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D3 NORAH 2.0 validation

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D3 NORAH 2.0 validation

Royal Netherlands Aerospace Centre (NLR)

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SUMMARY

NORAH2 is a tool to calculate noise exposure in the vicinity of rotorcraft landing places or rotorcraft flight tracks. This report contains results from a functional validation of NORAH2. It covers the implementation of NORAH2 methodology into the prototype software.

A summary of the main validation actions and corresponding results is:

1. Validation of NORAH2 source data against certification levels. For all the new helicopter types in NORAH2, specific measurements have been made to replicate the respective certification levels.

2. Comparison with other available noise models. Calculations with NORAH2 have been compared to simulations with a more advanced sound propagation method, Nord 2000. The more advanced method is a modified version of NORAH2 where the sound propagation algorithms are replaced with corresponding algorithms from the Nord 2000 method. Thus, the validation is targeting sound propagation over varying terrain. The comparison shows generally good agreement, which validates the sound propagation method in NORAH2.

3. Independent implementation of new propagation methodology. The most advanced algorithms of NORAH2 have been peer reviewed and implemented a second time, independently from the NORAH2 program. A comparison test has revealed some unclear parts in the method description, which have been clarified in an updated version of D1.5c. The comparison also resulted in some minor updates to the NORAH2 software. After processing this, the final version of NORAH2 agrees with the test.

4. Other validation work. Finally, the report describes other validation actions made, including reviewing the method against recent updates in Cnossos-EU, review and updates of the rotorcraft modelling guidance, and measurement of full helicopter operations for future comparison with detailed calculations.

CONTENTS

1. Introduction

The goal of this research is to make a limited validation of NORAH 2.0. New noise source data shall be validated against certification noise levels, and the software shall be compared with independent calculation tools. A validation plan was outlined in [1]. The validation reported below has a limited scope compared to this plan, mainly because comparisons with independent measurements of real flight operations could not be made. This is a result of validation being given reduced priority, compared to the ambition level in [1], during the budget allocation process, prior to contract signing.

The contents of the chapters are as follows:

Chapter 2 describes the general approach to validate NORAH 2.0;
Chapter 3 describes actions and results from validation of NORAH 2.0.

2. General approach to validate NORAH 2.0

2.1 Objective of the validation

Generally, validation is done to facilitate acceptance of a method or tool among the intended users for the intended use. This is done by specific actions to provide evidence related to requirements and expectations to the method or tool.

The objective of the validation work is to ensure that NORAH satisfies the intended performance and quality. This includes calculation of strategic noise maps for helicopter traffic, in line with the requirements given in the END directive (ref. 2). This is done by a set of actions described below. Specification of overall requirements and final performance qualification is not part of this exercise. Validation on functional and detailed level is carried out within the project team.

2.2 Validation structure

The validation is basically about confirming that the end product is in compliance with the given specifications. The specifications are either given externally or described among the project participants at a proper stage of the work. The resulting qualification at a later stage are aimed at being as independent and objective as possible given the integrity implications of performing development and validation within the same single project team.

Generally, the validation actions are conducted at three levels; one overall level dealing with the overall requirements, one intermediate level dealing with the derived functionality, and one detailed level dealing with concrete construction or implementation. A schematic of the validation process is given in Figure 1. The schematic process is general and can be applied to any NORAH component like source database, calculation methodology, and software implementation.

