annualization in the AEDT 2a graphical user interface.

In its simplest form, a scenario annualization may be depicted in the following equation:

$$A(s) = \sum_{c} R(c,w) \qquad \text{Eq. 6-1}$$

where

A(s) annualized result for scenario, s; and

R(c,w) result for each case, c, weighted by weight, w.

The final annualization weight for each case, FAW(c), is an aggregate factor that encompasses the annualization weights of all parent groups in the case's hierarchy – including the final annualization weight:

$$FAW(c) = \mathrm{AW(c)} \times \mathrm{FAW(pg)} \qquad \text{Eq. 6-2}$$

where
AW(c) annualization weight for the case; and
FAW(pg) final annualization weight for the case's parent group.

Similarly, the final scale factor for each case, FSF(c), is an aggregate factor that encompasses the scale factors of all parent groups in the Case's hierarchy – including the final scale factor:

$$FSF(c) = \mathrm{SF(c)} \times \mathrm{FSF(pg)} \qquad \text{Eq. 6-3}$$

where
SF(c) scale factor for the case; and
FSF(pg) final scale factor for the case's parent group.

The final weight applied at each case, w(c), is the aggregate weight that is a combination of the annualization weight and the scale factor:

$$w(c) = \mathrm{FAW(c)} \times \mathrm{FSF(c)} \qquad \text{Eq. 6-4}$$

where
FAW(c) final annualization weight for the case; and
FSF(c) final scale factor for the case.

For example, given the following hierarchy of user-specified annualization weights, AW, and scale factors, SF:

- Case AW=0.5, SF=2.0
  - Group AW=0.4, SF=1.0
    - Group AW=0.9, SF=1.0
      - Final parent group AW=1.0, SF=1.0

the final weight for the case, w(c), is computed as:

FAW(c) = (0.5 X 0.4 X 0.9 X 1.0) = 0.18
FSF(c) = (2.0 X 1.0 X 1.0 X 1.0) = 2.0
w(c) = 0.18 X 2.0 = 0.36

If the final weight (w) for a case is computed to be zero, then the annualization will still proceed but the case will be omitted from the final annualized result (that case occurs 0% of the year). If a case that is included in an annualization tree does not have any valid results, the annualization will not proceed and an error will be logged.

When applied to emissions, the weight for each case is a simple multiplier on the case-level emissions results. When applied to noise results at receptors, the weight for each case is a simple multiplier on the raw sound energy at each point, which in effect, scales the number of operations for the entire case.

7 Analysis Tools

7.1 Change Analysis

This Section describes statistical and summary calculations performed by the change analysis functionality in AEDT 2a.

7.1.1 Change Analysis Report Statistics

The requirements to run change analysis are as follows:

- Two different annualizations run with the same receptor set;
- Jobs must be run with the DNL noise metric; and
- The jobs used must have been run through to successful completion.

The change analysis report performs two sets of calculations:

1. A threshold calculation to find the cases most responsible for the noise contributions at a given receptor point.
2. A grouping of cases and receptor points to provide the user with causality groups (or sets).

The change analysis calculations are described below.

For each receptor and case, the baseline weighted raw energy values BRAW(c,r), see Eq. 7-1, and baseline DNL values BDNL(c,r), see Eq. 7-2, are computed.

$$BRAW(c,r) = 10^{\left(\frac{\mathrm{B(c,r)}}{10}\right)} \cdot \mathrm{AW(c)} \qquad \text{Eq. 7-1}$$

where

B(c,r) baseline DNL noise for case, c, and receptor, r and
AW(c) final annualized weighting factor for the baseline or alternative case, c.

$$BDNL(c,r) = 10Log_{10}(BRAW(c,r)) \qquad \text{Eq. 7-2}$$

Similarly, the alternative equivalents are calculated. See Eq. 7-3 for the alternative weighted raw energy equation, ARAW(c,r) and Eq. 7-4 for the alternative DNL equation, ADNL(c,r).

$$ARaw(c,r) = 10^{\left(\frac{\mathrm{A(c,r)}}{10}\right)} \cdot \mathrm{AW(c)} \qquad \text{Eq. 7-3}$$

where

A(c,r) alternative DNL noise for case, c and receptor, r.

$$ADNL(c,r) = 10Log_{10}(ARAW(c,r)) \qquad \text{Eq. 7-4}$$

Next, the total RAW and DNL values are computed for each receptor, see Eq. 7-5 through Eq. 7-8.

$$BRAW(r) = \sum_{c} BRAW(c,r) \quad \text{Eq. 7-5}$$

$$BDNL(r) = 10Log_{10}(BRAW(r)) \quad \text{Eq. 7-6}$$

$$ARAW(r) = \sum_{c} ARAW(c,r) \quad \text{Eq. 7-7}$$

$$ADNL(r) = 10Log_{10}(ARAW(r)) \quad \text{Eq. 7-8}$$

Then, the total differences DRAW(c, r), DDNL(c,r), DRAW(r), and DDNL(r) are computed, see Eq. 7-9 through Eq. 7-12.

$$DRAW(c,r) = BRAW(c,r) - ARAW(c,r) \quad \text{Eq. 7-9}$$

$$DDNL(c,r) = BDNL(c,r) - ADNL(c,r) \quad \text{Eq. 7-10}$$

$$DRAW(r) = BRAW(r) - ARAW(r) \quad \text{Eq. 7-11}$$

$$DDNL(r) = BDNL(r) - ADNL(r) \quad \text{Eq. 7-12}$$

Next, the percentage RAW difference, PDR(c,r) for each case at a given receptor is computed, see Eq. 7-13.

$$PDR(c,r) = 100 \cdot \left| \frac{DRAW(c,r)}{DRAW\ (r)} \right| \quad \text{Eq. 7-13}$$

The mean percentage difference for the receptor over all the case differences, MPDR(r), is computed by Eq. 7-14.

$$MPDR(r) = \sum_{c} \frac{PDR(c,r)}{Nc} \quad \text{Eq. 7-14}$$

Finally, the standard deviation of the percentage differences over all the cases, PSIG(r), is computed by Eq. 7-15.

$$PSIG(r) = \sqrt{\sum_{c} \frac{(PDR(c,r) - MPDR(r))^2}{Nc}} \quad \text{Eq. 7-15}$$

Cases that have a percentage raw difference, PDR(c,r), that is greater than the mean percentage, MPDR(r), plus one-half the standard deviation of the percentage differences, PSIG(r), are considered significant contributors of noise for a given receptor, see Eq. 7-16.

$$PDR(c,r) > MPDR(r) + 0.5 \cdot PSIG(r) \quad \text{Eq. 7-16}$$

After the statistics for each case and receptor have been computed, the receptors are organized into groups. Each group contains receptors that have the same set of significant case contributors as defined by Eq. 7-16, therefore changes to a given significant case will affect all the receptors in that group in a similar fashion. Both the statistical information and the grouping information are displayed in the change analysis report.

7.2 Impact Evaluation

The Impact Evaluation functionality provides the percent contribution of each flight in a given case to a selected set of receptor points (those in a change zone). Cases must be run with detailed noise (event level noise results) before impact evaluation can be utilized. The percentage contribution calculation is discussed below.

The total noise, N(f), is calculated over all the receptors in the change zone for each flight in the case, see Eq. 7-17.

$$N(f) = AW(c) \cdot \sum_{r} N(f,r) \qquad \text{Eq. 7-17}$$

where

N(f,r) SEL noise for flight, f, at receptor, r; and
AW(c) final annualized weighting factor for the alternative case, c.

Next, the total noise, TN, is calculated by summing the total noise N(f) for each flights in the case, see Eq. 7-18.

$$TN = \sum_{f} N(f) \qquad \text{Eq. 7-18}$$

Finally, the percentage noise, PN(f), of each flight is computed by dividing each flight’s noise by the total noise as shown in Eq. 7-19.

$$PN(f) = 100 \cdot \frac{N(f)}{TN} \qquad \text{Eq. 7-19}$$

8 Appendices

8.1 Noise Adjustment and Metric Derivations

This appendix provides detailed derivations for the following noise adjustments and metrics: the acoustic impedance adjustment (Section 8.1.1), the noise exposure fraction adjustment (Section 8.1.2), and the equation to compute the time-above metric (Section 8.1.3).

8.1.1 Derivation of the Acoustic Impedance Adjustment

The majority of noise level data in the AEDT 2a FLEET 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)[27]. 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°F (25° C);
3. Relative humidity of 70%; and
4. Zero wind.

The concept of acoustic impedance (denoted by the symbol ρ c) is used in AEDT 2a 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 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 correct for the differences between reference-day sea-level conditions to airport-specific temperature and altitude.

