HELIPORT NOISE MODELING REPORT

Model Review and Program Plan

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1.0 Introduction

The Federal Aviation Administration (FAA) is responsible for development, maintenance, and support of models and tools for assessing and predicting aircraft noise. The FAA currently supports two primary models for evaluating aircraft noise. The Integrated Noise Model (INM) provides the capability to predict noise levels for fixed-wing aircraft operations, and the Heliport Noise Model (HNM) provides the capability to predict noise resulting from rotary-wing aircraft operations.

- INM Version 6.0 [1] is the standard computer program used by the civilian aviation community for evaluating aircraft noise impacts in the vicinity of airports. The model is typically used in the U.S. for FAR Part 150 noise compatibility planning and for Environmental Assessments and Environmental Impact Statements under FAA Order 1050.1.

- HNM Version 2.2 [2] is a computer program that helps assess the impact of helicopter noise on communities in the vicinity of heliports. It is based on INM but differs from INM in its ability to accommodate the greater complexity of helicopter flight activities.

In addition to the FAA development of the HNM model, NASA, in cooperation with the Department of Defense, has developed the Rotorcraft Noise Model (RNM).

- RNM Version 1.0 [3] is designed to model details of tiltrotor operations not possible to model with HNM. The model can be used to develop approach and departure noise abatement procedures to promote civilian use of rotorcraft.

1.1 Purpose and Need

The Heliport Noise Model is a DOS-based program that was last released in February 1994. Since this date, no updates have been performed and at least one HNM user outside the United States has reported that HNM no longer functions on his version of the DOS operating system. There are also no programs in place for collecting HNM source data, nor is there a capability to add new helicopters to HNM without code changes to the system. For these reasons, the FAA has begun a series of projects to update the current modeling system. Previous work efforts on HNM focused exclusively on integrating the present HNM into the INM Windows Graphical User Interface program. It did not address the strategic issues associated with maintaining and updating the source data nor the necessary standards documents necessary for communicating with Industry. Also, FAA requirements concerning helicopter noise modeling have changed largely due to NASA's development of RNM.

It is necessary therefore to evaluate various ideas supporting rotorcraft modeling for environmental studies, such as

- Integrating the HNM or RNM model into INM software,
- Combining HNM or RNM output with INM output,
- Converting RNM data for use within HNM,
- Determining HNM and RNM data acquisition requirements, and
- Promoting heliport noise modeling standards.

1.2 Report Outcomes

The purpose of the current project is to perform a model review, develop a program plan and to begin developing supporting software that will eventually provide a fully integrated fixed and rotary wing modeling capability. For this phase, software development and modifications include:

- A recompilation of HNM 2.2 using current compilers
- Development of software to link HNM to NMPLOT
- Modification to INM 6.0a to support combining NMPLOT contours developed from either the new Rotorcraft Noise Model (RNM) or the current version of HNM 2.2

This phase of the project also identifies software changes necessary to add new helicopters to the existing HNM and began the design necessary to combine the core noise calculation engines of the current INM with a new helicopter specific noise calculation engine. This new core noise calculation engine will be developed first as a research and development version that will be expanded based on research and development efforts associated with the Rotorcraft Noise Model described above.

In conclusion, much of the first phase was devoted to learning the RNM development history, the Federal commitment to support the model, it’s use within industry, becoming acquainted with using the model, and developing procedures for combining RNM and INM noise calculations. Under any implementation scenario, users will be able to combine RNM and INM results, if desired, and such a procedure was developed for this phase of work.

2.0 Previous Work on HNM Integration

Technical efforts were undertaken by the FAA to determine the feasibility of developing an enhanced aircraft noise modeling capability to fully integrate the capabilities of HNM into INM. These efforts showed that the integration of the two models was feasible. Also, specifications, designs, and implementation plans were developed under previous work sponsored by FAA; however, the actual implementation was not carried out.

2.1 INM Modification

In a 1997 paper [4], ATAC described in detail the work and issues involved with integrating HNM 2.2 functions into INM 5.1. For INM 6.1 integration, the design outlined below would remain substantially the same, except for additions relating to spectral classes and modification to the HNM methodology to incorporate a common lateral attenuation model for both fixed-wing and rotary-wing aircraft.

HNM input and output capabilities would be provided inside the INM graphical user interface, and HNM noise calculation methods would be added to the INM noise computation module. A utility program to convert from HNM 2.2 text file input to INM dBase *dbf* file format would be provided.

To accommodate HNM input data in INM 5.1; nine new *dbf* files would be required.