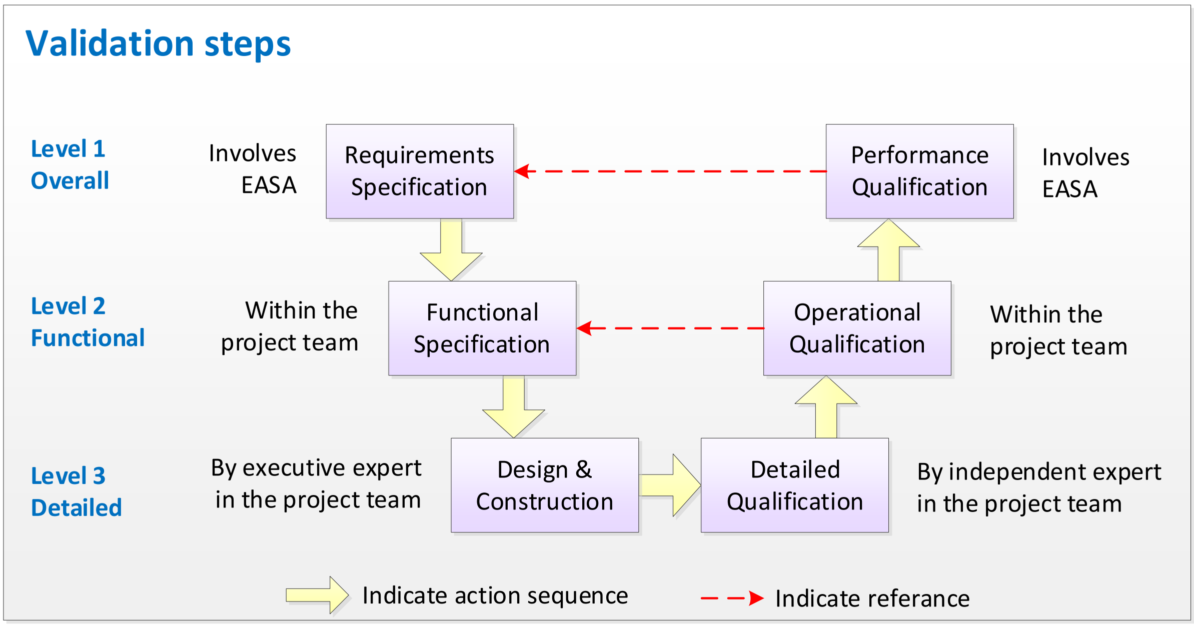

Figure 1: Schematic of the validation process

Three levels of validation are defined.

1. Overall performance qualification
   The overall requirements for NORAH are given by EASA through the initial descriptions of the project and tasks and other inputs to the project team. Consequently, the validation on this level is done by EASA, primarily through approval of the agreed deliverables in the project.

2. Operational qualifications
   The intermediate level validation deals with the functional operation of NORAH. It is managed within the project team. A list of functional requirements is made on basis of the overall requirements. During the development of the methodology the goal is to address and solve all the items in this list. Afterwards compliance with the specifications is demonstrated through test actions.
   - Reference to published or standardized descriptions validated elsewhere
   - Comparison with measured data
   - Comparison with other methods or simulations
   - Elaboration relative to commonly accepted international knowledge
   - Inquiry of external independent expert opinions
   - Scientific reasoning

3. Detailed qualification
   The validation actions on this level deals with all the details in the description of the calculation method or measurement procedure. The validation on this level is in line with what was done for NORAH 1.0. A second expert within the project team did review the details in the software code and related details in the method description. To facilitate independence, the second expert was from another partner organisation than the one writing the method.

3. NORAH 2.0 validation actions and results

The results provided below target *operational qualification* of NORAH 2.0, which aims to show that the program works according to the functional specifications. It is not intended to provide the overall *performance qualification*, which is something that should be made outside the project development team.

The validation is sectioned into four themes as given in the following four chapters.

3.1 Validation of NORAH 2.0 against certification levels

The validation of NORAH 2.0 against certification levels is done in two steps:
- Determination of certification noise levels based on the measurements
- Prediction of certification noise levels with NORAH 2.0

Hereafter the results of both steps are provided.

The development of NORAH 2.0 comprises the measurement of original sets of noise emission hemispheres for three helicopters. These are supplements to the source database developed for NORAH version 1 and expands the range of helicopter classes supported by NORAH.

During the measurement campaigns, additional operations/measurements were made to reproduce the helicopter's noise certification test procedures and the corresponding noise levels, in accordance with ICAO Annex 16. Comparison with official certification levels is a validation action to prove the hemisphere measurements (rotorcraft, setup, instrumentation, analyses etc.) are correct. Background for comparisons is described in detail in the respective measurement reports [2]. The results are shown in table 1.

