Rotorcraft Noise Model

by

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Abstract

The Rotorcraft Noise Model (RNM) is an aircraft noise impact modeling computer program being developed for NASA-Langley Research Center which calculates sound levels at receiver positions either on a uniform grid or at specific defined locations. The basic computational model calculates a variety of metrics. Acoustic properties of the noise source are defined by two sets of sound pressure hemispheres, each hemisphere being centered on a noise source of the aircraft. One set of sound hemispheres provides the broadband data in the form of one-third octave band sound levels. The other set of sound hemispheres provides narrowband data in the form of pure-tone sound pressure levels and phase. Noise contours on the ground are output graphically or in tabular format, and are suitable for inclusion in Environmental Impact Statements or Environmental Assessments.

Notation

BB	Broadband
CNEL	Community Noise Equivalent Level
DNL	Day-Night Average Sound Level
EPNL	Effective Perceived Noise Level
L_{eq}	Unweighted Energy-Equivalent Sound Level
$L_{eq}(A)$	A-Weighted Energy-Equivalent Sound Level
$L_{eq}(C)$	C-Weighted Energy-Equivalent Sound Level
$L_{max}(A)$	A-Weighted Maximum Sound Level
PNL	Perceived Noise Level
PNLT	Tone-Corrected Perceived Noise Level
P T	Pure Tone
R_{min}	Closest Point of Approach
SEL	Overall Sound Exposure Level
SEL(A)	A-Weighted Sound Exposure Level
SEL(C)	C-Weighted SOund Exposure Level
SPL	Overall Sound Pressure Level
SPL(A)	A-Weighted Sound Pressure Level
SPL(C)	C-Weighted Sound Pressure Level
θ	Spherical Angle 0 to 180 Degrees
ϕ	Spherical Angle -90 to +90 Degrees

Introduction

As more and more U.S. airports approach their capacity with respect to the maximum number of daily aircraft operations, those slots used by commuter aircraft flying short routes with fewer passengers will limit the total number of passengers that can use a congested airport each day. Tiltrotor aircraft, which have the capability to take off and land vertically while flying like an airplane during cruise, could provide an alternative means of transportation that could reduce the demand on airports. However, noise generated by large (40-passenger, V-22 size) tiltrotor aircraft is a potential barrier issue for civil market penetration. The Civil Tiltrotor Development Advisory Committee[1] found that a civil tiltrotor (CTR) was technically feasible, but also noted that noise is the most critical environmental issue facing scheduled passenger service. Reducing noise at the source is one approach to addressing this issue. However, consideration must also be given to CTR aircraft noise abatement operational procedures and overall land-use planning. For CTRs, noise abatement primarily refers to making use of the nacelle tilt capability of a tiltrotor, in conjunction with airspeed and flight path angle, to reduce the noise footprint on the ground. Both noise abatement and land-use planning require the development and application of an appropriate noise model.

As a noise source, all rotorcraft, including CTRs, are more complex than fixed-wing aircraft in that the noise characteristics are more dependent on how the aircraft is operated, and also more complex than conventional helicopters, because of the added degree-of-freedom of nacelle tilt. Current noise models, such as the Federal Aviation Administration's (FAA) Helicopter Noise Model[2] (HNM), apply the same analytical techniques that are used in the FAA fixed-wing Integrated Noise Model[3] (INM). Both HNM and INM use as a measured noise database A-weighted SEL versus slant distance and both models use a single omni-directional point source to represent the vehicle noise emission. These assumptions preclude consideration of the noise source spectra and directivity patterns. In the horizontal plane of the main rotor, it has been demonstrated that the sound levels can be significantly higher than those measured directly

underneath the helicopter.[4] The implication is that current noise models that assume an omni-directional point source may not be accurately estimating the noise levels on either side of the helicopter track.

A new Rotorcraft Noise Model (RNM) is being developed for NASA–Langley Research Center as a research tool to calculate and assess the noise propagated by CTRs under various operating conditions. The model is based on the propagation algorithms that are contained in ROTONET.[5] ROTONET is an element of the NASA Aircraft Noise Prediction Program (ANOPP)[6,7,8] specifically designed for helicopter noise. In RNM, the noise source is represented by sets of broadband and narrowband sound hemispheres that can be obtained from either measured test data or computational models. RNM is capable of calculating cumulative noise exposures using maximum A-weighted sound levels, Sound Exposure Level (overall, C-, A-weighted), Tone Corrected Perceived Noise Level, Effective Perceived Noise Level, Day-Night Average Sound Level, C-weighted Day-Night Average Sound Level, and Community Noise Equivalent Level. Output from RNM can be directly imported into a Geographical Information System which in turn can be used for displaying the noise contours and evaluating environmental noise impacts associated with rotorcraft operations.

