NINHA

Noise Impact of aircraft with Novel engine configurations in mid- to High Altitude operations

D.4.6
Publishable project results

Nico van Oosten (ANOTEC)

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EXECUTIVE SUMMARY

The introduction of aircraft with advanced counter-rotating open rotor (CROR) engine power plants will contribute significantly to the reduction of fuel burn and gaseous emissions. In the 1980s, it was found that the noise generated by these engines, even in the en-route flight phase, was significant, thus hazarding public acceptance. Since then significant effort has been dedicated to improving the CROR aero-acoustic design. The NINHA project determined the level and impact of the en-route noise to assess the viability of this new generation of novel engine concepts.

The project was organised around 3 main challenges:
1. Adapt existing models for long-range propagation and validate them
2. Predict noise levels on ground generated by CROR en-route
3. Assess ground noise impact of CROR re. conventional powerplant

Challenge 1: Long-range propagation modeling

To assess the en-route noise of an aircraft with Counter Rotating Open Rotor engines, there is a requirement for adequate modeling of the acoustic propagation through a realistic atmosphere. Long-range atmospheric propagation models for propeller-driven aircraft at cruise conditions were developed and validated.

Challenge 2: CROR en-route noise levels

A large experimental database of near-field CROR noise, obtained in earlier research projects, was exploited. Since at the start of the project significant uncertainty existed in extrapolating from high-speed wind-tunnel data to the far-field, different methodologies and parallel approaches were applied on data from different data sources. Propagation models from Challenge 1 were implemented in the SOPRANO aircraft noise prediction platform in order to obtain a complete calculation chain to predict CROR en-route noise levels as received on the ground.

Challenge 3: Assessment of en-route noise impact

An en-route noise impact model was developed. Noise data for turbofans, turboprops and CROR aircraft were obtained from the EASA BANOERAC study, dedicated measurements in NINHA and predictions (Challenge 2), respectively. Combined with en-route air traffic data generated in NINHA, the en-route noise impact was established for various fleet compositions (CROR share). Based on the results of the impact calculations a first assessment was made whether or not the new generation of CROR aircraft might face challenges related to their en-route noise. Communication of the project results with rulemaking bodies has also been addressed.

The NINHA project has established that at cruise the noise of Contra Rotating Open Rotors with today's technology will be significantly reduced from that of the UnDucted Fan of the 1980s. The maximum noise level (when the aircraft is overhead) will be equivalent to that of today's TurboProps. Further reductions in Open Rotor noise are expected to be forthcoming before they enter service in the late 2020s

NINHA also provides recommendations for future work aimed at addressing beyond the NINHA achievements the issues, shortcomings, gaps and needs identified with respect to the development of a fully effective predictive framework aimed at en-route noise impact assessment.

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1. Summary description of project context and objectives

NINHA (**N**oise **I**mpact of aircraft with **N**ovel engine configurations in mid- to **H**igh **A**ltitude operations) is an FP7 Level 1 project with 9 partners (Anotec Consulting (Spain) [Coordinator], Airbus Operations SAS (France), COMOTI (Romania), FOI (Sweden), NLR (Netherlands), ONERA (France), Rolls-Royce (UK), SNECMA (France), University of Southampton (UK). The total budget is 2.9 M€, with an EU grant of 1.9M€. The project started on 1st October 2010 and with a duration of 3 years finished on 30th September 2013.

1.1. Background

The introduction of aircraft with advanced counter-rotating open rotor (CROR) engine power plants will contribute significantly to the reduction of fuel burn and gaseous emissions. In the 1980s, prototypes of the first generation of open rotor engines were developed and tested. One of the findings was that the noise generated by these engines, even in the en-route flight phase, was significant, thus hazarding public acceptance. Since then significant effort has been dedicated to improving the CROR aero-acoustic design; the new generation of CROR engines currently envisaged will be much quieter than its predecessors.