Helicopter	Operation	Unit	Measured	Certification	Difference
Guimbal Cabri G2	Flyover	SEL	75.8	75.7	0.1
Agusta A109	Take-off	EPNdB	92.4	92.4	0.0
Agusta A109	Flyover	EPNdB	89.8	88.8	1.0
Agusta A109	Approach	EPNdB	91.7	90.1	1.6
Sikorsky S-92	Take-off	EPNdB	95.3	94.6	0.7
Sikorsky S-92	Flyover	EPNdB	98.7	97.2	1.5
Sikorsky S-92	Approach	EPNdB	96.9	97.5	-0.6

Table 1: Comparison of measurement results against certification levels for three helicopter types

The results show good agreement, which shows that the measurements produced reliable noise data.

In a second step, the noise certification procedures of the S-92 were reproduced with NORAH 2.0. Table 2 gives the results of this exercise.

Helicopter	Operation	Unit	Predicted	Certification	Difference
Sikorsky S-92	Take-off	EPNdB	96.0	94.6	1.6
Sikorsky S-92	Flyover	EPNdB	99.0	97.2	1.8
Sikorsky S-92	Approach	EPNdB	97.4	97.5	-0.1

Table 2: Comparison of NORAH 2.0 prediction results against certification levels for the S-92 helicopter

It can be seen that the resulting differences are in the same order of magnitude as the measured differences, which indicates that the prediction procedures in NORAH 2.0 provides reliable results.

3.2 Comparison with other available noise models

The purpose of this validation action is to compare the NORAH 2.0 ground- and topography modelling methodology with an alternative and preferably more advanced methodology. After considering available tools and resources it was decided to compare NORAH 2.0 with a Nord 2000 based simulation. This validation is targeting the sound propagation methodology. This includes a scientific evaluation of conformity and differences between the results from the two calculations.
A duplicate of the single event module of NORAH 2.0 prototype was created, with the only change that the algorithms for ground reflections and diffractions from varying topography was replaced by Nord 2000 algorithms. Nord 2000 is a more advanced model compared to NORAH 2.0 and can be regarded as a state-of-the-art methods, similar to the European *Harmonoise* model and the Swiss model *SonAir*. It was chosen due to its availability at SINTEF.

An artificial test case was designed as a combination of flat terrain and a mountain. This is illustrated in figure 2. The extent of the modelled area is 2 by 2 km. The mountain is located inside a rectangle, as seen in the figure. The mountain top is a ridge ranging from 220 m height at the southern point to 120 m at the northern point. The ridge is indicated with a line in figure 2. The terrain elevation at the sides of the mountain falls from the ridge towards the base rectangle along a s-shaped curve ($\cos^2$ - function), giving smooth transitions for the elevation.

A limited part of the flat terrain is modelled with hard surface. This is located within a square in figure 2. The rest of the terrain is modelled as soft ground.

A take-off is modelled using the NORAH helicopter R22. As illustrated by a partly curved line in figure 2. It starts in the southern area, and flies northward. The initial part of the take-off is done over flat area, before a 60˚ left turn that takes the helicopter westward over the mountain ridge.

Different parts of the area will show somewhat isolated effects of different elements in the methodology. This covers effects of flat-soft terrain, flat-hard terrain, varying terrain effecting the ground attenuation, and screening effects of the terrain.