The major elements of the RNM noise model are presented in Figure 1. These consist of: the source level noise data, the input file that describes the aircraft operations, the propagation algorithms, and the program output. A detailed explanation of this process follows.
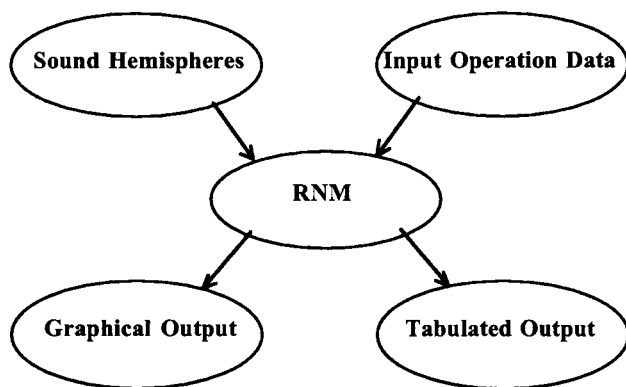

Figure 1. Overview of Rotorcraft Noise Model.

Sound Hemispheres

Source level noise data is presented to the model in the form of a sound hemisphere (see Figure 2) containing one-third octave or pure-tone noise levels. Points on the hemisphere are described in terms of a fixed radius and two spherical angles. The spherical coordinate system used by RNM assumes the origin of the coordinate system is located at the center of gravity of the noise source and the Z-axis is aligned along the diameter of the main portion of the fuselage. The direction angle, theta, points from the bow of the aircraft where theta is zero, to the stern where theta is 180 degrees. Phi is zero directly underneath the vehicle, positive 90 degrees on the port side, and minus 90 degrees on the starboard side. While the angles of theta and phi are defined in different ways by different authors, the notation is consistent with that used by ROTONET, and was used in RNM to facilitate comparison between the two systems.
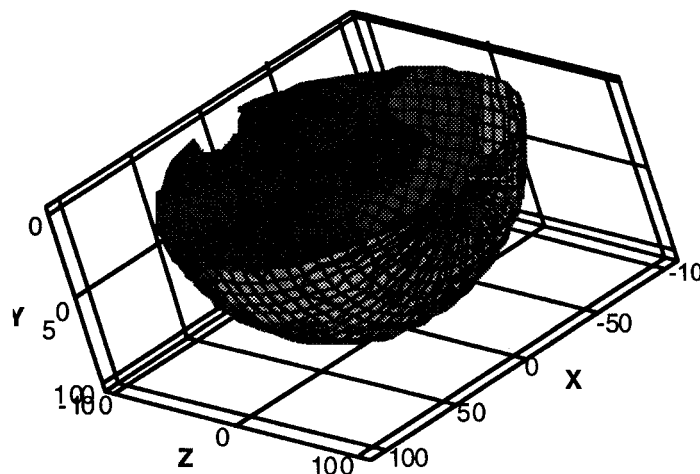

Figure 2. Sound Hemisphere.

A sound hemisphere is stored as a computer file that contains either broadband or pure-tone noise data for a single aircraft flight condition. The file format that has been adapted is self-describing. Each file contains a set of variables and attributes which define the flight condition and the location of the noise data on the hemisphere. The three independent variables that describe the flight condition for a tiltrotor are the flight path angle, the pylon angle, and the airspeed. For conventional helicopters, only flight path angle and airspeed would be used. There can be more then one sound hemisphere for each set of conditions. For instance, if the sound hemisphere is obtained from a dedicated flight test, there can be one broadband and one narrowband sound hemisphere. If the sound hemisphere is generated from a computational

model than for one set of flight conditions, there can be several sets of broadband and narrowband sound hemispheres centered at different points on the aircraft (i.e., engine noise, prop rotor noise, main rotor noise, and/or tail rotor noise). Each sound hemisphere is stored as a separate file which RNM reads.

The sound hemisphere is stored in a packed binary file using Network Common Data Form (netCDF).[9] This data format is an abstract data type (ADT) which means that access to the data is limited by a set of functions or routines. Hidden from the user are the details of data compression and retrieval. NetCDF efficiently stores and retrieves the data, is self-describing, and is platform independent. Raw binary files can be passed between computers over the network and accessed so long as they use netCDF functions and utilities. A complete distribution of netCDF utilities including a user manual is available at the web site ftp.unidata.ucar.edu. Included with the RNM distribution is a set of utilities used to display the data. Table 2 presents a list of keywords that RNM recognizes as input to the noise model. Sound hemispheres are constructed using these keywords and the utilities provided at the ftp site.

Table 2
Variables Used to Describe
Sound Hemisphere in NetCDF Format

Variable Name	Unit	Description
BB	none	Value 1 or 0
PT	none	Value 1 or 0
Radius	feet or meter	Radius of Sound Hemisphere
Flight_Path_Angle	degree or radian	Elevation Angle of Flight Track, 0° level flyover + ° departure − ° arrival
Pylon_Angle	degree or radian	Pylon angle 0° airplane mode 90° helicopter mode
Speed	knots or meter/sec	Aircraft Speed
XYZ	feet or meter	Center of noise sphere relative to center of gravity. Array ordered by X, Y, Z
Phi	degree or radian	Spherical angle phi -90° to +90°
Theta	degree or radian	Spherical angle theta -0° to +180°
Frequency	hertz	One-third octave center frequencies or pure-tone frequency
Amplitude (phi, theta, frequency)	decibel	Amplitude of band or tone
Phase (phi, theta, frequency)	degree or radian	Phase of tone

Input Operation Data

A major consideration in the development of RNM is the input file format. Although RNM is designed for aeroacoustic research purposes (primarily to develop noise abatement flight procedures), RNM can also be used for developing noise contours around vertiports. The file format must be simple to use for research applications involving a single flight track and also capable of accepting operational data to model the noise environment at a major vertiport involving multiple tracks with different types of rotorcraft assigned to each of the tracks. For these reasons, RNM reads two types of file formats: a single-track format and a multiple-track format.

