

# The new EU helicopter noise model NORAH

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## Summary

To support the monitoring activities required by the European Environmental Noise Directive (END) as well as ICAO noise standard setting, an adequate noise modelling capability is required that encompasses all types of aircraft, including rotorcraft. However, the international guidance to model aircraft noise - such as ICAO Doc 9911 and ECAC Doc 29 - is limited to fixed-wing aircraft, thus not covering rotorcraft. The interim approach in the Environmental Noise Directive (END) is to handle helicopters as a fixed-wing aircraft. Although this assumption has been considered to be acceptable when used at macroscopic level, it lacks in robustness when applied to the assessment of airport noise or other urban noise. A more robust modelling method, better accounting for the specific noise characteristics of helicopters, is therefore required.

Under a DG-MOVE contract a state-of-the-art methodology to model noise emissions of helicopter operations was developed. An extensive flight test campaign was performed to obtain a noise database for a range of relevant operational conditions for 8 different helicopter types. The calculation method and the noise database were implemented in the new EU helicopter noise model NORAH (NOise of Rotorcraft Assessed by a Hemisphere-approach).

This paper presents the main characteristics and capabilities of NORAH..

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## 1. Introduction

Under a DG-MOVE contract a state-of-the-art methodology to model noise emissions of helicopter operations was developed. An extensive flight test campaign was performed to obtain a noise database for a range of relevant operational conditions for 8 different helicopter types. The calculation method and the noise database were implemented in the new EU helicopter noise model NORAH (NOise of Rotorcraft Assessed by a Hemisphere-approach).

NORAH allows for the calculation of noise levels, amongst others metrics like SEL and L<sub>Amax</sub>, on a grid of ground points for a given input helicopter 4D trajectory (along with other relevant flight

parameters). The software prototype has been thoroughly validated by European aircraft noise model specialists.

## 2. Noise modelling methodology

Helicopter noise source modelling based on first principles is not mature enough to serve as input for a helicopter noise model. An empirical model based on hemispheres, derived from measurements is therefore the best available approach. Helicopter noise measurements for the purpose of hemisphere derivation should be performed with great care and generally should follow the guidelines given in ICAO Annex 16 [1].

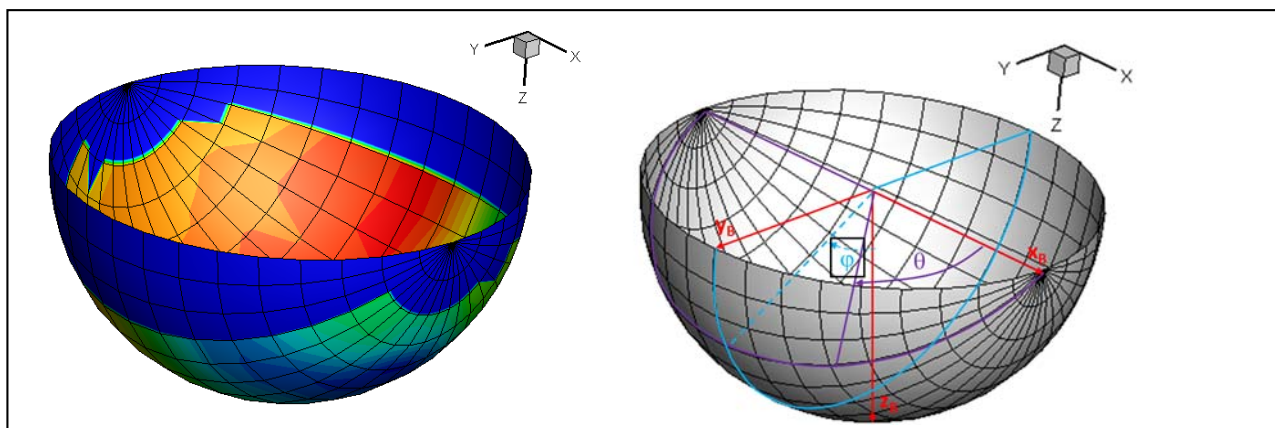


Figure 1 - Example of a noise hemisphere (left), based on measurements of a R22 helicopter, 80Hz 1/3 octave band frequency, given in aircraft body axis system (right)

## 2.1. Hemispheres

Noise hemispheres are used to describe the acoustic emission of a helicopter as a function of emission angles for a given flight condition. An example of a noise hemisphere is given in Figure 1.