Harris[47] and Beranek[48] both contain empirical curves showing acoustic impedance adjustment as a function of temperature and atmospheric pressure (see Figure 8-1 and Figure 8-2). 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 AEDT 2a noise-power-distance (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 in AEDT 2a.

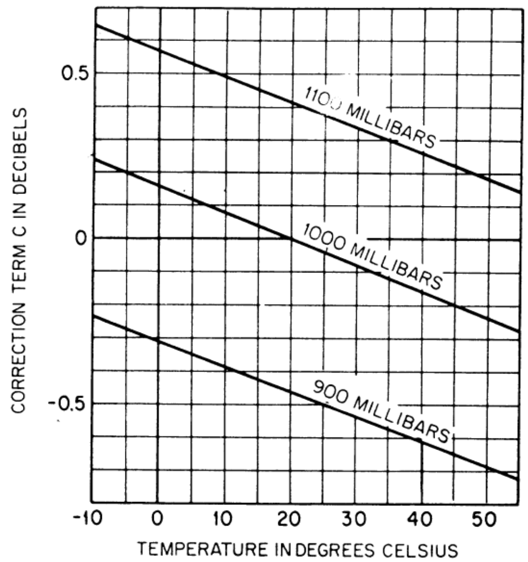

Figure 8-1 Acoustic Impedance Adjustment re. 406 newton-second/m^3

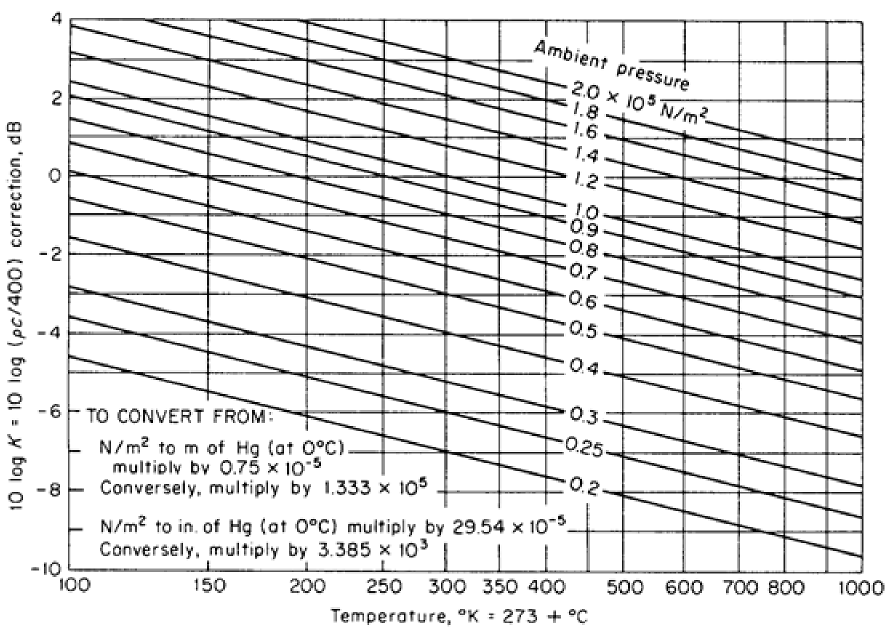

Figure 8-2 Acoustic Impedance Adjustment re. 400 newton-second/m^3

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 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:

$$AI_{ADJ} = 10 \cdot \log_{10}\left[\frac{\rho c}{409.81}\right] \qquad \text{Eq. 8-1}$$

where

AI$_{ADJ}$ acoustic impedance adjustment to be added to noise level data in the AEDT 2a NPD database (dB);

ρc acoustic impedance at observer altitude and pressure (newton-seconds/m^3);

$$\rho \cdot c = 416.86 \cdot \left[\frac{\delta}{\theta^{½}}\right] \qquad \text{Eq. 8-2}$$

where

δ ratio of atmospheric pressure at observer altitude to standard-day pressure at sea level,

$$\delta = \left[\left(\frac{P}{29.92}\right)^{\frac{1}{5.256}} - \left(\frac{0.003566A}{518.67}\right)\right]^{5.256} \qquad \text{Eq. 8-3}$$

θ ratio of absolute temperature at observer altitude to standard-day temperature at sea level,

$$\theta = \frac{[459.67 + T - 0.003566 \cdot (A - E)]}{518.67} \qquad \text{Eq. 8-4}$$

where

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).

Harris[47] and Beranek[48] 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:

$$I = \frac{p^2}{\rho c} \qquad \text{Eq. 8-5}$$

where

I sound intensity (power per unit area);
p^2 mean-square sound pressure; and
ρc acoustic impedance.

Two sound intensities at a given distance from a given acoustical power source, one measured under actual conditions and the other measured under reference-day conditions are equivalent as shown:

$$\frac{p^2}{\rho c} = \frac{p_{ref}^2}{\rho c_{ref}} \quad \text{Eq. 8-6}$$

where

$\frac{p^2}{\rho \cdot c}$ sound intensity, actual conditions; and

$\frac{p_{ref}^2}{\rho \cdot c_{ref}}$ sound intensity, reference-day conditions.

By rearranging terms and dividing by a constant p_o = 20 µPa, the equation becomes:

$$\frac{p^2}{p_0^{\ 2}} = \left(\frac{p^2{}_{ref}}{p_0^{\ 2}}\right)\left(\frac{\rho c}{\rho c_{ref}}\right) \quad \text{Eq. 8-7}$$

Converting to decibels,

$$10 \cdot \log_{10}\left[\frac{p^2}{p_0^{\ 2}}\right] = 10 \cdot \log_{10}\left[\frac{p^2{}_{ref}}{p_0^{\ 2}}\right] + 10 \cdot \log_{10}\left[\frac{\rho c}{\rho c_{ref}}\right] \quad \text{Eq. 8-8}$$

and substituting symbols, produces the noise level adjustment equation (in dB):

$$L = L_{ref} + 10 \cdot \log_{10}\left[\frac{\rho c}{\rho c_{ref}}\right] \quad \text{Eq. 8-9}$$

where

L	corrected NPD level at an airport;
L_{ref}	NPD level in the AEDT 2a database for reference-day conditions; and
$10 \cdot \log_{10}\left[\frac{\rho c}{\rho c_{ref}}\right]$	acoustic impedance adjustment, AI_{ADJ}, as seen in Eq. 8-1.

8.1.2 Derivation of the Noise Exposure Fraction Adjustment[49,50]

This Section presents a derivation of the noise exposure fraction equation used in AEDT 2a. 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 the figure below.

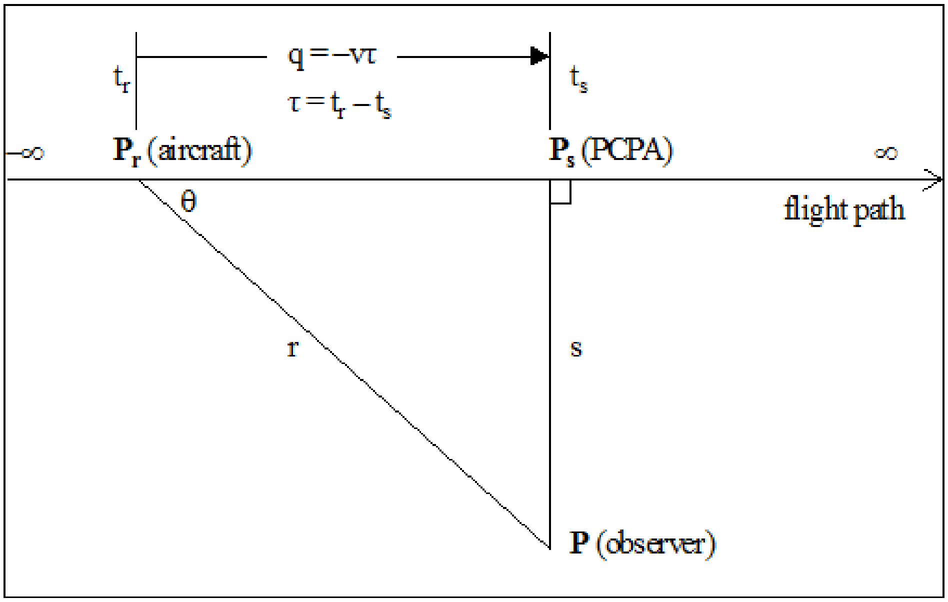

Figure 8-3 Observer/Flight Path Geometry

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: $\mathbf{P_rP}$, from the aircraft to the observer; and the unit vector, **u**, in the direction of the flight path.