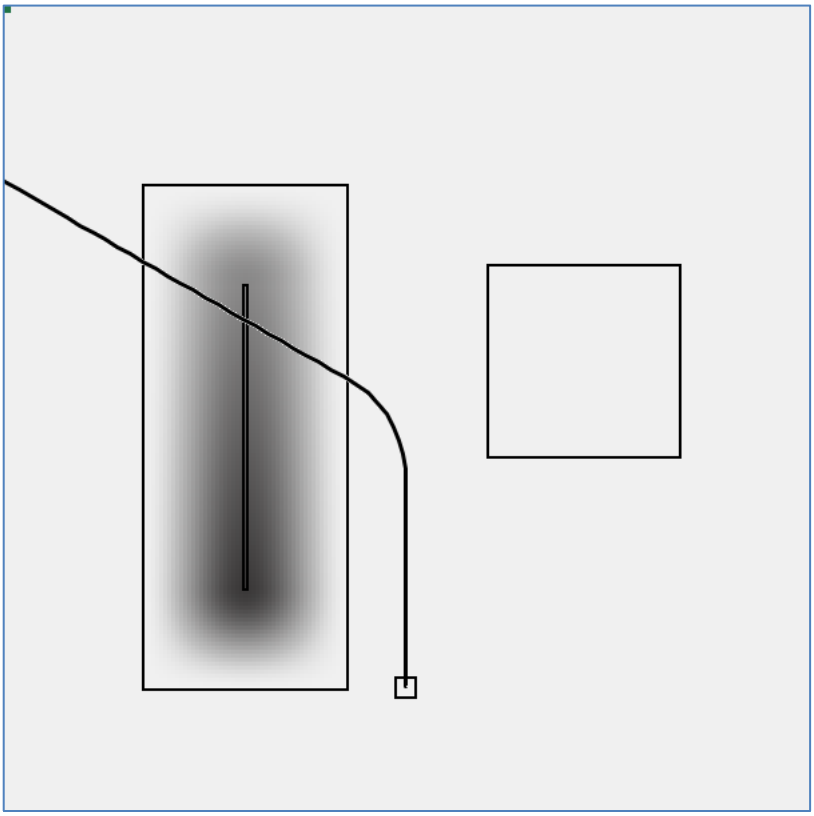

Figure 2: Artificial terrain model, 2x2 km

Noise is calculated by NORAH 2.0, in a 10 by 10 m grid, covering the whole terrain area illustrated in figure 2. This means calculations in 201 by 201 microphone points. Only SEL results (A-weighted sound exposure level) are considered in the following. The results are illustrated in figure 3, left part. The noise level is covering a large range from approx. 50 dB in shielded areas behind the mountain, to approx. 100 dB close to the take-off point.

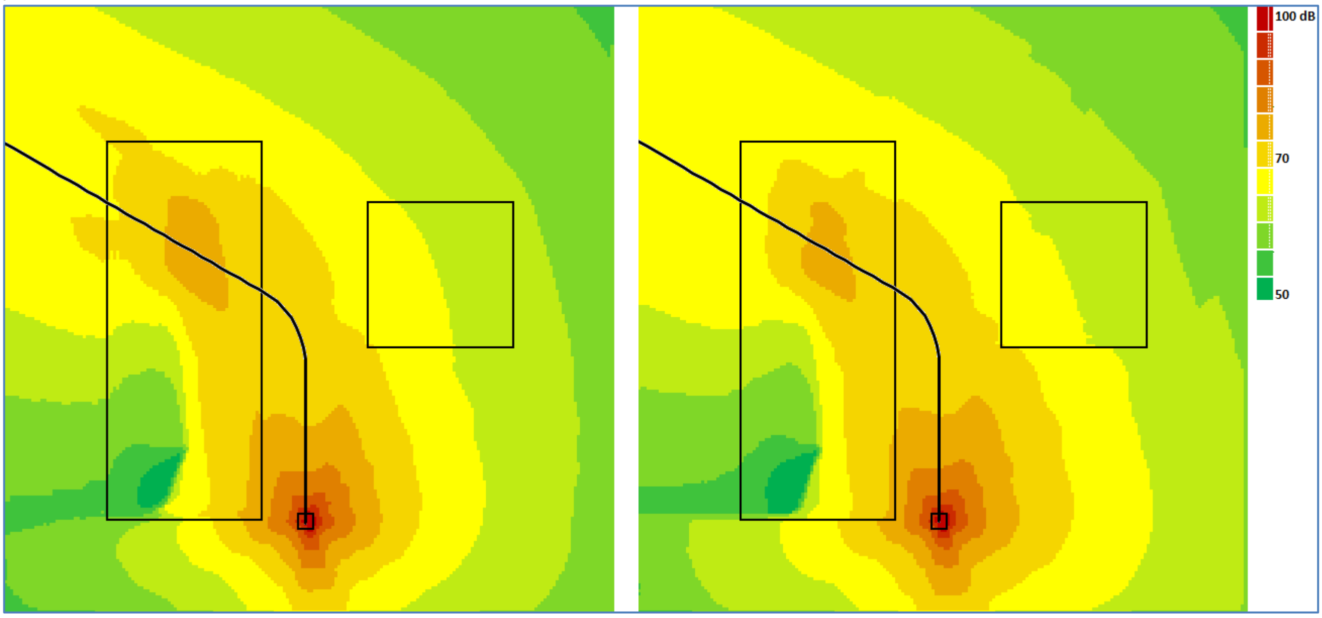

Figure 3: Noise map according to NORAH 2.0 (left) and Nord 2000 (right)

The same calculation exercise has been made with the duplicate version of NORAH having Nord 2000 algorithms instead of the original ones. In the following, calculation results from this version are named Nord 2000. Results are illustrated in figure 3, right part.