Hemispheres are given in 1/3 octave bands, for frequencies between 10Hz to 10 kHz. The hemisphere noise levels are defined at a fixed reference distance of 60m and include effects of atmospheric absorption under ICAO atmospheric reference conditions ( $p_a=101325\text{Pa}$ ,  $T=298.15\text{K}$  and  $RH=70\%$ ). This distance corresponds to that used for the frequency extrapolation method outlined in Doc 9501 [2], which is used to reconstruct measured 1/3 octave bands levels above 2 kHz, masked by background noise. Hemispheres are defined as a function of azimuth  $\phi$  and polar angle  $\theta$ , binned in intervals of 10 degrees. For reasons of practicality and data quality issues hemisphere data the azimuthal angle  $\phi$  should at least cover from  $-60^\circ$  to  $60^\circ$ , whereas the polar angle  $\theta$  should at least be available for the 10-dB down interval. When the source noise level has to be calculated for emission angles covered by the measurements, interpolation between hemisphere data bins should be applied. For directivity angles beyond the measured intervals, constant value extrapolation should be applied from the nearest filled data bin.

## 2.2. Flight conditions

In order to model helicopter noise for realistic flight procedures, a set of hemispheres is required that cover the complete range of relevant flight

conditions within the flight envelope of the helicopter.

Climb segments can usually be limited to the best rate of climb speed ( $V_y$ ) and climb angles of  $9^\circ$ ,  $12^\circ$  and the maximum climb angle according to the aircraft flight manual.

However, for descents a strong dependency of noise levels is exhibited on rate-of-descent and airspeed. The number of approach conditions should therefore be sufficient to cover the whole range of velocities and rates of descent.

Level flight conditions should be available for a range of speeds.

No interpolation between flight conditions is allowed. The recommended practice is to reconstruct flight paths using existing flight conditions in the database.

## 2.3. Helicopter type

The total European helicopter fleet consists of around 350 helicopter types. An investigation showed that this fleet could be (acoustically) represented by 15 helicopter classes. Table I gives the results of this fleet modelling exercise.

An extensive flight test campaign has been performed by NLR and Anotec in which noise data was gathered and hemispheres were derived for 8 helicopter types (indicated in red in Table I) for a variety of flight conditions. These types represent around 70% of the European helicopter fleet.

In the proposed helicopter noise model the following situations can occur when predicting noise for an arbitrary helicopter:

a) The helicopter type is one of the types for which a noise database is established. In this case the hemisphere set can be directly used to predict helicopter noise.

Table I. Helicopter classes considered in the model.

<i>Helicopter class</i>	<i>ATD</i>	<i>Included helicopter types</i>
Robinson 44	R44	<b>R44</b> , B47G, B47J, ELTO, UH12
Robinson 22	R22	<b>R22</b> , CH7, V500, [A600], [BABY], [DRAG], [EXEC], [SCOR], homebuilts
AS350 Ecureuil	AS50	<b>AS50</b> , ALO2, ALO3, LAMA, PSW4
Bell 206 JetRanger	B06	B06, B06T, B47T, H12T, <b>R66</b>
Schweizer 300	H269	<b>H269</b> , BRB2, EN28, [ZA6]
EC135	EC35	<b>EC35</b> , EC145T2
Agusta A109	A109	A109, B105, B427, B429, BK17, EC45
EC120 Colibri	EC20	<b>EC20</b> , EC30, GAZL
Bell 412	B412	<b>B412</b> , B430, S76
AgustaWestland AW139	A139	A139
AS332 Super Puma	AS32	AS32, AS3B
Sikorsky 92	S92	S92
AS365 Dauphin 2	AS65	AS65, EC55
Guimbal Cabri G2	G2CA	G2CA
AS355 Ecureuil 2	AS55	AS55, MI2

b) There is no noise database for the considered helicopter type. There is however a noise database established for a helicopter within the class of this helicopter. In this case the helicopter type under consideration is represented by helicopter with similar characteristics, in which case a correction has to be applied to the overall hemisphere noise levels based on the difference in certification noise levels. For the helicopters in Table I within [brackets], the azimuth angle should be mirrored, in order to account for their main/tail rotor configuration (direction of rotation).