- Helicopter data would be distributed as part of the INM standard database in three files (*Helicopters.dbf*, *HeloNoise.dbf*, and *Directivity.dbf*).
- User input data would be saved in six files (*HeloProfiles.dbf*, *HeloProcedures.dbf*, *HeloPads.dbf*, *HeloTracks.dbf*, *HeloTrackSegments.dbf*, and *HeloOps.dbf*).

The structures of these files were specified.

The INM 5.1 graphical user interface would support nine new windows to view and edit the new *dbf* files. Also, new menus, dialog boxes, windows, and functions would be developed to (1) include helicopters in the INM study, (2) graphically create helipads and helicopter tracks, (3) select and display graphs of helicopter NPD curves and flight profiles, and (4) view and summarize helicopter operations.

Two major computations modules would be developed: Helo Flight Path Module and Helo Noise Module.

- The Helo Flight Path Module would compute helicopter operations on sub-tracks, compute profiles using procedure step data, compute ground tracks and sub-tracks using track segments, build three-dimensional flight path segments, compute missing NPD curves using average-value equations, and write case data into new sections in the *flight.pth* file.

- The Helo Noise Module would read new sections in the *flight.pth* file, process helicopter input data, compute directivity patterns, compute single metric and multi-metric intermediate results, compute exposure, maximum-level, and time-above metrics, integrate helicopter results with fixed-wing results, output recursively subdivided grid data for contour generation, and output detailed grid information.

The modified INM output would consist of noise contours, standard and detailed grid reports, and a case echo reports. Noise contours would include contributions from both fixed-wing and helicopter aircraft. The current algorithm for preparing the *nmplot.grd* file using subdivided grid data would be used, and NMPlot software would compute the noise contours. The current methods for displaying contours would be used. The detailed grid file, *Grid_Dtl.dbf*, and the case echo report file, *Report.txt*, would be revised to accommodate helicopter parameters.

2.2 INM Redesign

In a series of papers [5,6,7,8], ATAC discussed, specified, and designed a new INM software architecture that would, among many other advantages, accommodate rotorcraft noise modeling as an integral part, rather than as an add-on. INM 7, as it was called at the time, would consist of three separate modules: Windows program, Core Module, and Database Module, which would include a standard database.

The Windows Program would be the user-interaction module. It would have a different look-and-feel than the current INM program because it would be designed for a user to interact with aircraft data at the object level, rather than at the *dbf* file level, as is presently done. The object-oriented nature of the redesign would make it easier for a user to navigate though data and easier to edit and copy objects and their connected objects.

The Core Module would be the flight-profile, flight-path, and noise-metric computation part of INM. It would exist in a separate module consisting of one or more dynamic link libraries. Several important features of this redesign would be:

- INM core computations would be accessible to special purpose programs, such as batch processing console programs.
- The Core Module would be designed so that multiple threads could run at the same time on one computer processor. This capability would allow a user to interact with the INM Windows Program while core computations are running.
- The Core Module would be designed so that multiple processors could compute simultaneously. This capability would decrease runtime on computers that have multiple processors.
- The Core Module would be designed to predict fixed-wing and rotary-wing aircraft noise both inside and outside airport terminal areas. Wide-area, high-altitude modeling would be supported.
- Standard INM noise metrics and ICAO noise metrics would be programmed into INM 7.
- The Core Module would be designed to handle large amounts of input data, such as data obtained from radar tracking and noise monitoring systems.

The Database Module would be developed as an object-oriented database management system, meaning that functions would be provided to Core Module programmers to directly access, navigate, and save objects, without consideration for whether they are on disk or in memory.

Methods for data storage and retrieval, data validation, relational integrity, version conversion, and import/export of popular file formats would be provided.

The standard database would include INM and HNM aircraft performance and noise data that are considered valid by the FAA for use in Part 150 studies and Order 1050 assessments. These standard data would be encoded in an object format in a binary file and could be exported to a text format for viewing. FAA National Flight Data Center data (U.S. airports, runways, navaids, and fixes) would be processed and included in the INM standard database.

Study data also would be encoded in an object-formatted a binary file. Users would interact with the binary file only through INM. Once data were in the binary file, they would be considered valid by INM, with no further error checking. New INM import functions would allow users to bring data into a study database without manually typing data into the INM Windows Program. Data could be imported from one or more file formats. During the data import operation, INM would check error conditions and handle data validation problems before writing the binary file. Also, study data could be exported from the binary file to various file formats.

INM would be redesigned with the idea that it would be a tool among tools. It would be assumed that users would employ other applications, such a spreadsheet programs and graphical information system programs, to produce high quality, visually appealing, noise analysis products. The INM 7 design would (1) develop a few well-supported generalized data importing methods, (2) promote standardized and publicly common input and output formats, and (3) eliminate special-purpose data conversions.