The purpose for developing RNM was to simplify the process of identifying low noise takeoff and landing profiles by creating a propagation model that reads a simple input file format for a single track and outputs detailed information on the noise exposure footprint. To this end most applications of RNM will involve manual construction of the input file using a text editor. Plans also include RNM to be incorporated into an optimizer and exercised automatically by the host program with the objective of searching out a minimum noise footprint for a single departure or arrival track. An additional application for RNM would be in the comparison between noise footprints using sound hemispheres created by a numerical model and sound hemispheres created by field measurements or wind tunnel measurements. In this situation, a single-track format would be ideal for drawing a comparison.

Another application for RNM will be in predicting the noise contours for vertiports (civilian and military). This application requires RNM to simulate all noise-generating activities that would result from rotorcraft operations. The multiple-flight track format which RNM reads is the same format used by NOISEMAP,[10] the Department of Defense aircraft noise model used at all military installations. The user can enter runway coordinates, airfield information, flight tracks, flight profiles (flight path angle, pylon angle, and airspeed) along each track by each rotorcraft, numbers of flight operations, run-up/hover coordinates, run-up/hover profiles, and run-up/hover operations. This file format is significantly more complicated to use than the single track version, but has the advantage that its form and structure are consistent with the way data is logged and collected by the flight crews and vertiport personnel.

The United States Air Force, which serves as the lead Department of Defense agency for aircraft noise modeling, is developing a new PC-based graphical user interface (GUI) called BASEOPS.[11] This will be used to create the input file for NOISEMAP and RNM. The GUI will allow for quick and efficient building of an RNM input file, and provides the data entry, noise calculations, and contouring capabilities under a single "umbrella program". BASEOPS will be used to develop a single input file that will be read by both NOISEMAP and RNM. NOISEMAP will calculate the noise from fixed-wing operations and RNM will calculate the noise from rotary-wing operations. The output from these two noise models will be combined and graphically displayed using NMPLOT,[12] which is a noise contouring program developed by the Department of Defense.

Rotorcraft Noise Model

Figure 3 shows the organization of the major modules that form the software package. Each block represents a specific function RNM performs. The first three blocks are dedicated to reading the input file provided by the user, scanning the netCDF files that contain rotorcraft noise data, and computing several look-up tables. The next two blocks represent the core propagation algorithms. The final block writes the output in the form of tables and grid files.

The core algorithms are the flight track module and the propagation module, which are nested inside several loops that increment the flight tracks, the types of rotorcraft, and the receiver locations. Receiver locations are described either as X, Y, and Z values identifying the location of specific points under the flight track or as a uniform grid of X and Y points (Z=0.0). Input to the flight track module are the X, Y, and Z values for the receiver location. Returned from the flight track module are the X, Y, Z points of the aircraft in the observer's frame of reference, the airspeed, the crab angle, aircraft angle of attack, roll angle, the flight path angle, and the pylon angle, at half-second intervals. This information, in the form of arrays, is passed directly to the propagation module which uses these arrays to construct the sound spectra at each receiver position as a function of time and, in turn, to calculate the integrated noise metrics. The remainder of this section provides an overview of each of the modules presented in Figure 3.
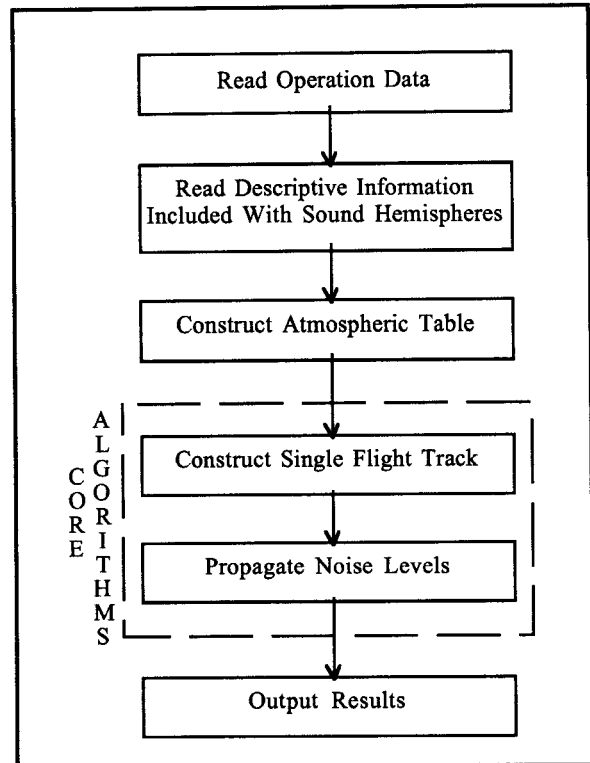

Figure 3. Overview of RNM.