The NINHA project assessed whether noise issues away from airports (i.e. during mid- to high-altitude operations, hereafter called "en-route" (see Figure 1)) might potentially hinder the introduction of this new generation of power plant. To date, the International Civil Aviation Organisation's (ICAO) Committee for Aviation Environmental Protection (CAEP) and aviation stakeholders have primarily been concerned with aviation noise around airports. The means for assessing en-route noise were not standardised and the ability to predict en-route noise was quite limited. NINHA addressed this limitation.
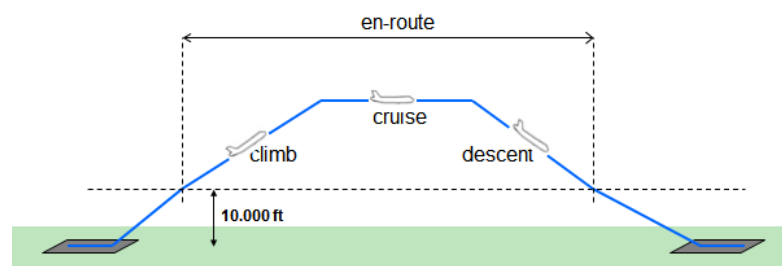

Figure 1. Definition of "en-route"

1.2. Project objectives

The NINHA project determined the level and impact of the en-route noise of open rotor power plants in order to assess the viability of these new engine concepts.

The project was organised around 3 main challenges:

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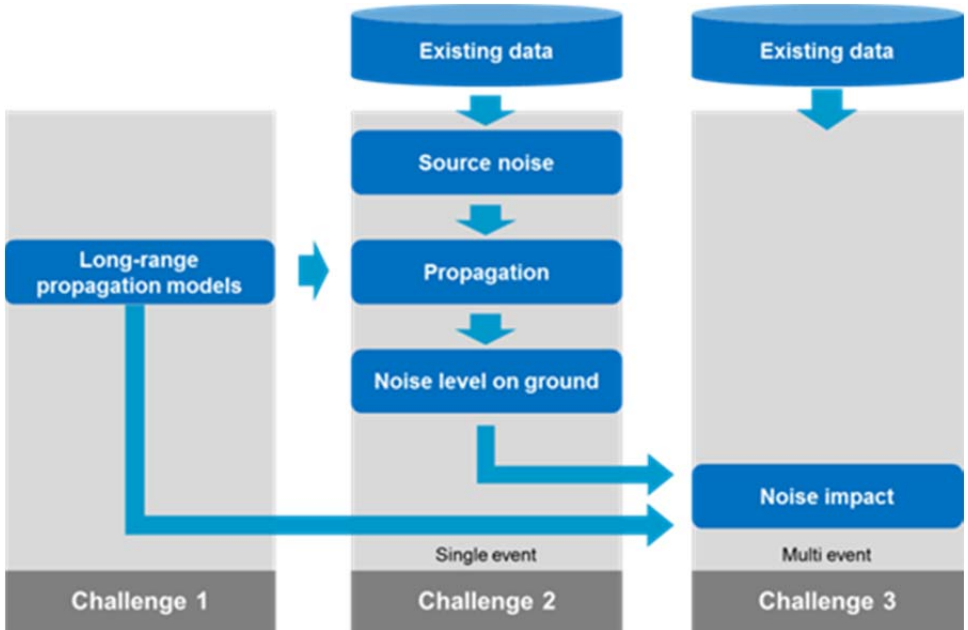
Figure 2. NINHA main challenges and related project structure.

2. Description of main S & T results / foreground

2.1. Challenge 1: Long-range propagation modeling

Flight tests with A400M

One of the main objectives within this challenge was to validate long-range propagation models. In order to achieve this goal, measurements of the noise attenuation between a propeller aircraft and the ground were necessary in very representative conditions (en-route noise). The tests consisted of two main parts:

- Near-field measurements which are performed with microphones positioned on an A320 chasing the A400M at around 100m below it, to measure the noise radiated by the airplane before being propagated to the ground.
- Far-field measurements with microphones located on the ground