$$q = \mathbf{P_r P} \cdot \mathbf{u} = \frac{\mathbf{P_r P} \cdot \mathbf{P_r P_s}}{\left|\mathbf{P_r P_s}\right|} \qquad \text{Eq. 8-10}$$

The value of q is positive if the aircraft is located behind the perpendicular closest point of approach to an extended line segment, PCPA, (as pictured in Figure 8-3), and the value of q is negative if the aircraft is ahead of PCPA. In terms of speed and time,

$$q = -v \cdot \tau \qquad \text{Eq. 8-11}$$

The sign in Eq. 8-11 is negative 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:

$$p_r^{\ 2} = p_s^{\ 2} \cdot \left(\frac{s^2}{r^2}\right) \cdot \sin^2(\theta) \qquad \text{Eq. 8-12}$$

which becomes:

$$p_r^{\ 2} = p_s^{\ 2} \cdot \frac{s^4}{r^4} \qquad \text{Eq. 8-13}$$

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[51]. When the $\sin\theta$ 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

$$r^2 = s^2 + q^2 \qquad \text{Eq. 8-14}$$

Which can be rewritten as follows, based on Eq. 8-11:

$$r^2 = s^2 + (v\tau)^2 \qquad \text{Eq. 8-15}$$

$$\left(\frac{r}{s}\right)^2 = 1 + \left(\frac{v \cdot \tau}{s}\right)^2 \qquad \text{Eq. 8-16}$$

Equation C-7 can then be substituted into Eq. 8-13, in order to derive the mean-square pressure as a function of time:

$$p_r^{\ 2}(\tau) = \frac{p_s^{\ 2}}{\left(1 + \left(\frac{v \cdot \tau}{s}\right)^2\right)^2} \qquad \text{Eq. 8-17}$$

The integral of the mean-square pressure, from time τ_1 to τ_2, is the segment noise exposure E_{12}

$$E_{12} = \int_{\tau_1}^{\tau_2} p_r^{\ 2}(\tau) d\tau \qquad \text{Eq. 8-18}$$

By using the substitution:

$$\alpha = \frac{v \cdot \tau}{s} \qquad \text{Eq. 8-19}$$

the segment noise exposure integral becomes:

$$E_{12} = p_s^{\ 2} \cdot \left(\frac{s}{v}\right) \cdot \int_{\alpha_1}^{\alpha_2} \frac{1}{(1+\alpha^2)^2} d\alpha \qquad \text{Eq. 8-20}$$

and its solution is:

$$E_{12} = p_s^{\ 2} \cdot \left(\frac{s}{v}\right) \cdot \left(\frac{1}{2}\right) \cdot \left\{ \left[\frac{\alpha_2}{(1+\alpha_2^{\ 2})} + \tan^{-1}(\alpha_2) \right] - \left[\frac{\alpha_1}{(1+\alpha_1^{\ 2})} + \tan^{-1}(\alpha_1) \right] \right\} \qquad \text{Eq. 8-21}$$

The total noise exposure from $\tau_1 = -\infty$ to $\tau_2 = \infty$ is:

$$E_\infty = \frac{1}{2} \cdot \pi \cdot \mathrm{p_s}^{\ 2} \cdot \frac{\mathrm{s}}{\mathrm{v}} \qquad \text{Eq. 8-22}$$

The noise exposure fraction, F_{12}, is the noise exposure between time τ_1 and τ_2 divided by the total noise exposure:

$$F_{12} = \frac{\mathrm{E}_{12}}{\mathrm{E}_\infty} \qquad \text{Eq. 8-23}$$

$$F_{12} = \left(\frac{1}{\pi}\right) \cdot \left[\frac{\alpha_2}{(1+\alpha_2^{\ 2})} + \tan^{-1}(\alpha_2) - \frac{\alpha_1}{(1+\alpha_1^{\ 2})} - \tan^{-1}(\alpha_1) \right] \qquad \text{Eq. 8-24}$$

The next part of the derivation shows how to calculate α_1 and α_2.

The AEDT 2a 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:

$$L_{E,160} = 10 \cdot \log_{10} \left[\left(\frac{v}{v_0}\right) \cdot \frac{E_\infty}{(\mathrm{p}_0^{\ 2} \cdot t_0)} \right] \qquad \text{Eq. 8-25}$$

$$L_{Smx} = 10 \cdot \log_{10}\left[\frac{p_s^{\ 2}}{\mathrm{p}_0^{\ 2}}\right] \quad \text{Eq. 8-26}$$

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 Eq. 8-22 is consistent with AEDT 2a NPD data, the following relationship must hold:

$$L_{E,160} - L_{Smx} = 10 \cdot \log_{10}\left[\left(\frac{v}{v_0}\right) \cdot \frac{\left(\frac{1}{2} \cdot \pi \cdot \mathrm{p_s}^{\ 2} \cdot \frac{s}{v}\right)}{\left(p_0^{\ 2} \cdot t_0\right)}\right] - 10 \cdot \log_{10}\left[\frac{p_s^{\ 2}}{p_0^{\ 2}}\right] \quad \text{Eq. 8-27}$$

therefore

$$\frac{1}{2} \cdot \pi \cdot \frac{s}{(v_0 \cdot t_0)} = 10^{\frac{\left[L_{E,160} - L_{Smx}\right]}{10}} \quad \text{Eq. 8-28}$$

and the distance, s, is scaled to fit the NPD data:

$$\mathrm{s} = \left(\frac{2}{\pi}\right) \cdot v_0 \cdot t_0 \cdot 10^{\frac{\left[L_{E,160} - L_{Smx}\right]}{10}} \quad \text{Eq. 8-29}$$

Using the symbol s_L to indicate a scaled distance, rather than the actual distance, the NPD-consistency requirement becomes:

$$\mathrm{s_L} = s_0 \cdot 10^{\frac{\left[L_{E,160} - L_{Smx}\right]}{10}} \quad \text{Eq. 8-30}$$

where

s_0 a constant dependent 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, Eq. 8-11, and Eq. 8-19, 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:

$$\alpha_1 = \frac{-q_1}{s_L} \quad \text{Eq. 8-31}$$

$$\alpha_2 = \frac{(-q_1 + L)}{s_L} \quad \text{Eq. 8-32}$$

where

q_1	relative distance (feet) from segment start point to point $\mathbf{P}_s$ and
L	length of segment (feet).

8.1.3 Derivation of the Time-Above Equation

The equation to compute the time-above metric in AEDT 2a can be developed by 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 Eq. 8-17:

$$p_r^{\;2} = \frac{p_s^{\;2}}{\left(1+\left(\frac{v\cdot\tau}{s_L}\right)^2\right)^2} \qquad \text{Eq. 8-33}$$

The time-history equation is solved for τ as a function of p_r:

$$\tau = \left(\frac{\mathrm{s_L}}{\mathrm{v}}\right)\cdot\left(\frac{\mathrm{p_s}}{\mathrm{p_r}-1}\right)^{½} \qquad \text{Eq. 8-34}$$

Given a noise threshold level, L_x, of root-mean-square pressure, p_x:

$$L_x = 10\cdot\log_{10}\left[\frac{p_x^{\;2}}{p_0^{\;2}}\right] \qquad \text{Eq. 8-35}$$

The time duration (in seconds) during which the noise level exceeds L_x, Δt_x, is twice the τ-value at $p_r = p_x$:

$$\Delta t_x = 2\cdot\left(\frac{\mathrm{s_L}}{\mathrm{v}}\right)\cdot\left[\left(\frac{\mathrm{p_s}^2}{\mathrm{p_x}^2}\right)^{½}-1\right]^{½} \qquad \text{Eq. 8-36}$$

which can be written as:

$$\Delta t_x = \begin{cases} 2\cdot\left(\frac{\mathrm{s_L}}{\mathrm{v}}\right)\cdot\left[10^{\frac{\left[L_{Smx,adj}-L_x\right]}{20}}-1\right]^{½} & L_x < L_{Smx,adj} \\ 0.0 & L_x \geq L_{Smx,adj} \end{cases} \qquad \text{Eq. 8-37}$$

where

$L_{Smx.adj}$	the adjusted maximum noise level at the observer.

Note that:

$$\frac{s_L}{v} = \left(\frac{2}{\pi}\right) \cdot \left(\frac{t_0 \cdot v_0}{v}\right) \cdot 10^{\frac{\left[L_{E,160,adj} - L_{Smx,adj}\right]}{10}} \qquad \text{Eq. 8-38}$$

and that:

$$L_{E,adj} = L_{E,160,adj} + 10 \cdot \log_{10}\left[\frac{v_0}{v}\right] \qquad \text{Eq. 8-39}$$

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.