2.3 INM Software Development Issues

The software development effort to produce INM 5.0 took approximately 2.5 years from the time it was first discussed (February 1993) to the first public release (August 1995). The number of people working on INM 5.0 varied during this time period, with the full-time-equivalent average being about 7.5 people, including FAA, VNTSC, ATAC, and subcontractors to ATAC. There is no reason to expect a complete redesign of INM to take any less time or effort. Therefore, a considerable amount of resources over multiple years would be required to support an INM redesign effort. Although the costs would be high, the benefits would be high too. A redesigned INM would support the needs of noise analysis community for another 8-10 years in the future.

Modifying INM to directly incorporate HNM would take less time and effort. A rough estimate is 1.5 years and 5 full-time-equivalent people. An issue with modifying INM is that the original software was not designed with the expectation of adding a new large modeling capability. Most likely, the flight path calculation and run management modules will have to be completely rewritten, and the noise calculation module substantially enhanced. Another issue is that the more INM is modified beyond its original design, the more likely a major problem, either software breakdown or performance degradation, will occur.

The advantage of modifying INM would be a shorter time and cost to field a product; however, the retrofitted product would not be as solid, high performing, nor long lived as a new product would be.

2.4 System Review

The previous redesign work focused on the current HNM and current ideas about INM. INM development up to that point gave users access to *ALL* of the core standard data supplied from industry. A full windows system was developed to support modifications and additions to these data. This high level-of-access allows a very flexible and adaptable system, but in turn carries the cost and overhead of maintaining the edit windows, converting input/output formats when the model is updated, and, a significant amount of error check reporting of changed standard data.

As acoustic models become more complicated, it is necessary to weigh the cost and benefits of adding functionality particularly if the expense would only benefit a small group who are using additional functions for research purposes. As an example, after spectral classes were added to INM 6, there is now an expense for maintaining the windows necessary to support spectral classes. Given the added complexity of helicopter modeling, it is necessary to review the original HNM design, and consider a design more similar to the implementation of the spectral class idea as in INM 6. Under the current system, users are given the most basic accesses to spectral classes. They are not able to add a spectral class. However, the FAA supports a research version of INM for which researchers, who have a need for additions or modifications, can obtain them without the cost of an expensive front end. This level of review for the final implementation is even more necessary given that the data requirements will most likely increase based on work derived from the Rotorcraft Noise Modeling effort.

In general, future graphic design implementations should consider:

1) Data Availability and End User Requirements

For the most part, helicopter directivity data will not be a common commodity for the majority of users. Helicopter modeling is complex, and data may be difficult to obtain. A sample pool of users should be surveyed prior to a full Windows implementation to verify that the front-end elements identified above would actually be used. At this time, it is expected that only a small percentage of end users would benefit from a system that allowed direct access and modification to source data.

2) Research Version Implementation

It is possible that the needs of users, who would require additional access to the source data, could be accommodated via a research version of the noise model. This is in fact the present situation with INM spectral classes. The front-end expense identified above would be avoided, and research projects that require additions and modifications could be handled economically through a research release. The present INM use of spectral classes may serve as a successful guide for this kind of design.

3) Maturity of Modeling System
Developing and documenting a fully accessible front-end benefits a small portion of the modeling community. However, if the model process has not fully matured, implementing a full front end may cause more difficulty as conversions between user-defined databases become much more complex if the underlying definition is still being defined. In the present environment, the current FAA modeling methodology addressed in previous work will be augmented by the data and noise modeling algorithms developed for RNM. Also, it is expected that in the future, the Society of Automotive Engineers (SAE) Aviation Noise Committee (A-21) will develop a guidance document on the data required for a land-use noise model. This document may specify the RNM, a subset of the RNM, or the current RNM augmented to model additional situations. The outcome however will most likely alter the present database. Great care must be taken in developing a complex front end and support system that may be obsolete by the time it comes on-line.

The next phase of Heliport Model review will focus on the above issues. As resources allow, it is recommended that research versions of INM be developed that allow for integrated fixed/rotary wing noise calculations. Then, depending on FAA priorities and resources, a release version of a combined fixed/rotary wing model could be developed following one of the four design models:

1) Add Helicopters with limited editing capability (Spectral Class idea)
2) Add Helicopters with full edit capability
3) Add Helicopter as part of INM redesign with limited editing capability
4) Add Helicopters with full edit capability as part of INM redesign.