Both tests were performed for different test conditions (Mach and cruise altitude). The atmospheric conditions were measured with a weather balloon. Figure 3 shows the general test setup.
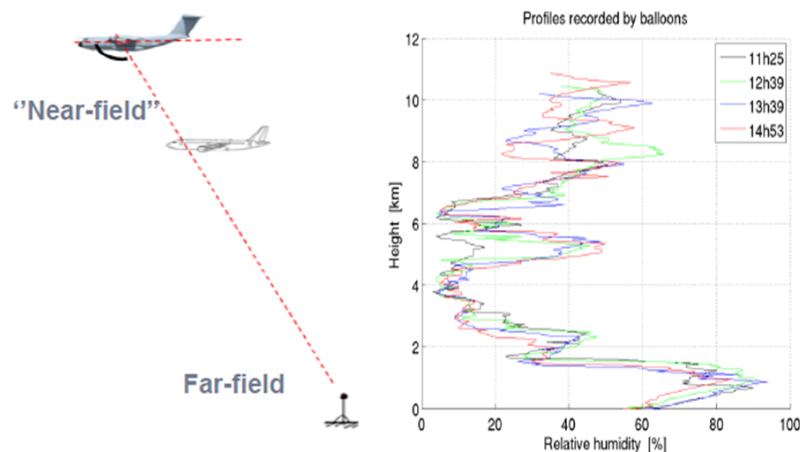

Figure 3. A400M flight test.

The near-field measurements show a good tonal noise emergence from boundary layer noise for the first BPFs (blade passing frequency) as shown in Figure 4.
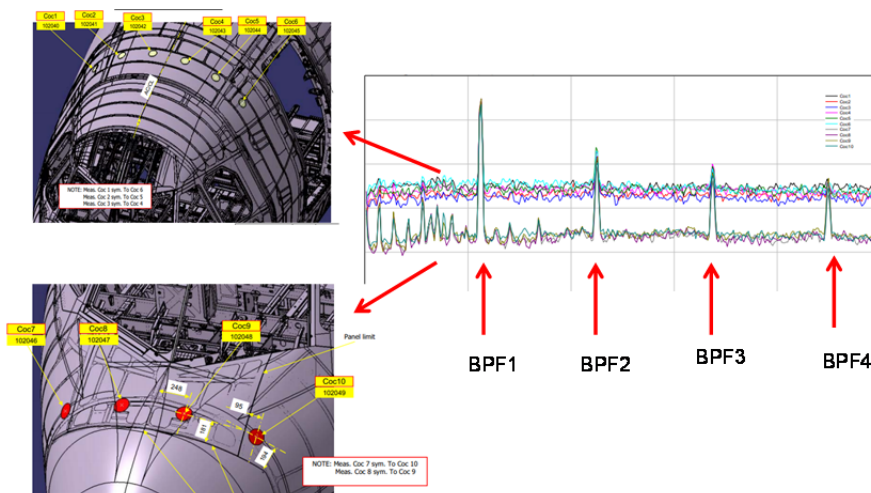

Figure 4. Near-field measurement results.

Once tonal noise was extracted for in-flight and ground conditions, propagation loss could be computed by subtracting BPFs measured at the ground level from BPFs measured at the source level at the same emission angle.

Long-range propagation modelling

Two existing ray-acoustics methods were modified to allow for the specific characteristics of long-range propagation. These methods are capable of computing the sound wave propagation from source to observer, with incorporation of locally varying (but time-averaged) atmospheric conditions. Special care was taken to minimise computational cost of these methods when applied to real-life situations.

RAYTRAC is based on the resolution of a system of 16 coupled differential equations, which gives both the ray trajectory and the pressure amplitude. The equations are solved numerically by application of fourth-order Runge-Kutta integration with adaptive step size.

In APHRODITE, the atmosphere is divided in several layers in which wind and temperature profile are considered linear. Under this assumption, an analytic expression exists to compute the ray trajectory for each layer. Finally, the variation in pressure amplitude is found by computing two adjacent rays. A detailed description of the programs has been