Eq. 8-36 can be written to express time-above duration (in minutes) in terms of adjusted exposure and maximum levels:

$$\Delta t_x = \left(\frac{1}{60}\right) \cdot \left(\frac{4}{\pi}\right) \cdot t_0 \cdot \left[10^{\frac{\left[L_{E,adj} - L_{Smx,adj}\right]}{10}}\right] \cdot \left[10^{\frac{\left[L_{Smx,adj} - L_x\right]}{20}} - 1\right]^{½} \qquad \text{Eq. 8-40}$$

8.2 Acoustic Data Development

This appendix provides detailed descriptions of the acoustic data development process for AEDT 2a: the acoustic data development criteria (Section 8.2.1), and an overview of spectral class development (Section 8.2.2).

8.2.1 Acoustic Data Development Criteria

Guidance for developing acoustic aircraft source data is presented in detail in Appendix B of SAE-AIR-1845 "Procedure for the Computation of Airplane Noise in the Vicinity of Airports"[14]. While this guidance is specific for developing SEL NPDs for fixed-wing aircraft, it may be modified in order to develop NPDs for other base noise metrics (LAMAX, EPNL and PNLTM) and aircraft types (helicopters and military aircraft).

Supplemental criteria for developing fixed-wing aircraft and helicopter NPDs are presented below.

For fixed-wing aircraft, criteria for development of NPD data for use by AEDT 2a include the following[15]:

- Acoustically soft ground under the measurement microphone, similar to the terrain around the microphone during aircraft noise certification tests[27,52].
- 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-ARP-866A[28].

- L_{AE} and L_{EPN} values time-integrated over the upper 10 dB of the noise event as prescribed by FAA[27] and SAE[14]. (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 for both approach and departure NPDs.

- Noise levels specified as a function of power, in the form of corrected net thrust per engine[xix].

In addition, criteria for development of helicopter NPD data for use by AEDT 2a 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 to establish helicopter directivity during this configuration (see Section 4.5.3).

For the complete AEDT 2a Database Submittal Forms, please contact aedt-support@dot.gov.

The FAA position is to adhere closely to the above criteria both for the development and validation of the AEDT 2a NPD data. Diligent compliance is needed to ensure confidence in having consistent and comparable aircraft NPD and performance data. More information on the AEDT 2a data validation is presented in Section 8.3.

It is important to note that the civil fixed wing aircraft noise and performance data that make up the AEDT 2a 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.

8.2.2 Overview of Spectral Class Development

For each aircraft acoustic data submittal to the AEDT 2a Fleet database, a spectral class assignment is made by either pairing the aircraft with an appropriate existing spectral class, or developing a new spectral class for the aircraft. The original development and assignment of spectral classes was performed in 1999[53]. Additional spectral classes are developed as needed, if there are no reasonable representations of that aircraft's spectral acoustic data in the current database.

[xix] FAA AEE approval is required, in order to develop NPDs for fixed-wing aircraft for AEDT 2a with any power parameter other than net corrected thrust.

This Section provides an example of the derivation of a spectral class for the AEDT 2a 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 turbofan aircraft.

The B737700 and the hushkit retrofitted B737N17 and B737N19 have NPD curves referenced to spectral class 104. They were added to the AEDT 2a 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[54]. A more detailed description of the spectral class assignment process is described in Section 8.3.2.

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 8-4.

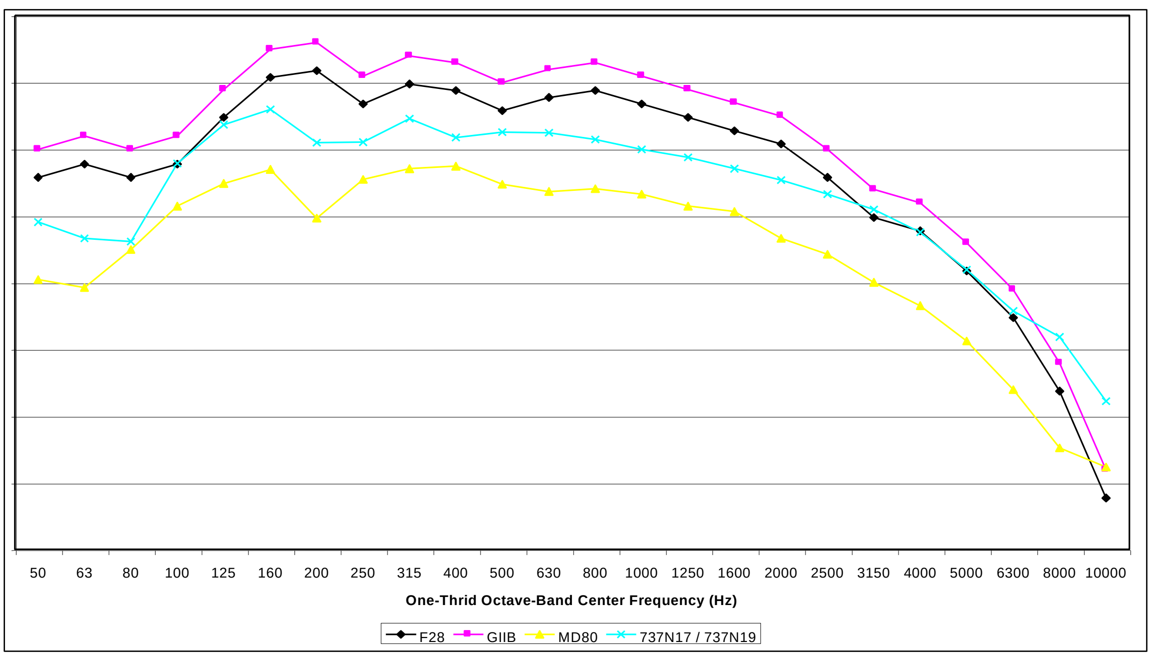

Figure 8-4 Departure Class 104

To aid in the visual inspection of the spectra, each one is normalized to a value of 70 dB at 1000 Hz. Figure 8-5 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.

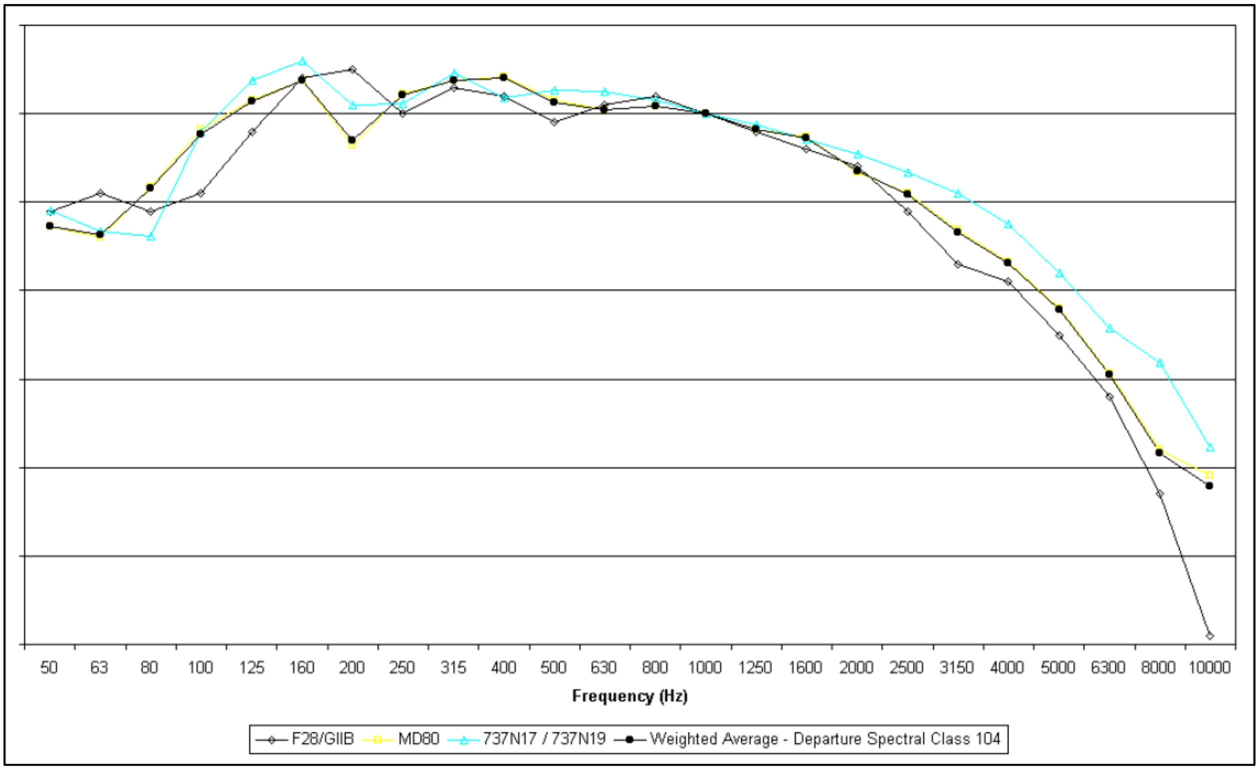

Figure 8-5 Normalized Spectral Class 104 Data

Step 3: Verification of Proposed Spectral Class

In order to verify the appropriateness of the proposed spectral class, the individual spectra and the representative were systematically evaluated using the acoustical calculations that require third-octave band spectra data: atmospheric absorption effects (Section 4.3.1) , and barrier (or line of sight blockage, Section 4.3.6) effects. Testing parameters were chosen to represent the range of plausible airport conditions (temperature, humidity, slant distance, and path-length difference due to line-of-sight terrain blockage).