Options 2 and 4 have been addressed in sections 2.1 and 2.2 above, assuming implementation would involve the current version of the FAA HNM model. The following sections of this modeling report begin to explore data requirements, acoustical capabilities, and model execution issues of the Rotorcraft Noise Model (RNM).

3.0 RNM Integration

A possible way to support rotorcraft noise modeling is to integrate the RNM methodology into INM. This section evaluates RNM methodology in terms of model run-time, data inputs, and software development effort that would be required to support the RNM methodology.

3.1 RNM Run Time Evaluation

There were two RNM programs included in the software supplied to ATAC. The programs *rnm.exe* (10/26/99) and *rnm_dos.ex*e (10/1/98) both worked but they produced different results. Since *rnm.exe* has a later date and ran slightly faster, it was used for testing.

The supplied input files *sample.run* and *sample.ops* were modified to use the noise hemisphere data in the supplied *nc* files. Four rotorcraft flight paths were run, two for the XV-15 and two for the V-22A. The COMPUTEGRD section in the *run* file was changed so that RNM computed 101x101 grid points. The RNM run time was 30 minutes on a Pentium-II, 350-MHz, 128-Mb, NT-4.0 computer. For comparison, INM 6.0 was setup to run four aircraft flight paths over 101x101 grid points. The INM run time was 50 seconds.

INM ran 35 times faster than RNM because of the underlying differences in the way the two models compute noise.

- RNM calculates many more source-to-receiver noise values than does INM. RNM computes points along a flight path at approximately 1/2-second intervals, whereas INM only computes at the end points of flight path segments.
- RNM computes a three-dimensional directivity pattern at every point, whereas INM computes a single two-dimensional directivity pattern only during takeoff ground roll.
- RNM individually propagates 26 1/3-octave frequency band SPLs (in this test case) and then adds them at the receiver, whereas INM propagates one SEL and one Lmax value.
- RNM sums power at the receiver over time to develop noise exposure, whereas INM uses SEL, Lmax, and an exposure fraction algorithm to accumulate the noise exposure contributions per flight path segment.

Although different combinations of input parameters in either model probably will produce different run-time comparisons, it is clear that the INM computation method (and therefore the HNM method) is many, many times faster than the RNM method. As to whether HNM-vs-RNM run-time is important in analyzing community noise impacts depends on how many rotorcraft flight paths have to be computed compared to the number of aircraft flight paths. If there are only a couple of rotorcraft flights and thousands of aircraft flight paths, then computing rotorcraft noise using RNM-methodology may not be an important consideration for a typical INM-like case. However, if there are ten or twenty or a hundred rotorcraft flights, then run time is a serious consideration in developing a rotorcraft noise capability within INM.

3.2 RNM Input Data Requirements

If the RNM-methodology were programmed into INM, user-created and model-supplied databases would have to be modified to support rotorcraft noise calculations.

3.2.1 User-Created Case Data

RNM user-created study parameters, case parameters, location points, navaids, pads, ground tracks, flight profiles, and flight operations are very similar to INM user-created input data.

- Study parameters include an airport description and lat/long in the *ops* file AIRFIELD section.
- Case parameters include a title in the *ops* file CASE section; temperature, pressure, and humidity in the AIRFIELD section; and noise metric and grid size data in the *run* file RUN section.
- Location points are given in the POINTS and NAVAID sections of the *ops* file. In RNM, noise is calculated at points-of-interest but not at navaids. Navaid data are passed through to the *grd* file for display in NMPlot.
- Helopad data include pad positions in the VTOLPAD and STATICPAD sections of the *ops* file. Vtolpads are used for flight operations and static pads are used for runup operations.
- Track data are in INM vectors-type format. Track data include a track identifier, track description, operation type (e.g., departure) and a list of track segments that contain a straight segment distance or a circular segment turn angle, direction, and radius.
- Rotorcraft flight profile and operations data are in the ROTARYWINGPROF section of the *ops* file. The data in this section include rotorcraft identifier, ground track identifier, number of day, evening, and night flight operations, and vertical profile data. RNM profiles are not independent of flight operations, as they are in INM. The RNM input format can be accommodated within the INM structure.
- RNM rotorcraft flight profile data are in a format that is similar to the INM fixed-point profile format. Profile point data include cumulative ground distance, altitude, indicated airspeed, yaw angle, angle of attack, roll angle, and nacelle tilt angle. The four angles serve a purpose similar to INM corrected net thrust. These angles, plus flight path geometry and receiver position, are used to calculate two angles (theta and phi) that index into source noise data.
- RNM does not provide standard profiles like INM does. Apparently, there is no auxiliary computer program to help a user create rotorcraft fixed-point profiles.
- The input formats for rotorcraft <u>idle</u> operations and <u>hover</u> operations were not described in the RNM Manual. It is not clear that RNM supports either one of these operational modes.