A comparison was made of the results of both models, APHRODITE and RAYTRAC, for a reference case, showing that the differences are only marginal (Figure 5).
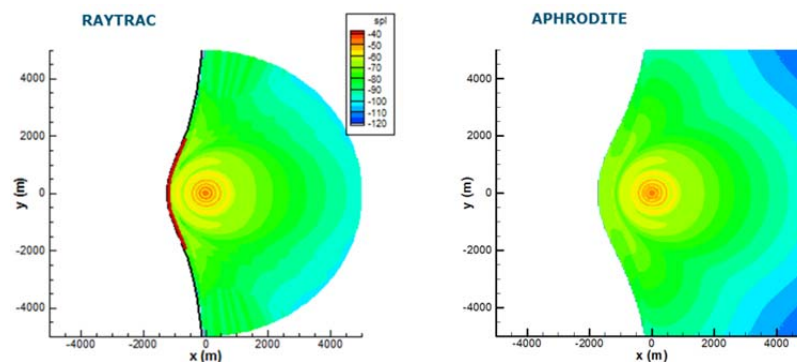

Figure 5. Comparison between 2 ray-tracing models

Validation of these methods was done against the measured data from the A400M flight test (Figure 6).
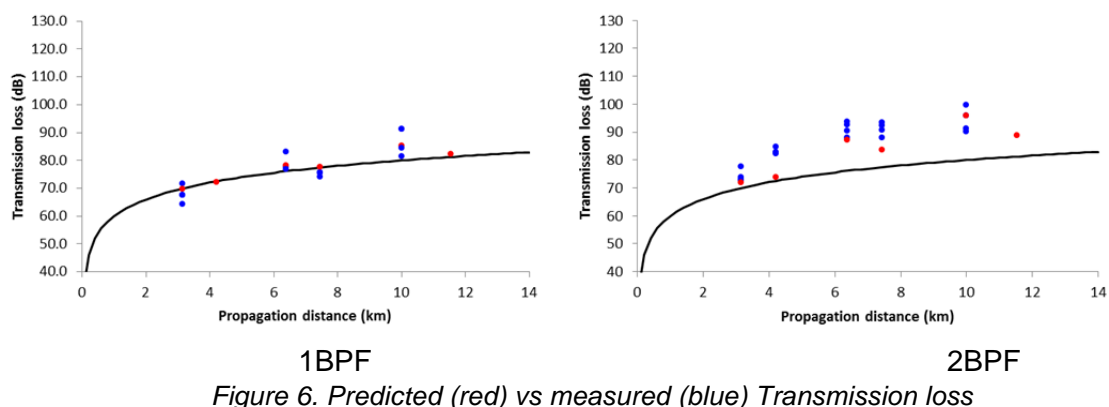

1BPF   2BPF

Figure 6. Predicted (red) vs measured (blue) Transmission loss

An existing Parabolic Equation (PE) model was modified and used for a comparison with both ray models (Figure 7). It was concluded that the ray models give accurate results for the typical NINHA applications.
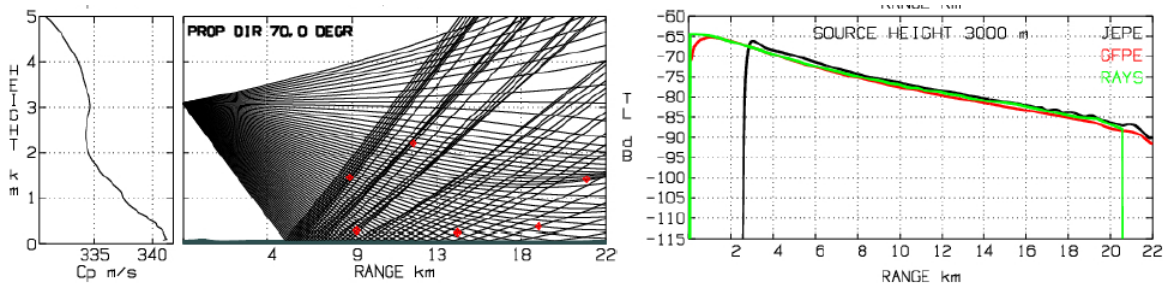

Figure 7. Comparison between PE and ray models

A specific characteristic of en-route noise is the wide variation of noise levels received on the ground, even when considering the same noise source. A comprehensive statistical analysis was performed by predicting ground noise levels for a variety of atmospheric conditions, using the APHRODITE model, embedded in SOPRANO (see 2.2). Based on this analysis an engineering model was developed with which it is possible to determine the likely variation in en-route noise level produced by a CROR aircraft at a certain operating condition (Figure 8).