Step 3.A: Atmospheric Absorption Effects

The assessment of spectral classes in the calculation of atmospheric absorption adjustment (AA_{adj}) effects was conducted using a range of atmospheric conditions which are representative of realistic airport conditions. Monthly atmospheric data for the 34 Operational Evolution Plan (OEP) airports was originally obtained from the National Oceanic and Atmospheric Administration (NOAA) website by accessing the “Local Climatological Data Annual Summary” report. Reported were the 30-year average (1971-2004) monthly temperature, and a 1-year (2004) average monthly minimum and maximum relative humidity at each airport weather station. Thus, the database for this analysis contained 816 representative temperature/humidity conditions (34 airports, 12 months, 2 temperature/humidity combinations per month); 670 of these values were unique, 146 were duplicates. Table 8-1 contains the descriptive statistics of this database. Notably, the average condition at these airports closely resembles the International Standard Atmosphere, Standard Day condition of 59 °F and 70% relative humidity. Figure 8-6 graphically depicts the conditions represented in this database.

Table 8-1 OEP Airport Atmospheric Condition Statistics

	Mean	Median	Minimum	Maximum
Temperature	59 °F	61 °F	51 °F	93 °F
Relative Humidity	67%	67%	12%	93%

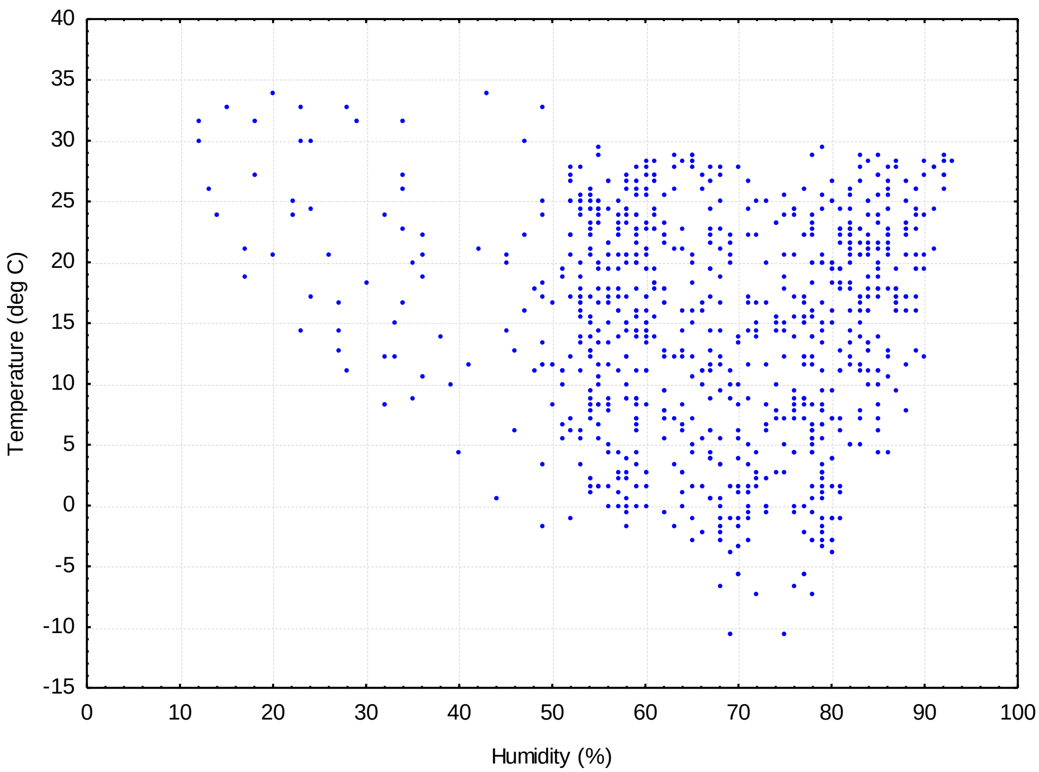

Figure 8-6 Spectral Class 104 Ground Effect

The AA_{adj} was calculated for each aircraft using discrete points from a uniform distribution of slant distance and the 816 values collected from the temperature and humidity condition distribution. These discrete slant distance points correspond to the 10 standard AEDT 2a distances (200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, and 25000 ft). The uncertainties associated with the use of spectral classes in the calculation of AEDT 2a's atmospheric absorption adjustment (ΔAA_{adj}) were computed by subtracting the AA_{adj} calculated using each individual aircraft from the AA_{adj} calculated using the representative spectrum from the associated spectral class. In this manner, a positive value indicates that the use of spectral classes results in an over-prediction of the resulting noise level. The resulting database of approximately 1.2 million ΔAA_{adj} uncertainty values is depicted in Figure 8-7. Table 8-2 presents further summary of these values grouped by aircraft power setting, aircraft type, atmospheric conditions, and slant distance. It tabulates the distribution of these values within ±1 and ±2 dB bounds. In general, the vast majority of these values are within ±1 dB. Slightly larger errors occur for the following: 1) approach conditions, where SPLs in the high-frequency bands are prevalent in the source spectrum; 2) propeller-driven aircraft, where tonal components are present in the spectrum; and 3) low humidity conditions, where atmospheric absorption is most significant.