Input Data Modules

RNM begins by reading the input file containing operation data, and checking the file for data and syntax errors. When an error is detected, the program will display an error message with a line number that points to the line in the text file that generated the error. Next, RNM reformats the data input by organizing the input into a format that is suitable for the noise model. When the input module returns to the main program, the track information is organized as a series of connecting points. Defined at each point are the X, Y, Z values for the flight track in the observer coordinate system, the aircraft speed, the crab angle, aircraft angle of attack, roll angle (referred to here as the three Euler angles), and the pylon angle.

Next, the program reads the sound hemispheres that are stored as netCDF files in a common directory. RNM reads from each file the type of rotorcraft, the type of hemisphere (broadband or pure-tone), the flight path angle, the pylon angle, the airspeed, the hemisphere radius, and the location of the hemisphere origin. This information is stored in a look-up table that is sorted by flight path angle, pylon angle, and airspeed. The propagation module searches the look-up table for the source level data it needs in its computations.

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Atmospheric Module

The sound speed profile and the atmospheric absorption coefficients are calculated at 1,000-foot increments of altitude. Estimates for the pressure and temperature are entered by the user. If the user does not specify a profile, RNM will use as a default values tabulated in the U.S. Standard Atmospheric Profile, 1976.[13] The sound speed is calculated directly from the temperature profile assuming ideal gas laws. The air absorption coefficients are determined using methods described in ANSI S1.26-1978.[14] Weighted averages of sound speed and air absorption coefficient are calculated at each altitude. Returned to the main calling program and accessed by the propagation module is an array of ambient atmospheric parameters averaged at equal increments of altitude.[15]

Flight Track Module

Input to the flight track module are the X, Y, Z points, the aircraft speed, and the three Euler angles that were returned by the input module at each specified location along the flight track. The flight track module computes from this input the intermediate positions of the aircraft so that the reception times at the observer's frame of reference are at half-second intervals. It is necessary to resolve the position of the aircraft at half-second intervals for the propagation module to calculate PNL, PNLT, and EPNL. If the specified airspeed at successive points along the flight track is different, the airspeed at the intermediate positions between these two locations is calculated assuming the motion of the aircraft is limited to a constant acceleration or deceleration along a straight-line path. The three Euler angles at these intermediate positions are calculated by linearly interpolating between the points the user defined on the track.

Propagation Module

The propagation algorithms are embodied inside a loop that increments the position of the aircraft at half second intervals. Contained within this loop are two separate loops: the first loop (see Figure 4, point 1) propagates the noise from the broadband sound hemisphere and the second loop (see point 2) propagates the narrow band sound hemispheres. This loop structure enables efficient processing of one or more broadband and narrow band sound hemispheres. At a single aircraft position (defined by the outer loop), a maximum of ten broadband and ten narrow band sound hemispheres can be propagated (defined by the inner loop). Following is a description of the algorithms contained in the propagation module.
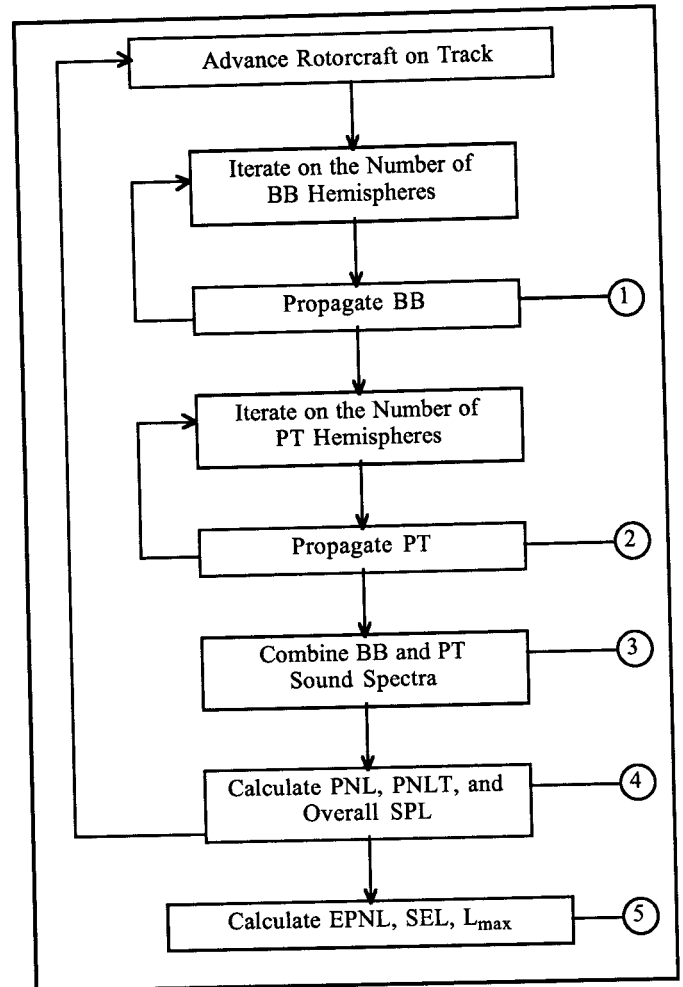

Figure 4. Flowchart of Propagation Module. Input to the Module are the Coordinates for an Observer.