3.2.2 Model-Supplied Noise Data

For each aircraft, INM supplies tables of noise exposure level (or maximum noise level) as a function of several corrected net thrust per engine (or percent of static thrust) values at ten slant distances. These are pre-calculated noise levels at a receiver. INM 6.0 can adjust noise levels for an atmospheric absorption model other than the one implicit in the NPD data.

RNM input noise data are very different from INM input noise data. For each rotorcraft, RNM supplies many files of data in netCDF (*nc*) binary format. A *nc* file contains either 1/3-octave broadband noise levels or pure-tone levels, at a given distance, for a single flight condition, over a hemisphere below the rotorcraft.

- A flight condition is determined by flight path angle (climb or descent angle), airspeed, and nacelle tilt angle.
- There can be more than one file per flight condition. Multiple broadband and pure tone noise sources at different locations on a rotorcraft and can be modeled.
- A broadband file contains unfiltered 1/3-octave levels for a given set of frequency bands, and a set of angles *theta* and *phi* that cover a hemisphere-centered rotorcraft. The source levels are relative to a defined radius.
- A pure-tone file contains unfiltered tone level and phase values versus theta and phi.
- The free-field source levels (1/3 octaves or tones) are propagated from source to receiver by applying spherical spreading, atmospheric absorption, ground reflection, and frequency filtering. Tones are combined in amplitude and phase.
- Noise values are interpolated for a given set of model parameters (flight path angle, airspeed, theta, and phi) based on flight path position, rotorcraft attitude, and receiver position at a point in time.

The size of the noise database to support the RNM methodology inside of INM would be enormous compared to the current INM database. For example, the noise database for the XV-15 comprises 76 *nc* files using 2.16 megabytes of disk space. By comparison, the INM 6.0a database (which includes 229 aircraft, 775 profiles, 186 sets of noise curves, and 71 spectral classes) is contained in two binary files using 142 kilobytes. The noise database for just one RNM rotorcraft is 15 times larger than the entire INM database.

3.3 INM Software Development Issues

Integrating the RNM methodology into INM would require substantial modification to INM software. As discussed above relative to HNM integration, an alternative to modifying INM would be to redesign and re-code it. The same arguments for and against modification versus redesign apply equally well to RNM integration.

A decision would have to be made about allowing user input of rotorcraft noise data. Since these voluminous noise data have to be developed from specialized noise measurements, it would be reasonable not to allow user input. INM would supply *nc* files; however, users would not be able to create their own *nc* files. This would reduce the amount of work to incorporate RNM into the graphical user interface because the HNM-related noise data function and the directivity pattern function would not have to be programmed, and the noise hemisphere would not have to be displayed.

Modification or redesign of the noise computation module would require considerably more work than integrating HNM methodology. The input *flight.pth* file would contain rotorcraft flight path segments that would be similar to aircraft flight paths segments, except that corrected net thrust would be replaced with orientation angles. After reading the flight path segments, the noise computation module would apply an extensive set of equations, as documented in the RNM Manual. Coding and testing these equations would take a long time.

A development shortcut, which should be investigated if the RNM alternative were to be seriously considered, would be to directly link RNM Fortran *obj* files into INM. The advantages are that (1) the equations would not have to be coded and tested, and (2) changes to RNM by NASA could be propagated to INM without extra coordination and software modification. This approach would depend on the details of how RNM is designed and how INM could take advantage of that design. Evaluation of this idea is beyond the scope of this paper.

Because of the extensive development time to integrate RNM methodology into INM, the estimated time to modify INM is 2 years, and the estimated time to redesign and re-code INM is 3 years. Perhaps this time estimate could be reduced somewhat if linking RNM *obj* files worked out. The level of effort is estimated to be about the same as HNM integration -- 5 people per year for modification and 7.5 people per year for redesign.

4.0 HNM/RNM Output Combined with INM

The NMPlot computer program can combine two *grd* files that are in Noise Model Grid Format (NMGF). In particular, NMPlot can add two *grd* files containing noise level data, and then display noise contours representing the total noise. Since INM uses NMPlot software to generate contours, an easy way of "integrating" rotorcraft into INM is by combining HNM or RNM output *grd* files with INM *grd* files.