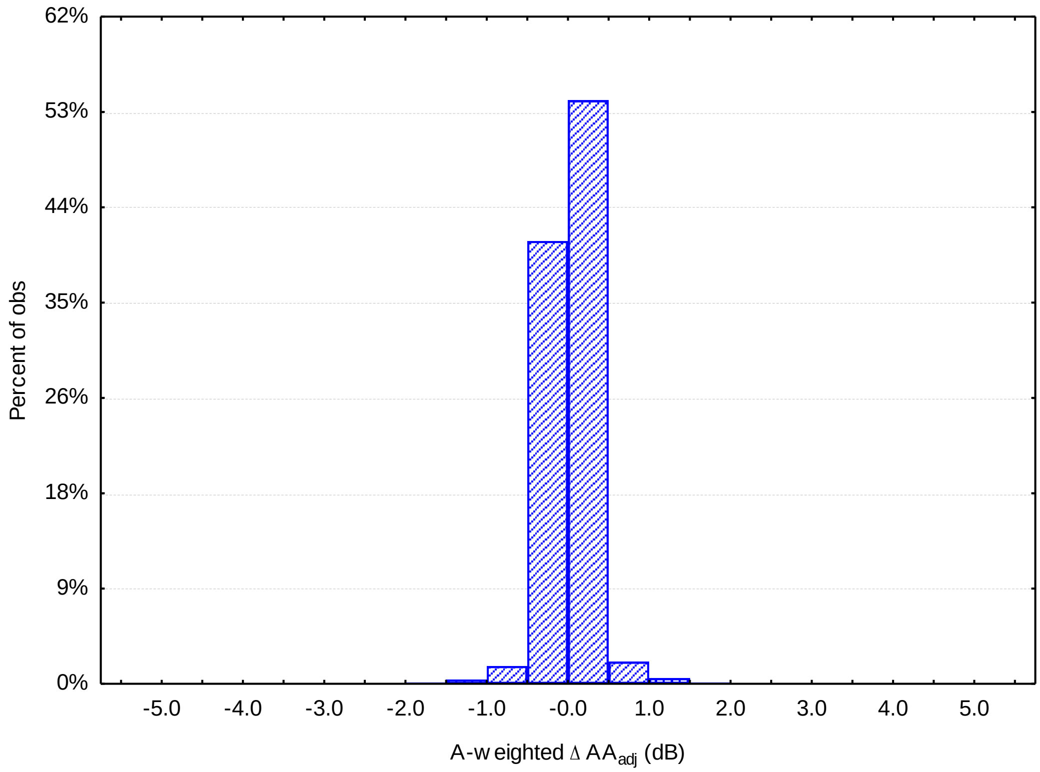

Figure 8-7 Histogram of A-weighted ΔAA_{adj}

Table 8-2 Summary of A-weighted ΔAA_{adj}

Data Subset	% of Data Within ±1 dB	% of Data Within ±2 dB
All	98.7	99.9
Departure Power	99.4	100.0
Approach Power	98.1	99.8
Jet Aircraft	99.0	99.9
Prop Aircraft	98.0	100.0
Departure Power, Jet Aircraft	100.0	100.0
Approach Power, Jet Aircraft	98.0	99.7
Departure Power, Prop Aircraft	98.0	100.0
Approach Power, Prop Aircraft	98.4	100.0
Temp≤39°F, Humidity≤55%	97.7	99.5
Temp≥80.6°F, Humidity≤55%	99.1	99.8
Temp≤39°F, Humidity≥80%	98.1	99.3
Temp≥80.6°F, Humidity≥80%	98.7	99.9
200 ft Slant Distance	98.7	99.8
400 ft Slant Distance	97.4	99.6
630 ft Slant Distance	98.0	99.7
1000 ft Slant Distance	99.2	100.0
2000 ft Slant Distance	99.8	100.0
4000 ft Slant Distance	99.6	99.9
6300 ft Slant Distance	99.8	100.0
10000 ft Slant Distance	99.9	100.0
16000 ft Slant Distance	99.1	100.0
25000 ft Slant Distance	96.0	100.0

Step 3.B: Line-of-Sight Blockage Effects

The second assessment was conducted to determine the uncertainty associated with the use of spectral classes for the calculation of the LOS_{adj}, which accounts for the attenuation due to line-of-sight blockage from terrain features. The LOS_{adj} uncertainty values (ΔLOS_{adj}) due to the use of spectral classes were computed by subtracting the LOS_{adj} calculated using each individual aircraft spectrum from the LOS_{adj} calculated using the representative spectrum from the associated spectral class. In this manner, a positive ΔLOS_{adj} represents an over-prediction of the resulting noise level.

ΔLOS_{adj} was calculated for 14 path-length differences (-1, 0.1, 0.5, 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 ft) at the 816 average monthly OEP temperature and humidity conditions and the 10 standard AEDT 2a slant distances. The resulting database of approximately 17 million ΔLOS_{adj} values, or differences, associated with the use of spectral classes is depicted in Figure 8-8.

Table 8-3 summarizes the ΔLOS_{adj} with breakdowns by aircraft power setting, aircraft type, atmospheric conditions, slant distance, and path-length difference. The A-weighted ΔLOS_{adj} values are almost all within a ± 2.5 dB range, and the large majority of values (over 90%) are within a ± 1 dB range. Slightly larger errors occur for the following: 1) propeller-driven aircraft, where tonal components can dominate the spectrum; 2) shorter slant distances; and 3) path-length differences between 1 and 6 ft (near grazing incidence), where barrier attenuation is most frequency dependent.

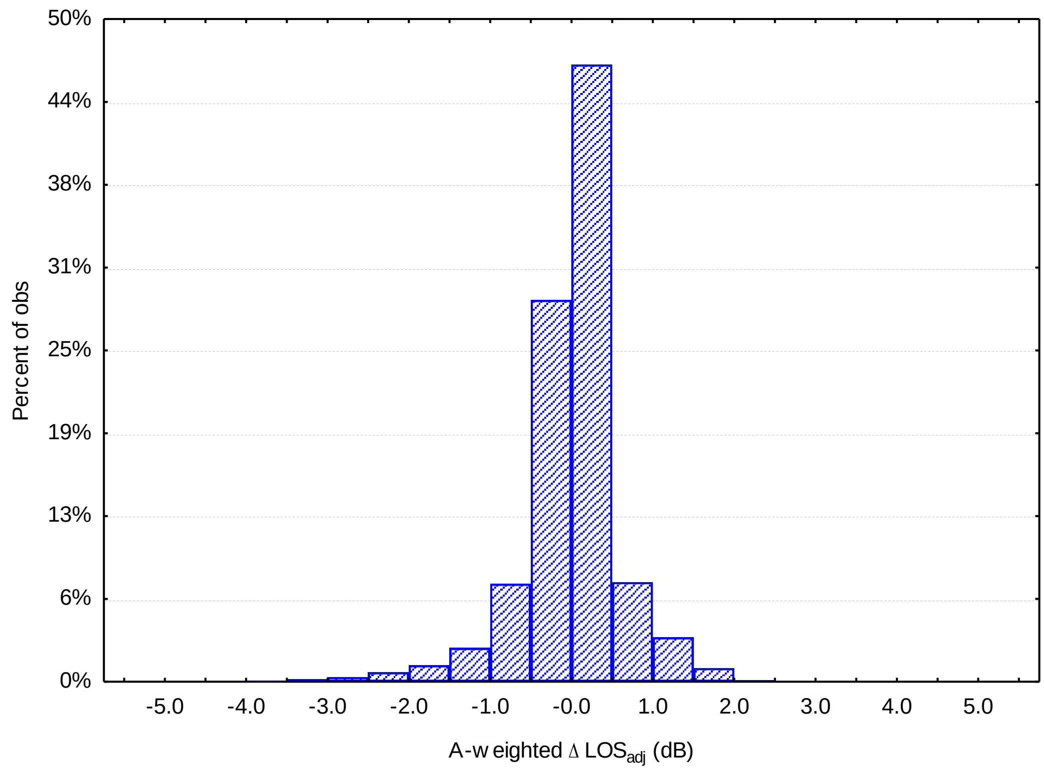

Figure 8-8 Histogram of A-Weighted ΔLOS_{adj}

Table 8-3 Summary of A-Weighted ΔLOS_{adj}

Data Subset	% of Data Within ±1 dB	% of Data Within ±2 dB
All	90.4	98.6
Departure Power	90.3	99.0
Approach Power	90.4	98.1
Jet Aircraft	93.8	99.4
Prop Aircraft	80.5	96.1
Departure Power, Jet Aircraft	92.8	99.7
Approach Power, Jet Aircraft	94.8	99.2
Departure Power, Prop Aircraft	83.0	97.0
Approach Power, Prop Aircraft	83.0	97.0
Temp≤39°F, Humidity≤55%	91.6	98.9
Temp≥80.6°F, Humidity≤55%	90.9	98.7
Temp≤39°F, Humidity≥80%	90.7	98.7
Temp≥80.6°F, Humidity≥80%	90.4	98.5
200 ft Slant Distance	87.4	96.5
400 ft Slant Distance	88.2	97.3
630 ft Slant Distance	88.8	97.8
1000 ft Slant Distance	89.1	98.3
2000 ft Slant Distance	89.0	98.8
4000 ft Slant Distance	89.2	98.8
6300 ft Slant Distance	89.9	99.0
10000 ft Slant Distance	91.7	99.4
16000 ft Slant Distance	94.2	99.7
25000 ft Slant Distance	96.5	100.0
δ_0 = -1 ft	100.0	100.0
δ_0 = 0.1 ft	96.6	99.0
δ_0 = 0.5 ft	87.4	97.6
δ_0 = 1 ft	83.0	96.9
δ_0 = 2 ft	80.9	96.6
δ_0 = 4 ft	82.2	97.2
δ_0 = 6 ft	83.9	98.0
δ_0 = 8 ft	87.5	98.6
δ_0 = 10 ft	89.2	98.6
δ_0 = 12 ft	91.8	98.7
δ_0 = 14 ft	94.3	98.9
δ_0 = 16 ft	95.4	99.7
δ_0 = 18 ft	96.1	100.0
δ_0 = 20 ft	96.9	100.0

Step 4: Final Spectral Class

Given that the curves for each individual aircraft spectrum adjusted by the aforementioned spectral-based effects 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 8-9 presents the final spectral class.