In general, sound levels at a distance r from a source can be expressed as:

$$L(r) = L(r_o) + A_{spread} + A_{atm} + A_{grd} + A_{wind} + A_{topo} \quad (Eq.1)$$

where: $L(r_o)$ = Sound level at a distance r_o from the source along the line joining the source to the receiver.

A_{spread} = Spherical spreading loss, which is due to the geometrical spreading from a point source.

A_{atm} = Atmospheric losses, which are due to four basic causes: classical absorption due to thermal and viscous effects; molecular loss due to the rotational relaxation of

nitrogen and oxygen; molecular loss due to the vibration relaxation of nitrogen molecules; and molecular loss due to the vibration relaxation of oxygen molecules.

A_{grd} = Ground reflection and attenuation losses, which are due to the reflection of the sound by the ground and the resultant interaction that takes place between the direct and reflected acoustic rays. The ground surface is characterized as a complex acoustic impedance. The reflected ray will either enhance or diminish the sound level at the receiver.

A_{wind} = Wind attenuation or amplification, which is due to the boundary layer wind profile that exists between the source and the receiver. Depending on the wind conditions and gradients in the wind profile, this parameter can have significant effect on the sound propagation.

A_{topo} = Topography attenuation, which is due to the reflections and absorption that occurs from barriers formed by the terrain that are located between the source and the receiver.

It is not necessary to include all of these terms in a noise model that will be used for developing noise abatement procedures or for modeling the noise around a vertiport. Most environmental noise models approximate air absorption losses by using monthly averages of the surface temperature and relative humidity. Wind attenuation and amplification are generally not considered because of the complexity involved in quantifying the wind profile. Attenuation due to topography is currently not included in most environmental noise models; however, the new release of NOISEMAP, Version 7.0, will have the ability to model the effects due to the terrain.

The propagation model this program uses assumes that the ray paths are straight lines, there is no wind present, and there is no attenuation due to barriers formed by terrain and other structures. Temperature gradients that occur in the atmosphere are modeled using the weighted average sound speed and air absorption coefficients calculated in the atmospheric module. Day-to-day variations in the atmosphere, which can be important when modeling community noise, were not factored into the noise calculations.

The source term $L(r_0)$ (see Equation 1) is calculated by interpolating points on the sound hemispheres. Before the interpolation can begin, the values for theta and phi,

which describe the position of a vector pointing from the center of the hemisphere to the point of observation, must be found. As the aircraft advances on the track, the crab angle, the angle of attack, and the roll angle are evaluated by matrix translation and rotation subroutines to find the center of the sound hemisphere in the observer's frame of reference. Next the values for theta and phi are determined by taking the vector product between the aircraft direction vector and the vector pointing from the center of the source to the point of observation.

The aircraft type, the flight path angle, the pylon angle, the airspeed, theta, and phi are passed to a search routine that finds in the look-up table the names of the sound hemispheres from which to interpolate the source term $L(r_0)$. The search routine steps through the table to first locate the sound hemispheres that have the same aircraft type and then finds the hemispheres with flight path and pylon angles that are nearest to the specified conditions. Selected from this subset are two sound hemispheres which will be used to interpolate sound levels based on airspeed.

RNM maintains a memory buffer that stores up to ten sound hemispheres. The buffer adds and removes sound hemispheres from memory based on their frequency of use. If the sound hemisphere is needed for interpolation but does not reside in memory, RNM reads the sound hemisphere from the hard disk drive, and exchanges one of the spheres in memory with the new hemisphere. If the sound hemisphere already resides in memory, RNM uses the levels directly in its calculations. This process provides a significant improvement in RNM's overall computational speed.

Interpolation of the sound levels from the sound hemispheres is done in two steps. First, a four-way interpolation for theta and phi is made using a "Coons" surface interpolation technique.[16] A second interpolation is used to find the sound levels for an airspeed that is between the airspeed of two sound hemispheres. The second interpolation assumes a linear variation in pressure squared with airspeed. The user can override the second (airspeed) interpolation by introducing a keyword in the input file that RNM reads. In place of the speed interpolation, RNM chooses the sound hemisphere that is nearest to the conditions being evaluated by the propagation module.

Returned to the main body of the propagation module are the values for $L(r_0)$ defined in terms of one-third octave or pure-tone noise levels. Now begins the main part of the propagation module where RNM accounts for spherical spreading, atmospheric losses, and excess ground attenuation.