4.1 HNM Output Combined with INM Output

Noise levels calculated by HNM are saved in binary format in the *for22.dat* file. This file contains three-dimensional triangles; the vertices of a triangle represent noise levels at x,y points. In support of this report, a Windows console computer program was developed to test the feasibility of converting HNM output data to *grd* format. The test program, *HnmGrd.exe*, transforms a *for22.dat* file into a *nmplot.grd* file.

The following steps describe how to combine INM and HNM outputs using the *HnmGrd.exe* program.

1. In INM, load a study, run a case (e.g., *Acft*), and display the output (e.g., *Acft.Out*).
2. Create an INM case for helicopter data (e.g., *Helo*). Set Run // Run Options "Run Type" to "Single Metric", and select a noise metric that is the same as for the INM case (e.g., DNL).
3. Create INM output for helicopter data (e.g., *Helo.Out*). Select the proper noise metric, select "OneCase", and select the *Helo* case.
4. In a DOS window, run HNM, and then copy the *for22.dat* file to the *Helo* case directory.
5. Create a text file, *input.cfg*, and save it in the same directory as the *HnmGrd.exe* program. Each parameter in *input.cfg* should be on a separate line in the following order:
    - Full path name to the INM study directory (e.g., *C:\InmStudy\HnmTest*). Directory names can contain blanks.
    - INM case name for helicopter data (e.g., *Helo*).
    - INM output name for helicopter data (e.g., *Helo.Out*).
    - Latitude of the INM study in decimal degrees (north is positive).
    - Longitude of the INM study in decimal degrees (east is positive).
6. In a DOS window, run *HnmGrd.exe* by providing *input.cfg* as a command line parameter. *HnmGrd.exe* reads the *for22.dat* file in the *Helo* case directory, and writes a *nmplot.grd* file into the *Helo.Out* output directory.
7. In INM, create another output directory (e.g., *Acft+Helo.Out*). Select the noise metric, select "Log-Add", and select Case1 *Acft* and Case2 *Helo*.
8. Display *Acft+Helo.Out*. INM combines the *nmplot.grd* files in *Acft.Out* and *Helo.Out* into a single *nmplot.grd* file, which is saved in the *Acft+Helo.Out* directory.

HNM does not save a rectangular array of grid points in *for22.dat*; instead, it saves only those triangles that have noise levels that exceed the lowest defined contour minus about 10 dB. This strategy causes the perimeter of the HNM grid points to be an irregular polygon instead of a rectangle. To extend the polygon to the edges of the contour window, the lowest contour should be set very low (e.g., DNL 35 dB).

The area containing the *Acft+Helo.Out* noise contours is the intersection of the *Acft* and *Helo* contour areas (i.e., the area in common). This means that when setting up a HNM run, the contour window size must be larger than INM window so that the HNM polygon completely covers the INM rectangle. A HNM run that is intended for integration with INM will have to cover much larger area than is usually considered for helicopter analysis.

Helicopter noise contours cannot be displayed by INM. This is because INM looks for files in the *Helo* case directory that would have been generated if noise had been computed by INM. Those files do not exist, and INM displays an error message. However, helicopter noise contours can be displayed using the HNM or NMPlot programs.

4.2 RNM Output Combined with INM Output

RNM output *grd* files can be combined with INM *grd* files as described above for HNM. The only difference is that there is no need for the output data conversion step because RNM already supports NMGF output.

Some points relating to RNM *grd* files:

- RNM produces a *grd* file that has a CART section containing the latitude and longitude of the origin of the x,y-coordinate system. The RNM *grd* lat/long must be the same as the INM study lat/long. The lat/long is set in the AIRFIELD section of the RNM *ops* input file.
- In the RNM *run* input file, use the COMPUTEGRD key word to create a *grd* file and set the type of noise metric. The RNM type of metric must be the same as the INM metric.
- RNM creates a regular array of grid points within a rectangular contour analysis area. The RNM contouring rectangle must be the same size as the INM rectangle, or larger, so that the combined area-in-common is the same size as the INM area.
- The RNM grid size must be small enough to produce the same fidelity in noise values as does the INM subdivided grids. RNM does not have a recursively subdivided grid capability.
- In addition to noise values at grid points, RNM writes points-of-interest, runways, pads, and track data into the *grd* file, but these data do not interfere with the INM Log-Add function.

5.0 Input Data Conversion

A way for the FAA to support helicopter noise analyses would be to convert RNM data into HNM format, so that rotorcraft data collected for RNM could be made available for HNM analyses.

5.1 Feasibility of Converting RNM Data to HNM

In a recent working paper [9], the Volpe Center investigated the feasibility converting RNM noise hemisphere data into HNM left-center-right NPD curves. RNM rotorcraft XV-15 sound hemisphere data were successfully converted into HNM format for two cases.