c) There is no noise database for the considered helicopter type nor is there a database for any helicopter within its class. In this case it is recommended to acquire a hemisphere data set based on noise measurements. An intermediate solution is to group the helicopter with an existing class. In this case certification noise levels are

decisive and should be lower than or within the range of the target helicopter class. In case no certification noise levels are available or multiple classes can be selected based on the certification noise level criterion, helicopter weight becomes the governing parameter. This should be lower or in the range of the class to be grouped with.

#### 2.4. Flight path construction

For single-event modelling of helicopter noise the source position is required as a function of time. This is used to calculate the atmospheric attenuation for a given observer. The 3D flight path is built up out of a ground track and vertical profile. The ground track can be chosen arbitrarily, however the vertical profile is dictated by the available hemispheres (i.e. flight conditions).

The flight path construction is done similar to ECAC Doc.29 [3]. A ground path is defined in segments with the parameters that defined the type of segment, the length/radius and orientation/arc

angle. An example ground track is illustrated in Figure 2.

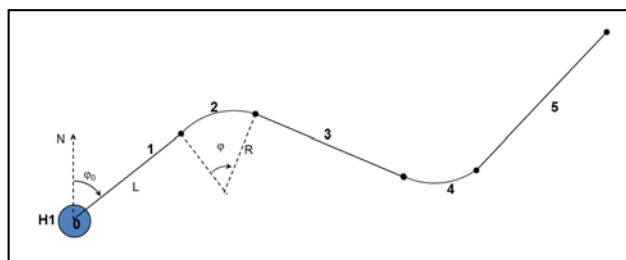


Figure 2 - Ground path of a helicopter track

Four segments can be defined: an origin (O), straight segment (S), a left turn (L) and a right turn (R). The ground track is defined relative to the helipad H1 (origin). The helipad coordinates in geographical coordinate system (latitude, longitude and elevation) are defined separately.

The vertical profile along the ground track is defined in a sequence of profile steps, which is defined by distance, time or final altitude. This is shown in Figure 3.

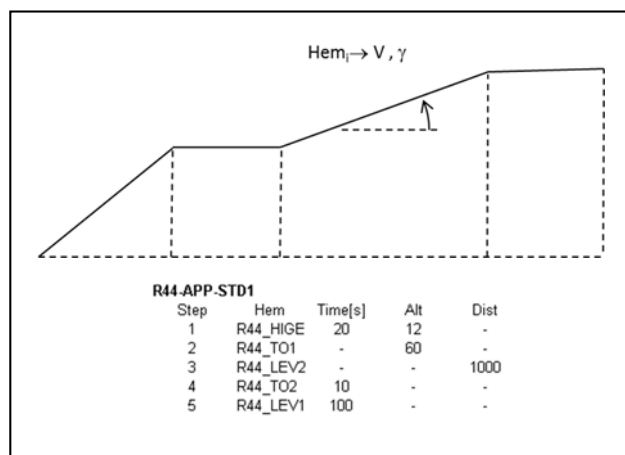


Figure 3 - Vertical profile of a helicopter track

Each step is linked to a hemisphere, which defines the velocity and flight path angle. With this information the vertical profile can be constructed and a 3D flight path is obtained. Finally, the track is divided in discrete points in location and time, which are used for the propagation calculations.

## 2.5. Propagation modelling

To calculate the noise received at an observer located on the ground several propagation effects are taken into account.

In this first version of the model, only those effects have been included that have a first order influence on the noise propagation of helicopter noise. However, since the methodology is based on 1/3 octaves and separates source from propagation modelling, more sophisticated methods (e.g. ray-tracing or shielding) can easily be implemented.