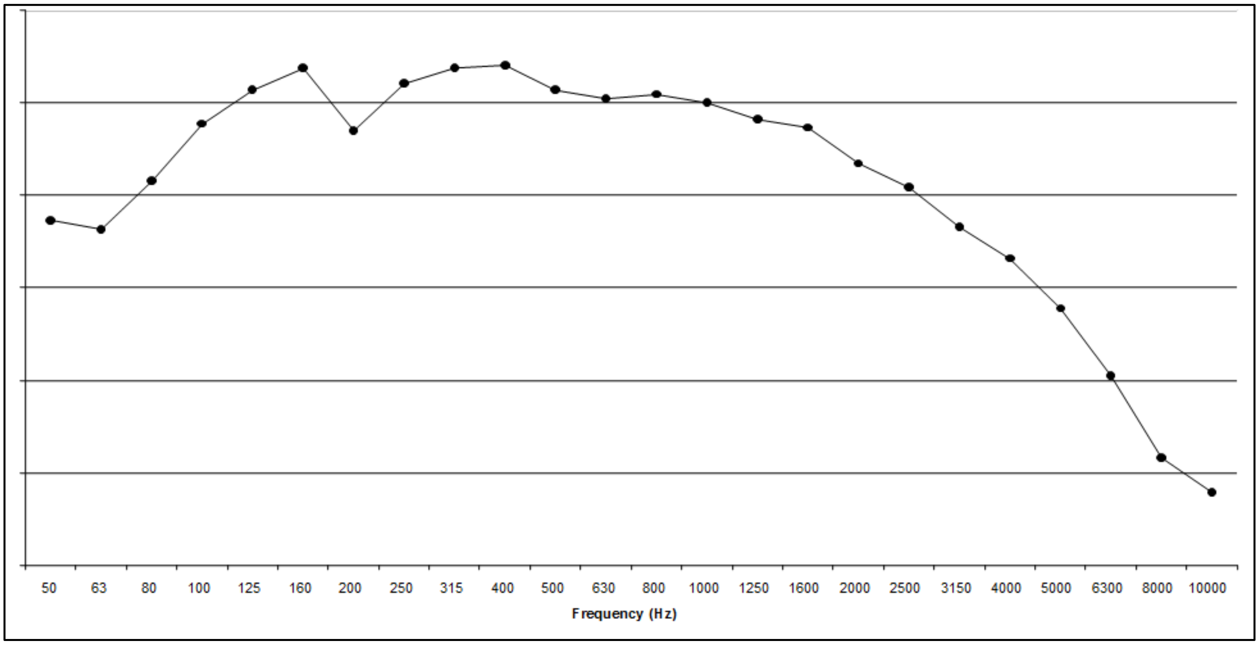

Figure 8-9 Departure Spectral Class 104

8.3 Aircraft Noise and Performance Data Verification and Validation

This Section describes the Validation and Verification (V&V) processes for new aircraft noise and performance database submittals for inclusion in AEDT 2a. Typically, the aircraft manufacturer or consultants to the manufacturer provide new database submittals. Because of the many different measurement and processing methodologies that could be employed by these parties, the quality of new submittals must always be inspected, to ensure high data quality, consistency and completeness in the AEDT 2a Fleet database. This inspection process is referred to as validation and verification. As far as updated or revised database submittals are concerned, the scope of the inspection process is specifically tailored to each submittal, based on the nature and extent of the update or revision. For in-depth updates, the full V&V process is conducted.

The format and content of a new database submittal are laid out in the AEDT Database Request Form. Contact aedt-support@dot.gov to request the AEDT Database Request Form. All database submittals should be checked against the requirements in this form for completeness. All required data must be present in order to run the submitted aircraft in AEDT 2a.

New database submittals are comprised of both noise and performance data. These two data sets may be evaluated independently. The noise portion of this database is divided into two major parts: the NPD data and the spectral data. Both of these data sets undergo the V&V process to insure the quality of the data. Once the quality of the data submittals has been checked, the spectral data are further processed and spectral class assignments are made.

The performance portion of this database (which also includes aircraft and engine data) also undergoes the V&V process to insure data quality. Performance data are checked for consistency with existing data and reasonableness. This includes a sensitivity analysis to determine impacts due to the new data.

After the noise and performance data have been reviewed, the entire aircraft noise and performance data set is incorporated into AEDT, and a comparison with noise certification data is conducted as a final check.

8.3.1 NPD and Spectral Data V&V

The new acoustic data for an aircraft consist of a set (or sets) of NPD data and corresponding one-third octave-band data. Typically these data would be derived from aircraft certification[xx], and would consist at Effective Perceived Noise Level (L_{EPN}), Sound Exposure Level (L_{AE}), Maximum A-Weighted Sound Level (L_{ASmx}), and Maximum Tone-Corrected Perceived Noise Level (PNLTmax or $L_{PNLTSmx}$) NPD curves, representing each operation mode and thrust parameter values that span the range of thrust values used in the flight profiles for the aircraft[xxi]. The corresponding one-third octave-band data are measured at the time of the maximum A-weighted sound level, or the maximum tone-corrected perceived noise level. This data are described in SAE-AIR-1845 Appendix B[14]. The data submitted by the manufacturer do not include recommended spectral class assignments, only spectral data corrected to 1000 ft assuming the SAE-AIR-1845 standard atmosphere[xxii].

The V&V of NPD and spectral data involves four major tasks:

1. Internal consistency check.
2. Comparison of new NPDs to NPDs of similar aircraft.
3. Reprocessing of the new spectral data to produce NPDs, and the comparison of these NPDs with the new NPDs submitted by the manufacturer.
4. Comparison of modeled results at certification distances to the corresponding manufacturer data (either certification or NPD data).

Tasks 1, 2 and 3 are described in further detail below (Sections 8.3.1.1 through 8.3.1.3, respectively). Task 4, which consists of the final comparison between modeled and certification data, is described in 8.3.4.

8.3.1.1 Internal Consistency

New aircraft acoustic data are checked for consistency across data files. The data must meet the AEDT 2a's requirements for completeness, consistency and must not contradict itself. For example, the aircraft NPDs must include sound pressure levels at all 10 NPD distances. The aircraft manufacturer is then contacted if significant anomalies or data gaps are observed.

8.3.1.2 Comparison with NPDs of Similar Aircraft

The new NPD data are compared with NPDs from similar aircraft. Aircraft are deemed to be similar based on airframe model, engine (type and number of engines), static thrust, engine bypass ratio, as well as maximum takeoff and landing weights. The NPDs are compared for each aircraft across all thrust values, in order to evaluate the overall shape of the NPDs. Approach and departure NPDs are evaluated separately. Although NPDs from different aircraft should not necessarily be the same, the comparison

[xx] Specific guidelines for developing NPD data are provided in SAE-AIR-1845.
[xxi] The submittal should differentiate between acoustic data for different operational modes (approach, departure, etc.).
[xxii] Although previous submittals utilized corrections using 25°C / 70% relative humidity or standard day sea level conditions of 15°C and 70% relative humidity, the use of these conditions is discouraged.

aids in the identification of erroneous data points and atypical data trends. The aircraft manufacturer is then contacted if significant anomalies are observed.

8.3.1.3 Reprocessing NPDs and Comparison with Manufacture Submitted NPDs

The spectral data provided by the manufacturer are reprocessed using the simplified correction method from SAE-AIR-1845[14] and ICAO Annex 16 – Environmental Protection, Volume I - Aircraft Noise [52,xxiii]. The process takes spectral data, sound pressure level, reference environmental conditions and aircraft speed and slant distance as inputs, and generates NPDs. This process is used to generate a NPD database for use in sensitivity tests of each new aircraft.

The resulting NPD database is then compared to the corresponding new NPD database submitted by the manufacturer. If both sets of NPDs were generated with the simplified method, then they should yield very similar results, barring any problems or errors in the NPD generation process. If the manufacturer utilized the integrated method for generating the new NPDs, differences between the sets of NPD curves are expected.

Typically, these differences may be around 0 to 1 dB at shorter distances (less than 4000 ft) and around 3 to 5 dB at 16000 to 25000 ft. In general, larger differences may be expected for $L_{PNLTSmx}$ and L_{EPN} NPDs, because the integrated method deals with tone corrections on a record-by-record basis, as opposed to the simplified method, which applies them at the time of maximum sound level. The aircraft manufacturer is contacted if large differences are observed.

8.3.2 Spectral Class Assignments

The data submitted by the manufacturer do not include a recommended spectral class (SC) assignment, only the corrected spectral data. These spectral data consist of, at a minimum, two sets of unweighted, one-third octave-band sound levels measured at the time of maximum sound level (typically either L_{ASmx} or $L_{PNLTSmx}$) and corrected to a reference distance of 1000 ft, representing thrust parameter values typical of departure and approach conditions. From these sets of data, a spectral class is assigned for each condition. When a submittal contains additional data which are representative of a range of thrust parameter values, spectral class assignments are based on the maximum departure and minimum approach thrust values.