Cases for level fly-over at 1000 feet in "helicopter" mode (nacelle tilt angle 90 degrees) and in "airplane" mode (nacelle tilt angle 0 degrees) were run in both models. The results of the comparative analysis showed that:

- For elevations angles of 45 to 90 degrees, there were no significant differences in HNM and RNM predicted SEL values for either case.
- For elevation angles below 45 degrees, HNM predicted higher SELs than did RNM.

It is likely that the RNM predictions are more accurate because of the detailed way noise is calculated in RNM.

If HNM methodology were to be integrated into INM, the current HNM method for extrapolating noise levels at low elevation angles would be replaced with the new INM lateral attenuation method. It is likely that HNM predicted SELs would be brought into line with RNM predictions because both the INM and RNM ground effects calculations are based on a common model. The INM model is documented in section D.1.2 of a Volpe Center report [10], and the RNM model is documented in section 3.6.3 of the RNM Manual.

Additional comparisons of HNM and RNM will be required with the new lateral attenuation methodology recently included in a research version of INM. This validation will be best accomplished using an aircraft that currently exists in both RNM and HNM, and for which a substantial amount of high quality field data are available. The U.S. Navy recently sponsored a field test at Cherry Point, NC that included several aircraft currently in the HNM database (e.g., the CH-53/S-65). The HNM will be independently run (with its standard database), and run separately with a database developed using RNM. In addition, comparable runs will be made using RNM. The output from each of these three sets of runs will be compared with the Cherry Point field-measured data. As part of this effort the HNM runs will be made with the newer, more accurate lateral attenuation equations referenced above. This will result in the most appropriate assessment of HNM and RNM.

5.2 RNM Noise Data Availability

RNM data, plus data that are included in the US Air Force NOISEMAP Version 7.0 model, comprise 264 *nc* files covering six rotorcraft (3 tiltrotors and 3 helicopters):

- V22A -- 6 broadband *nc* files; descent and level flight only; a few nacelle tilt angles and speeds, no hover; third-octave frequency bands 10 to 2500 Hz.
- MV22B -- 73 broadband *nc* files; descent, level, and ascent; range of nacelle tilt angles and speeds, including 9 *nc* files for 90º at 0 knots (hover) ; third-octave frequency bands 10 to 2000 Hz.
- XV-15 -- 76 broadband *nc* files; the range of flight path angles, nacelle tilt angles, and speeds were not investigated; third-octave frequency bands 10 to 3150 Hz.
- AH-1W -- 32 broadband *nc* files; descent, level, and ascent; range of speeds, including 2 *nc* files at 0 knots (hover); third-octave frequency bands 10 to 3150 Hz.
- CH46E -- 49 broadband *nc* files; descent, level, and ascent; range of speeds, including 2 *nc* files at 0 knots (hover); third-octave frequency bands 10 to 3150 Hz.
- CH43E -- 28 broadband *nc* files; descent, level, and ascent; range of speeds, including 2 *nc* files at 0 knots (hover); third-octave frequency bands 10 to 3150 Hz.

It is not clear whether the zero-speed *nc* files are for hover in-ground effects, for hover out-of-ground effects, or for both kinds of hover. Also, it is possible that a zero-speed *nc* file could represent ground-idle operation mode. Availability of hover and ground-idle needs to be investigated.

The RNM/NOISEMAP rotorcraft noise database does not cover the full range of third-octave frequency bands that are used in INM, namely, 50 to 10,000 Hz. The *nc* files would have to be reprocessed from the original test data to provide the missing bands.

By using the SCAN.EXE utility that is provided with RNM, it is noted that a large amount of acoustic power is in the very low frequency bands (10 to 40 Hz). These low-frequency data should be retained so that unweighted and C-weighted noise levels can be more accurately estimated.

5.3 Conversion Software Needed

The general approach to converting RNM *nc*-file data into a form that could be used by HNM, or HNM integrated into INM, would be to expand on the Volpe feasibility-test method:
- Develop a computer program that would write RNM input files, so that RNM could be run to create SEL and LAmax (EPNL and PNLTmax) noise levels at left-center-right (45-90-45 degrees) elevation angles, for 10 NPD distances (200 to 25,000 feet), at various flight path angles and speeds.
- Develop a computer program to process RNM input and output files to produce HNM-compatible input data, including (1) NPD curves adjusted to the SAE-AIR-1845 atmospheric absorption model, (2) spectral class data, and (3) coefficients used by HNM to compute noise level as a function of rotor-tip speed and flight path speed. This program could be augmented as needed to produce INM-compatible *dbf* files.
- Develop automated batch processing method to run RNM and process the output data.