### 3.1.1. Spherical spreading

To account for spherical spreading loss a point source is assumed. The reference distance for this calculation is the reference distance of the hemisphere (i.e. 60m).

### 3.1.2. Atmospheric absorption

The method used to calculate atmospheric absorption for pure-tone frequencies is described in SAE ARP5534 [4]. To calculate the attenuation for a 1/3 octave band the method described in [5] is used.

### 3.1.3. Ground reflection

Ground reflection effects are calculated with the Chien-Soroka method [6]. The surface impedance is modelled by a single parameter model by Delaney and Bazley [7].

## 3. Software prototype

The methodology described above has been implemented in a software to allow the use of the model by external experts. This software constitutes the prototype of the new EU helicopter noise model NORAH (NOise of Rotorcraft Assessed by a Hemisphere-approach).

### 3.1. High level design

Based on a set of basic requirements and the methodology described before, the following main elements have been defined as the core of the model:

#### - Single Event Module

This is considered the main noise calculation engine and contains all processes needed to calculate the noise at an observer grid for a single helicopter flying a given 4D trajectory in accordance with the methodology described above.

#### - Multi Event Module

This Module is conceived as a shell around the Single Event Module. Based on the user defined input it triggers this Module for each individual operation and captures the output for subsequent

merging so as to calculate and output the total noise at the observers.

This core is fed with all required input data through plain text files which can easily be created with any text editor. Three levels of input exist:

- *Fixed*

The user shall not edit these files. This mainly concerns the database with hemispheres

- *Case independent*

The user shall define these files only once for a study. This input can be seen as a database containing all (user-definable) parameters that may occur for the various scenarios within the study

- *Case dependent*

The user can build a specific scenario (“case”) by selecting the relevant values for the different parameters from the case independent databases and in addition shall provide calculation options

The output of the core will be a datafile containing the final noise levels received at the required observer positions.

Based on this, the high level design of the prototype as depicted in Figure 4 has been derived.

In order to facilitate future integration and also to maximize performance, both core modules (Single-Event and Multi-Event) were implemented as an executable in FORTRAN 95 and Python respectively, with ASCII interfaces that can easily be generated by and read from programming languages like C/C++, Python, Matlab, VB.net, C# and FORTRAN. The development of a GUI was outside the scope of the project.

The software consists in two console programs (NORAH.exe and SingleEvt.exe) that operate in a three level folder structure (Airport, Case and Single Event level).

At airport level, helipads, tracks, profiles and noise metrics are defined by means of ASCII tables with fixed names. Noise metrics and profiles usually are common to most airports but they are defined here to provide more flexibility.

At Case level, airport operations and run options are defined.

At Single event level, the noise levels calculated for each operation defined in the case are stored.