There are three acoustic propagation phenomena in AEDT 2a which are spectrally dependent: Atmospheric absorption, excess ground attenuation, and shielding caused by barriers or terrain. As a result, spectral class assignments are based on the both the ‘shape’ of the spectral data and the behavior of these three effects. The assignment process has five major parts:

1. Normalization and computation of free-field effect.
2. Comparison of aircraft (AC) spectral shape to SC spectral shapes.
3. Comparison of atmospheric absorption effects calculated using AC spectra and SC spectra.
4. Comparison of ground effects calculated using AC spectra and SC spectra.

[xxiii] Two methods of NPD generation are presented in ICAO Annex 16; simplified and integrated. The simplified method consists of correcting the maximum sound pressure level of an event for the test day slant distance, aircraft speed and meteorological conditions to the desired reference day conditions. The integrated method incorporates these corrections for each point on the time history of the event (0.5 second intervals) and corrects for background noise, yielding a corrected spectral time history from which NPDs are derived.

5. Comparison of barrier effects calculated using AC spectra and SC spectra.

These five processes are described in further detail below.

8.3.2.1 Normalization and Computation of Free-Field Effect

The submitted spectral data are normalized to 70 dB at 1000 Hz. This allows for a visual shape comparison shown in Figure 8-10 and a computed comparison as detailed in Section 8.3.2.2.

Figure 8-10 Shape Comparison of Spectral Data

The submitted spectral data should be representative of free-field conditions. In most cases, however, the data were measured for certification purposes, and an adjustment is necessary to correct the data, which are typically measured by a 4 ft microphone over acoustically soft ground, to free-field conditions.

This adjustment is derived by computing the theoretical ground effect (detailed in Section 8.3.2.4) as a function of the emission angle (B) for source-to-receiver geometries using the 10 NPD slant distances, emission angles of 30, 40, 50, 60, 70 and 80 degrees, and an effective flow resistivity equal to 150 cgs rayls. The resulting 60 data points are summed and retained as the free-field adjustment.

8.3.2.2 Comparison of Spectral Shape

The normalized AC spectra are compared to all of the potential applicable SC spectral shapes (i.e., approach or departure, jet or helicopter). This comparison is accomplished by subtracting the AC SPLs in each one-third octave band from the SC SPLs in the corresponding one-third octave band. The absolute values of the individual SPL differences are summed. The resulting sums are compared and the spectral class that provides the lowest sum is retained as a possibility for the final assignment.

8.3.2.3 Comparison of Atmospheric Absorption Effects

The normalized AC spectra are used to compute the atmospheric absorption effect at the 10 NPD slant distances under 6 different temperature/humidity conditions using SAE-ARP-866a[28]: the SAE standard atmosphere, the Annex 16[52] reference day (59°F /70%), and the four extremes of the Annex 16 allowable test window (86°F /35%, 86°F /85%, 50°F/55%, and 50°F /85%). These 60 points make up an atmospheric absorption profile. The individual point differences between the atmospheric absorption profile for the submitted AC and the atmospheric absorption profile for all of the SC's under consideration are summed. The resulting sums are compared and the spectral class that provides the lowest sum is retained as a possibility for the final assignment. In addition, any individual differences greater than +-3 dBA (for the best-possible spectral class) are flagged. These flagged differences are examined and the possibility of the creation of a new spectral class is considered.

8.3.2.4 Comparison of Ground Effects Calculated using AC Spectra and SC Spectra

The normalized AC spectra are used to compute the A-weighted, excess ground attenuation effect at the 10 NPD slant distances for 12 emission angles (0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 20 degrees). The theoretical ground effect calculation is an implementation of the model documented by Tony Embleton, Joe Piercy and Giles Daigle (the EPD Model) of the National Research Council (NRC) in Canada[55]. These 120 points make up a ground effect profile. The individual point differences between the ground effect profile for the submitted AC and the ground effect profile for all of the SC's under consideration are summed. The resulting sums are compared and the spectral class that provides the lowest sum is retained as a possibility for the final assignment. In addition, any individual differences greater than +-3 dBA (for the best-possible spectral class) are flagged. These flagged differences are examined and the possibility of the creation of a new spectral class is considered.

8.3.2.5 Comparison of Barrier Effects Calculated using AC Spectra and SC Spectra

The normalized AC spectra are used to compute the A-weighted barrier effect (insertion loss) at the 10 NPD slant distances for 7 path-length differences (-4, 0, 4, 8, 12, 20, and 100 ft). The barrier effect calculation is documented in Section 4.3.6. These 70 points make up a barrier effect profile. The individual point differences between the barrier effect profile for the submitted AC and the barrier effect profile for all of the SC's under consideration are summed. The resulting sums are compared and the spectral class that provides the lowest sum is retained as a possibility for the final assignment. In addition, any individual differences greater than +-3 dBA (for the best-possible spectral class) are flagged. These flagged differences are examined and the possibility of the creation of a new spectral class is considered.

8.3.2.6 Final Assignment of Spectral Class

Ideally, the spectral class possibilities resulting from Sections 8.3.2.2 through 8.3.2.5 are identical and a final assignment can be made without further analysis. If the possibilities do not agree, the reasons for disagreement are examined and either 1) a spectral class assignment is made based on a 'majority rule', or, if no clear majority exists, 2) the possibility of the creation of a new spectral class is considered.

8.3.3 Performance Data V&V

The new performance data for an aircraft consist of aircraft and engine data, default flight profiles with corresponding aircraft weights, and aerodynamic and engine coefficients. These data are described in SAE-AIR-1845 Appendix A.

The V&V of performance data involves four major tasks:

1. Internal consistency check
2. Consistency check with prior submittals
3. Reasonableness check
4. Suitability across different atmospheric conditions

These four tasks are described in further detail below.

8.3.3.1 Internal Consistency

New aircraft performance data are checked for consistency across data files. The data must meet the AEDT 2a's requirements for completeness, consistency and must not contradict itself. For example the aircraft weight for the highest stage-length profile must be lower than the aircraft's maximum gross takeoff weight in order to successfully run through AEDT 2a.

8.3.3.2 Consistency with Prior Submittals

The new performance data are compared with earlier submittals from the same source for consistency in content, naming conventions, etc. Comments are made to improve overall database consistency as appropriate. Although performance data from different aircraft should not necessarily be the same, the comparison aids in the identification of erroneous data points and atypical data formats. The aircraft manufacturer is then contacted if significant differences are observed.

8.3.3.3 Reasonableness

New performance data are checked for reasonableness by comparing to data from other similar aircraft types. Aircraft are deemed to be similar based on airframe model, engine (type and number of engines), static thrust, as well as maximum takeoff and landing weights. Any large deviation for a given field compared to other similar aircraft will be noted and questioned. Although performance data from different aircraft should not necessarily be the same, the comparison aids in the identification of erroneous data points and atypical data trends. In addition, single-event SEL contours are run to ensure that the data produces reasonable output in terms of contour size and shape. The aircraft manufacturer is then contacted if significant anomalies are observed.

8.3.3.4 Suitability for Varying Atmospheric Conditions

New performance data are checked to ensure they are suitable for use across the typical range of atmospheric conditions (airport elevation, temperature, etc.) encountered when modeling noise around an airport. For procedural profile data, the resultant altitude, speed, and thrust values vs. track distance are examined for a range of input atmospheric conditions to ensure that the profiles produce reasonable results. For example a defined procedural profile must be flyable from a sea-level airport on a 59°F day as well as from an airport at 5000 ft MSL on a 90°F day.

Performance coefficients are derived from a wide range of manufacturer generated flight profiles, reflecting different operating weights, procedures and atmospheric conditions. As a final cross check, the flight profiles are re-generated using the performance coefficients and compared with the original manufacturer-generated flight profiles.

8.3.4 Model Comparison of Submitted Data with Certification Data

Once the spectral class assignment and the performance data V&V process are completed, all of the new aircraft data (including the new NPDs) are entered into the AEDT 2a Fleet database (as either a User

Defined aircraft or as updated database files). AEDT 2a is run to mimic a noise certification flight test with receivers at the certification distances for both approach and departure tracks. The AEDT 2a results at the certification locations are checked against the corresponding data submitted to the sponsoring organization by the manufacturer (either certification or NPD data). This acts as a final check of both the noise and performance data. The aircraft manufacturer is contacted if large differences are observed.

Additionally, new or updated data may be run through a sensitivity analysis to determine single-event or airport-wide noise impacts from the new data, as necessary. The level of detail and level of effort involved for a given sensitivity analysis may vary depending on the purpose of the supplemental analysis. When there are significant changes in data for single-event or airport-wide noise contours, the aircraft manufacturer is contacted, and the new data are further analyzed.

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