6.0 Noise Data Requirements

Both HNM and RNM employ noise databases that are created from field measurements on individual rotorcraft. In the case of HNM, data are developed from FAR Part 36 Appendix H helicopter noise certification tests. In the case of RNM, specialized noise measurements provide input data required for detailed acoustic prediction.

6.1 HNM Noise Measurements

The Volpe Center working paper [9] describes the problem with obtaining data for HNM, namely that noise certification tests are now being preformed under FAR Part 36 Appendix J for lightweight helicopters. Appendix J does not require sideline measurements; therefore, left-center-right NPD data cannot be developed from noise certification data.

Instead of depending on noise certification tests, the FAA, or other Government agency, could sponsor a noise measurement program for lightweight helicopters. According to the Volpe Center, these noise measurement tests would be relatively easy to conduct compared to noise certification test for jets, or compared to the comprehensive field measurement and data reduction efforts required to develop sound hemispheres, as described in section 4.3 of the RNM Manual.

6.2 SAE Method for Estimating Noise Levels

The SAE-AIR-1989 report [11] provides an empirical means of estimating LAmax and SEL for helicopters when noise data are not available. Various restrictions apply to the kinds of helicopters that can be estimated (for turboshaft engines, no coaxial rotors, no tiltrotor aircraft in helicopter mode, etc.).

In 1994, Volpe Center and the FAA performed a statistical analysis [12] of the SAE method using HNM noise data. The analysis concluded that SAE-AIR-1989 could be used to estimate LAmax in hover mode, but the SAE equations for takeoff, flyover, and approach SELs were not recommended.

The empirically derived coefficients in the SAE equations could be updated using HNM data, thus providing a more acceptable model when compared to HNM. The SAE-AIR-1989 equations would provide a valuable substitute for measured noise data until measurements could be made.

7.0 Heliport Noise Model Standards

Both HNM and RNM represent the current state-of-the-art for heliport noise modeling. However, the methods used to develop data and perform the noise modeling have never been incorporated into an SAE Aerospace Information Report (AIR) or Aerospace Recommended Practice (ARP). These standards are essential for industry, model users and model sponsors such as FAA and NASA to support noise modeling programs.

HNM was developed to provide an FAA-standard for predicting community noise levels caused by helicopters. The model was based on the methods of INM, which is also an FAA-standard.

- HNM employs a segment/mode method. Helicopter operations are described by point segments (for idle, runup, or hover) and by line segments, and each segment is assigned an operating mode.
- HNM currently specifies 13 modes, including idle, hover, ascent, level, descent, and taxi operations. Additional modes can be introduced to account for nacelle tilt angles and additional descent angles.
- Noise exposure and maximum-level NPD curves are associated with modes.
- Time history of noise levels is not explicitly modeled, but a simple time history assumption is implicit in the equations relating exposure, maximum level, and time above.
- Total noise exposure is calculated by summing the exposures calculated for each segment.

RNM was designed for NASA engineering research on rotorcraft noise. The main use of the model is to develop tiltrotor approach and departure noise abatement procedures to promote public acceptance of community vertiports. The model can also be run in conjunction with NOISEMAP for the purpose of quantifying community noise levels.

- RNM employs a time-step method. Rotorcraft operations are described by orientation angles and speed at points in time.
- Free-field source spectrum levels are interpolated across data sets along source-to-receiver directions at each point in time.
- Time history of noise levels is directly calculated by summing attenuated, filtered SPLs over frequency bands at points in time.
- Total noise exposure is calculated by summing noise over time steps.

It is not possible to combine the methods of the two models into one SAE standard because their data inputs and computation methods are so different. Instead, two standards could be written, one for community noise prediction, and one for engineering research.

7.1 Community Noise Model Standard

The HNM method is computationally much faster than RNM, uses a much smaller and more easily obtained noise data set, and is similar to the method already developed by SAE to compute fixed-wing noise around airports [13].

The HNM method is the obvious choice for developing a community noise model standard, providing that it can adequately model directional rotorcraft noise.

- The HNM method models static directionality (for idle and hover) by using a two-dimensional directivity pattern. This should be adequate.
- The HNM method models dynamic directionality by using left-center-right NPD curves. This is probably adequate, based on measurements and comparisons of HNM to RNM results to date.

7.2 Research Noise Model Standard

The RNM method is superior for detailed analysis of single flight operations. In fact, the RNM method is general enough that it could be extended to include all aircraft noise modeling for research purposes, providing that the required sets of sound hemispheres could be dynamically measured.

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