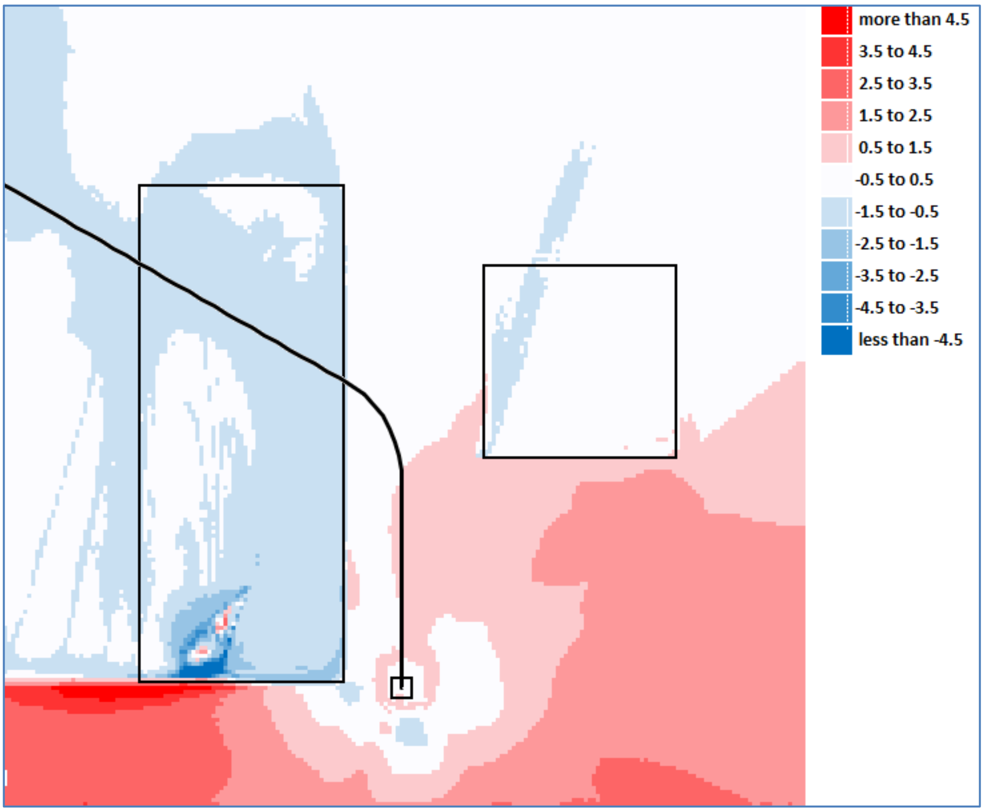

Figure 4: Difference between Nord 2000 and NORAH 2.0 sound propagation.
Red colours: Nord 2000 is higher than NORAH2.
Blue colours: Nord 2000 is lower than NOTAH2.

To explore details from the two calculations, a difference map is shown in figure 4. It has a colouring scale covering a range of ± 5 dB. The numbers are rounded to nearest whole dB and represented by discrete colours in the figure. Positive values (red colour scale) are where Nord 2000 is higher. White colour covers areas where the rounded difference is 0 dB. Here the two calculations give practically equal result. If we include pale blue and pale red, we get the areas where the differences are low or moderate (±1.5 dB).