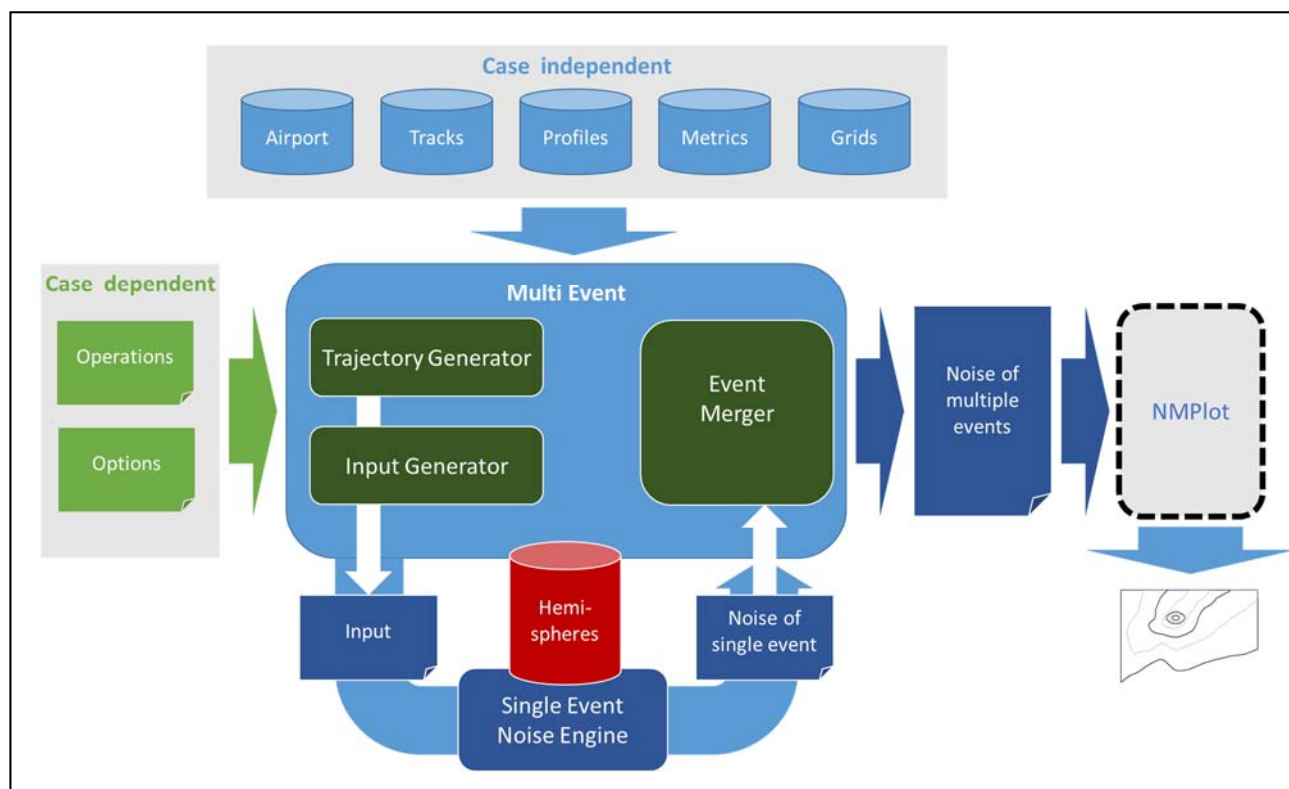


Figure 4 – High level design of NORAH



### 3.2. Multi Event Module (NORAH.exe)

Module NORAH is executed for a single case. It performs the following tasks:

- Reads all airport level files: Airport , Track, Profiles, Metrics
- Reads operations data
- Reads Run options like meteo conditions, flight path time step, grid to use and metrics to generate.
- For each operation it combines the track with the profile selected in the operations file (see Figure 5). When the profile is longer than a track, the track is extrapolated whereas in the case the track is longer than the profile, the track will be truncated.

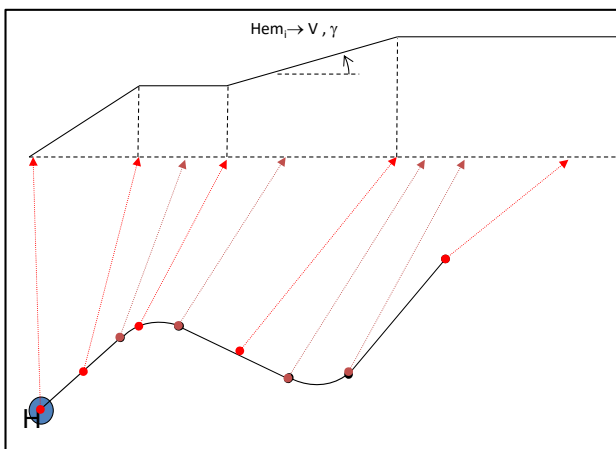


Figure 5 – Generation of trajectory based on tracks and profile

- Generates the input file for SingleEvent.exe which contains the 3D flight path, meteo conditions and links to the hemisphere file used in each flight path point. The input files are named as all the fields of the operation to easily identify them.
- Launches SingleEvent.exe which generates SEL and EPNL levels of the operation at each grid point.
- It sums all single events files onl accordingly with the metrics selected by the user.
- Writes Case noise levels for each metric as final output of the program.