Spherical spreading, A_{spread}, is calculated by modeling the sound source as a point source with the total acoustic power spreading over a hemisphere having an area proportional to r^2. The sound energy reaching the receiver decreases at a rate proportional to $1/r^2$ or at the well-known rate of 6 dB per doubling of the separation distance between the sound source and the point of observation.

Atmospheric losses, A_{atm}, are calculated by multiplying the slant distance by the air absorption coefficient. RNM uses an altitude average air absorption coefficient calculated in the atmospheric module.

Ground reflection and attenuation, A_{grd}, are calculated by considering the propagation of the sound field along a boundary having a finite impedance. This impedance is provided by the user, who also has the option of selecting a program default value. The sound field has both a direct and a reflected ray that produce two wave fronts that interact to produce either sound attenuation or amplification. The exact outcome of the interaction is dependent on the source and receiver height, the distance between the sound source and the receiver, and the impedance of the ground plane. The calculations are based on the work by Chessell[17] with the corrections noted by Daigle.[18] Returned to the propagation module are the values in decibels for the excess ground attenuation.

After determining the source and the attenuation terms, RNM adds the sound levels for each of the frequency bands. The pure-tone calculation considers the coherent combination of the direct and the reflected

ground rays from the narrow band sound hemisphere. Resulting from the summation are the one-third octave or pure-tone sound levels at the receiver position from one sound hemisphere. These sound levels are returned to the main body of the propagation module (Figure 4, point 1 or point 2) where the sound levels are summed with sound levels from previous hemispheres. The pure-tone summation includes the important situation that arises from the linear superposition of the individual tones.

The final step is to add, by pressure squared, the pure tones to the one-third octave bands (see point 3). The outcome is used to calculate the overall sound pressure level (overall, A-, and C-weighted), PNL, and PNLT (see point 4). Once the aircraft has advanced the entire length of the flight track, RNM calculates SEL (unweighted, A-, and C- weighted), Lmax (A-weighted), and EPNL. These values are then returned to the main program and stored on a grid of X and Y values of receiver locations.

RNM Output

RNM is capable of outputting cumulative exposure using a variety of measures. These are shown in Table 3. The type of output depends on whether the input is for a single track or multiple tracks. All of the graphical output is in TECPLOT[19] format. This is a commercial product that is available from Amtec Engineering, Inc. (http:// www.amtec.com). Noise exposure contours are in the form of a TECPLOT file and an NMPLOT grid file. NMPLOT[12] is a public domain noise contouring program (http://www.wasmerconsulting.com) used by the Department of Defense and the Federal Aviation Administration.

Table 3
Summary of RNM Output

Track Type	Output Type	Description
Single Track	GRAPHICAL OUTPUT	
	Noise Contours	SEL, SEL(C), SEL(A), Lmax(A), EPNL
	Noise Footprints	Displayed at points along bank – SPL, SPL(A), PNLT
	Specific Points	Time History – Overall SPL, SPL(C), SPL(A), PNL, PNLT
	TABULATED OUTPUT	
	Specific Points	Time History – Overall SPL, SPL(A), PNLT Summary Table – Lmax(A), SEL, SEL(C), SEL(A), EPNL
Multiple Track	GRAPHICAL OUTPUT	
	Noise Contours	DNL, CNEL, Lmax(A)
	Noise Footprints	none
	Specific Points	Time History – Overall SPL, SPL(C), SPL(A), PNL, PNLT
	TABULATED OUTPUT	
	Specific Points	Ranked by order of loudest event – SEL(A), Lmax(A), Rmin Summary Table – DNL, Leq, Leq(C), Leq(A), Lmax(A)

Noise footprints provide output of the noise exposure at points along the track that correspond to the points entered by the user. TECPLOT has the capability to produce an animation of the noise footprints as the aircraft progress on the flight track. The noise level at a specific point is presented as a graph that shows the time history of the noise event and in the form of tables. When the input file contains multiple tracks, RNM outputs a table for each specific point that ranks by loudness the major noise contributors. This feature is extremely useful when analyzing the sources of noise at specific points.

Results

Acoustic data for the XV-15 tiltrotor aircraft was obtained from a joint NASA/Bell/Army test program that was conducted in two phases. During Phase 1 the XV-15 was flown over a linear array of microphones that were deployed perpendicular to the flight path, at a number of fixed operating conditions. In the second phase the microphones were deployed over a large area to directly measure the noise footprint produced during realistic approaches and departures.[20]

Noise data collected during the first phase was processed using an acoustical repropagation procedure adapted from a paper by Wilson *et al.*[21] These algorithms were formed into a new program called Acoustic Repropagation Technique (ART). Input to ART is the measured one third octave noise data and aircraft tracking data. Output from ART is a netCDF file containing the sound hemisphere data for the specified test conditions. This program and an accompanying user's manual will be distributed with RNM to facilitate the creation of sound hemispheres from measured test data.