An evaluation of differences between Nord 2000 and NORAH 2.0 can be done by looking at the sound the level differences illustrated in figure 4. The following findings are noted:

- The differences between NORAH 2.0 and Nord 2000 are generally in the order of ± 1 dB. This is illustrated by the colour range from pale blue through white to pale red, that is covering most of the areas in figure 5. These differences occur both for flat ground and through varying topography.
- Generally, Nord 2000 gives slightly higher levels for propagation over flat soft terrain, and slightly lower levels for propagation oved hard terrain or varying topography.

- In areas with very high screening effects (the order of 20 dB or more attenuation), the differences are up to ± 10 dB. This is seen as dark blue and dark red colours in the lower left part of figure 5.
- In parts of the area behind helicopter, Nord 2000 gives 2-3 dB higher levels than NORAH 2.0, for flat soft terrain. This is seen as red colour in the lower right parts of figure 5.

A reasonable evaluation of the findings above is that there is a generally good agreement between the two methods. Deviations within 1 dB between different methods, should be considered as low. The deviations of up to 10 dB in areas with very high screening effects should also be considered acceptable, given that none of the methods have an accurate solution to the physical phenomena causing screening by heavy topography.

The differences of 2-3 dB behind the helicopter, over flat soft ground, indicates differences between the methods for ground-to-ground propagation over long distance soft ground.

The theoretical background from Chien & Soroka [3,4] predict a very strong ground effect (damping) for this situation. This is fully visible in the NORAH results. Nord 2000 use the same theory but includes additional consideration of turbulence effects in the atmosphere, which tend to reduce the ground effect (i.e. predict higher levels). This may explain the 2-3 dB differences. The observation therefore indicate that NORAH 2.0 may slightly underestimate the noise for long distance ground-to-ground propagation. The same goes for NORAH 1.

In this context it is worth noting that weather effects (wind and temperature gradients) will have a very strong influence on the effective ground attenuation for long distance propagation over flat soft ground. On the other hand, one should also note that helicopter noise problems in the society almost always are dominated by high elevation angles and/or shorter propagation distances. The long-distance over flat soft ground is very seldom an issue.

But, if one wants to improve these sides of the NORAH 2.0 methodology, one should include consideration of refraction phenomena due to weather; something which have not been addressed in this project. This is advanced methodology with heavy influence on calculation performance. Nord 2000, for instance, takes the order of 100 times longer calculation times than NORAH 2.0.

To conclude, the findings form comparison with Nord 2000 indicates that the new sound propagation method, and its implementation in NORAH 2.0 software, is valid. There is, however, a minor remaining concern regarding possible slight underestimation of noise for long distance ground-to-ground propagation over flat soft terrain.

3.3 Independent demonstration of new propagation methodology

The methodology in NORAH 2.0 for calculation of combined ground reflection and screening effects is new. It is composed as a combination of *ground reflection* algorithms for flat ground, inherited from NORAH 1.0, and additional algorithms for *diffraction* of sound over obstacles. Ground reflection is based on well-known methodology from scientific literature.. The theory, originally published by by Chien & Soroka [3,4], is fundamental in many advanced methods like Harmonoise, Nord 2000, AAM and SonAir. The diffraction part is based on the method *Cnossos-EU* [6] which is developed for ground-bound noise sources like road, rail and industry noise. It builds on well-known diffraction theory [5], which is incorporated in many traditional engineering methods like ISO 9613-2. Both parts (ground reflection- and diffraction methodology) are basically validated elsewhere. But the combination of them is a new construction introduced in NORAH 2.0. We therefore have put effort into validation actions to qualify method descriptions and implementation into the NORAH 2.0 software prototype. The validation is basically done by peer reviewing of method and a separate/independent implementation of the most complicated parts for testing. Validation was based on D1.5c, the *Rotorcraft Modelling Guidance*.

The programming of new algorithms into the single-event module of NORAH2 is done by a team of experts at SINTEF and Anotec. It is programmed in *Fortran* language, which is the language for NORAH 1.0. NLR implemented 'Screening effects from buildings and topography' in a MATLAB script, based on the description provided in the 'rotorcraft noise modelling guidance' (D1.5c SC01). This serves two validation objectives: (i) confirm that the guidance is complete and without ambiguity or errors and (ii) validate the implementation in the NORAH2 software prototype. Having this validation done by an expert at NLR gives best possible independence between developer and validator, within the frames of the consortium.