### 3.3. Single Event module (SingleEvt.exe)

Executable SingleEvt.exe is launched automatically from NORAH.exe. However, if so desired, the user may execute it from a console using the created input file as a template for further investigations (e.g. changing the options of the input file).

The input file contains a copy of the relevant parameters defined in the options file and a list of the hemispheres used in the selected profile of the operation. This is followed by a table that describes the flight path which results of merging the track with the profile. Each line contains the position and heading necessary to calculate the directivity angles  $\theta_{obs}$  and  $\varphi_{obs}$  to interpolate in the hemisphere specified. An additional  $\Delta dB$  may be added at each point to simulate helicopters that are not in the database

#### 3.3.1. Module source noise

This module reads in a pre-processing step the hemisphere tables, extrapolates the missing values to cover the whole hemisphere range and eliminates the atmospheric absorption to obtain freefield levels at the reference distance (60m). In the time and observer loop it interpolates in the hemispheres to obtain the 1/3 octave band levels at the desired  $\theta_{obs}$  and  $\varphi_{obs}$ .

#### 3.3.2. Module propagation

For each combination of flight path point and observer, the noise propagation effects (spherical spreading, atmospheric absorption and ground reflections) are calculated.

For each observer location metrics like SEL and EPNL are then calculated.

### 3.4. Interfaces

The model designed in the previous sections has several interfaces:

- With the user (providing initial system set-up)
- With downstream tools (using the results of the calculations)

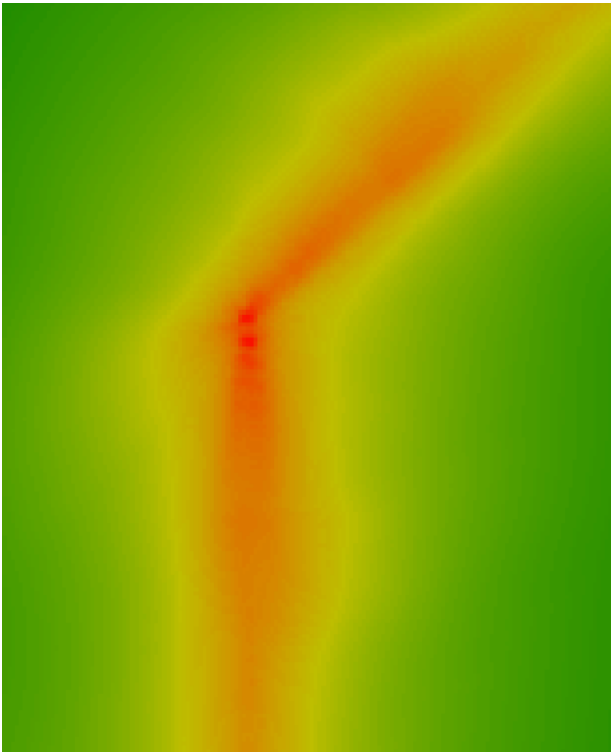
#### 3.4.1. Interface with user

For the purpose of the prototype development a simple user interface was considered appropriate. To this end plain ASCII files are used, which can easily be created and maintained with any text editor.

It is noted here that the term “user” may also be interpreted as any upstream tool or a shell that uses the prototype as the calculation engine for helicopter noise exposure around heliports. In this case the inputfiles would be generated by that tool.

### 3.4.2. Interface with downstream tools

The interface with downstream tools is limited to the files generated by the model, containing the total noise levels received at the requested observer positions, for the various noise levels considered. The outputfiles are compatible with the NMPlot tool [8]. Figure 6 gives an example of a noise contour generated with NMPlot and based on NORAH results.



.Figure 6 – Example noise contour generated by NMPlot

### 3.5. Validation

As part of the development process an exhaustive validation of NORAH was performed by SINTEF, both at component and global level. Comparisons were made with results from INM, Nord2000 and HELENA. At present additional validation is being made by external aircraft noise experts of the AIRMOD group, which is responsible for the maintenance of ECAC Doc29.

### Acknowledgement

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