Validation

Figure 5 presents the SEL as a function of sideline distance for the constant speed level flyover condition of 70 knots, 90 knots, 110 knots, and 140 knots at a nacelle angle of 60 degrees. The figure compares the overall SEL measured at each of the microphone positions (heavy dark line) with the RNM noise predictions (thin line). Generally, the noise predictions are within 0.5 dB, but there are a several instances where the sound levels are greater. The discrepancies between predicted and measured noise levels are attributed to the input file trajectory entered into RNM. This trajectory was modeled in RNM by defining two points, one at the beginning of the track and the other at the end. Hence, details of the actual trajectory flown were not entered into the noise model.
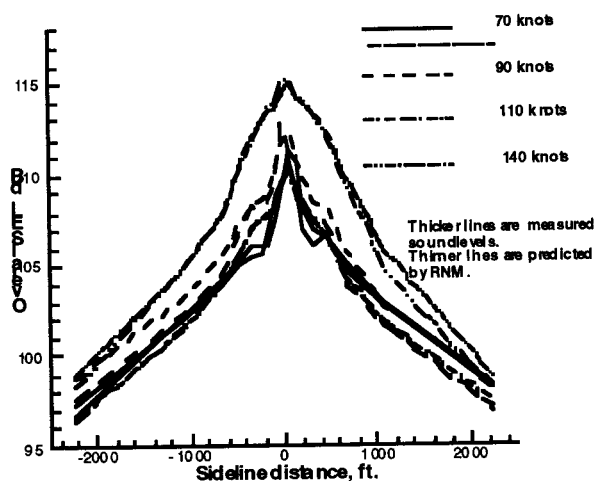

Figure 5. Comparison Between Measured and Predicted.

Sample Outputs

To provide the readers with a small demonstration of the capabilities of RNM, examples of the graphical output that can be obtained from RNM are presented in Figures 6, 7, and 8. A simple XV-15 track was entered into RNM with the following conditions: X varied from -10,000 feet to +4,000 feet, Y is set equal 0, Z decreases from 700 feet AGL to 20 feet AGL, and the aircraft speed decreases from 120 knots to 70 knots. This is not a realistic approach profile, but was selected to demonstrate the program. Shown in Figure 6 are the noise footprints for the overall sound pressure level at specific points along the track. Figure 7 presents the time history of the noise level at the point X = 0, Y = -144, -70, 0, 70, 144, and Z=0. Figure 8 shows the SEL noise contours for the modeled operation.
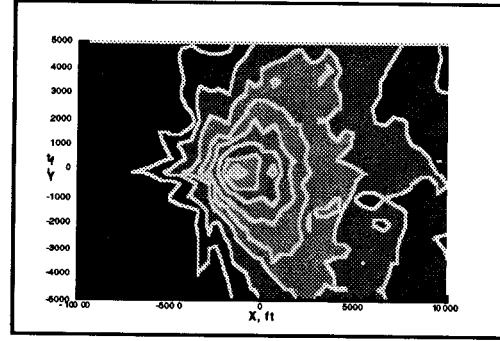
All of the graphics presented in this report were prepared using TECPLOT. Other noise metrics could have been presented. Table 3 provides a listing of the output available from RNM. To display another noise metric, the user chooses one of the metrics appearing in Table 3 from the TECPLOT pull down menus.
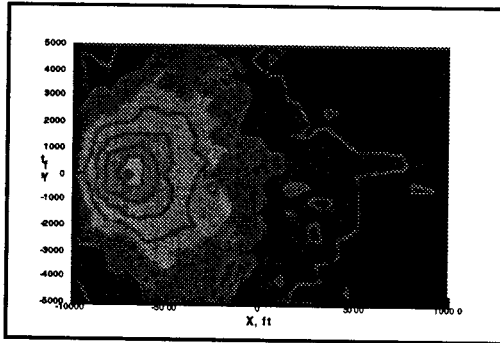
Acknowledgments

8
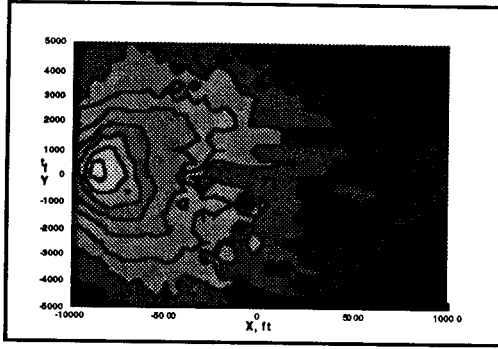
X = -10000 ft, Z = 700 ft, V = 120 kts