During this work, a number of questions was raised from the validator back to the development team. Most of the questions was about ambiguities and unclear parts in the descriptions of method details. A few of the questions revealed bugs in the implementation. This was dealt with through an email dialog between NRL and SINTEF from November 2022 to March 2023. After clarifications in the document and updates of the NORAH2 source code, the validation concluded with agreement between NORAH2 and the independent MATLAB implementation.

3.4 Other validation work

During the NORAH2 project a few other validation tasks have been made, in addition to what is described above. They are mentioned briefly here to provide a complete picture of the theme.

Review against recent updates in Cnossos-EU

The parts of NORAH2 methodology that handles diffraction phenomena are derived from the Cnossos-EU method. This method, however, is not maintained in one unique and complete document. The original description of Cnossos-EU published by JRC in 2012 [7] is obsolete. Current description starts with EU directive [6], with important adjustments in EU amendment [8]. In addition, crucial guidance about how to interpret difficult elements in the method is published by ISO [9]. Also, several updates have been suggested by the international research community on how to implement different parts of the method. Some of this is about shielding from topography.

In January 2023 both the description of NORAH2 methodology (D1-5c) and the source code was reviewed in light recent updates in Cnossos-EU. This was done by an expert at SINTEF who had not been involved in the NORAH2 project, but who had long experience with the Cnossos method. The review resulted in a few updates to D1.5c and corresponding adjustments in the source code. It is validated that the diffraction method of NORAH2 is in line with the relevant parts of Cnossos-EU, per January 2023.

Reviews of the rotorcraft modelling guidance

The rotorcraft modelling guidance D1.5c has been updated as a result of the validation work described above. Because this represents a real change in some of the details in the guidance, we decided to make a new deliverable which is intended to replace the previous one. The new deliverable is called D1.5d. It is dated 13th June 2023.

Measurements of normal helicopter operations

During the S-92 measurement campaign in July 2022, separate measurements were made for normal helicopter operations in the area. This contains detailed recordings of spectral noise levels with a time resolution suitable for comparison with NORAH2 simulation on a second-by-second basis. For at least one of the recorded operations, the on-board instrumentation operative, so that all relevant flight data are captured. This was done to collect data for a NORAH2 validation against measurements, targeting themes like source directivity, hemisphere interpolation, and time- and spectral parameter variations.

The final analyses of these measurement data, and the corresponding NORAH2 simulation has not been made, due to resource limitations. This remains as a possible future validation task.

3.5 Conclusion

The following points summarize the findings of the validation exercise.

- Measurements for source hemisphere data include results that comply with official certification noise levels. This is tested for all new helicopter types included in the project.
- Prediction with NORAH 2.0 give results that agree with official certification noise levels. This is tested for one of the new helicopter types.
- Comparison of sound propagation methodology between NORAH 2.0 and Nord 2000 show good agreement for situations of importance to noise mapping. But deviations are found for some less important low noise situations dominated by heavy screening effects or long-distance ground-to-ground propagation over flat soft terrain.
- Thorough peer reviewing of methodology has been made to ensure transparency and reduce ambiguity in the NORAH 2.0 methodology.
- A second, independent implementation of the core methodology has been made to demonstrate validity of the NORAH 2.0 sound propagation module.
- The NORAH 2.0 methodology has been reviewed to ensure that the parts inherited from the Cnossos-EU method are compliant with updates in EC directive, ISO standard and similar relevant publications.
- The Rotorcraft Modelling Guidance has been updated to reflect clarifications and adjustments made during the validation process.
- The NORAH 2.0 program has been updated to reflect adjustments and bug-fixes resulting from the validation process.

The conclusion from this is that NORAH 2.0 complies with the functional specifications covered.

Further validation actions could be considered in the future, to complete the whole plan laid out in [1].

- In-depth test of hemisphere interpolation methodology. This could preferably be done with the extra measurements of in-flight helicopter already that are already made during the S-92 measurement campaign.
- In-depth test of methodology for turns, against measurements. An initial analyse should be made to decide if sufficient data exist from previous campaigns, or new measurements are needed.
- Test of methodology for hover and taxi, against measurements. This will require a new measurement campaign.

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