X = -2000 ft, Z = 300 ft, V = 90 kts

X = -8000 ft, Z = 600 ft, V = 110 kts

X = 0 ft, Z = 200 ft, V = 80 kts
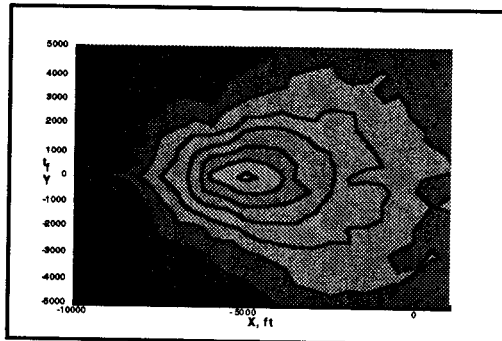
X = -6000 ft, Z = 500 ft, V = 100 kts
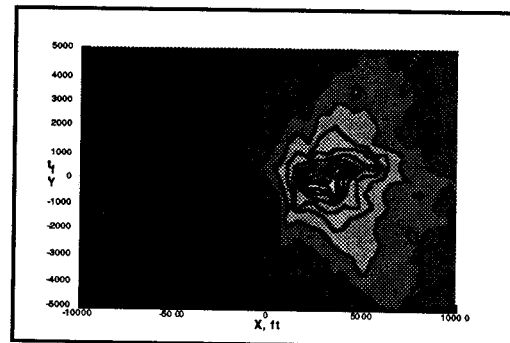
X = 2000 ft, Z = 100 ft, V = 75 kts
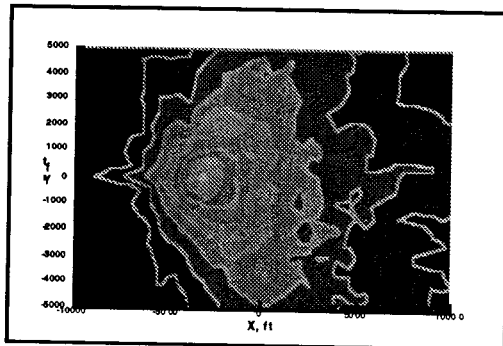
X = -4000 ft, Z = 400 ft, V = 95 kts
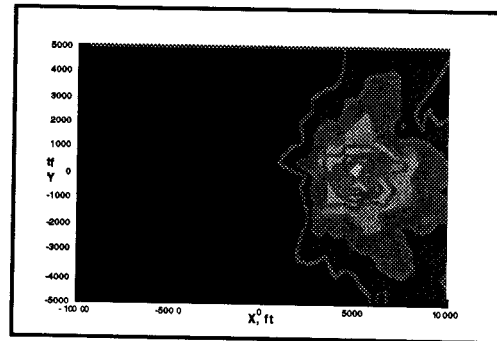
X = 4000 ft, Z = 20 ft, V = 70 kts

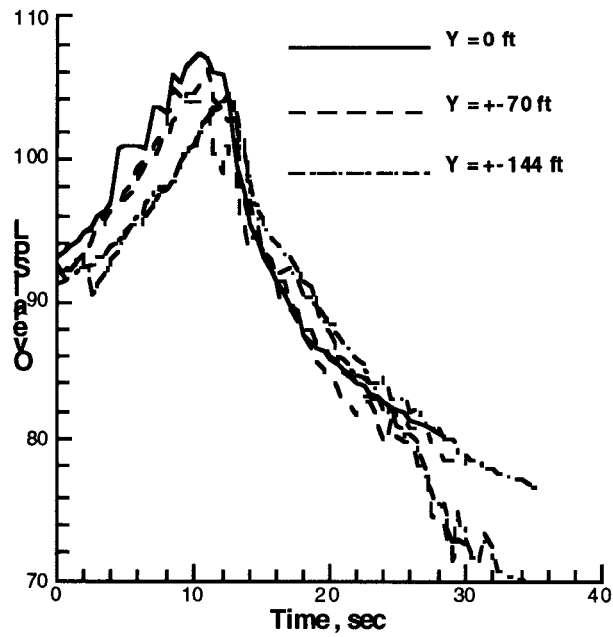Figure 6. Sample Output of Noise Footprints.

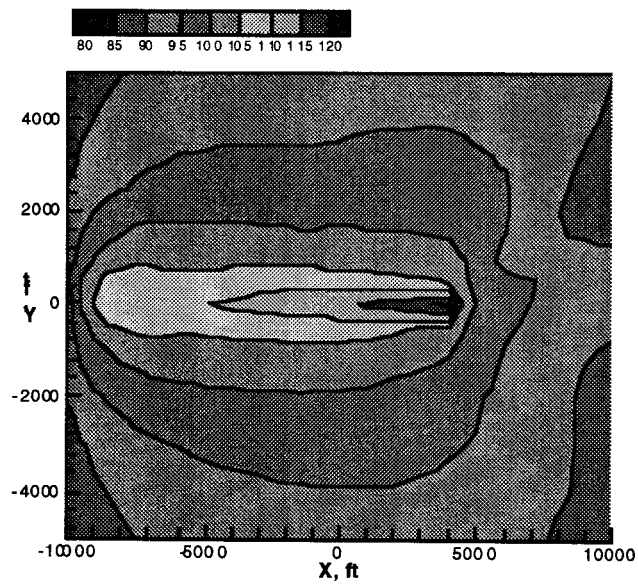Figure 7. Sample Output of Specific Point Time History.

Figure 8. Sample Output of Overall SEL Noise Contours.

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