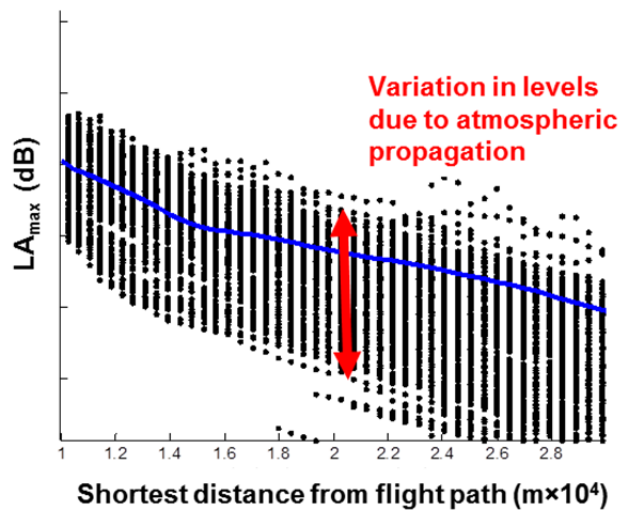Plot of LA_{max} versus shortest distance from aircraft

Figure 8. Variation in ground noise levels due to atmospheric propagation

The work performed successfully addressed Challenge 1:

Validated long-range propagation models are now available

2.2. Challenge 2: CROR en-route noise levels

CROR source noise data

A large experimental database of near-field CROR noise, obtained in earlier research projects (DREAM, CS-SAGE), was exploited (Figure 9).

Figure 9: DREAM CROR designs in ARA (left) and TsAGI (right) wind tunnels

In addition, data from CFD/CAA simulations were provided to enhance the source noise database (Figure 10).
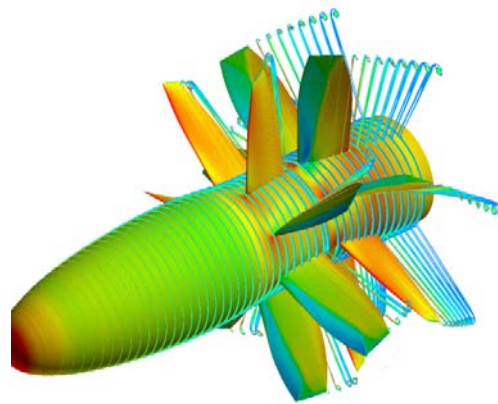

Figure 10. CFD simulation of CROR

Extrapolation of near-field data to the far-field

Most measurements of CROR cruise noise (whether wind-tunnel measurements or flight measurements on the fuselage) are taken in the acoustic near-field. To obtain far-field noise estimates, these measurements need to be corrected for near-field effects. In this respect the far-field refers to distances far enough from the source that the source can be regarded as a point source.. A full description of the far-field of a given noise source would thus consist of noise levels specified on a sphere, for an arbitrary reference distance, for each relevant frequency.

However, most available data is measured or computed at near-field distances. At each point in this near-field region, acoustic signals arrive from effectively a multitude of sources, and the result is a complicated interference pattern, which cannot simply be translated to the far-field. NINHA addressed this issue by developing different methodologies and parallel approaches.

Two extrapolation procedures and their application to extrapolating experimental scale open rotor rig data were delivered. The first extrapolation method, based on a method developed by Peake and Boyd[2], is very robust but potentially not as accurate as the second, based on a method developed by Brouwer[3]. Both extrapolation procedures have been implemented and have been used to produce a comprehensive database of far-field, open rotor noise levels.

Computational aero-acoustics was applied to a simple source model to simulate confinement effects on CROR acoustic wind tunnel data. The main objective was to simulate the near-field noise radiated by a CROR mounted on an aircraft in cruise conditions, accounting for (i) the acoustic scattering effects on the rear aircraft structure and (ii) the acoustic refraction effects due to the strong flow gradients. Further computations were carried out, in which (i) the axisymmetric non uniform mean flow and (ii) the exact shape of the CROR hub, were accounted for.

A computation method was applied to extrapolate near-field acoustic data of CRORs to the far-field and is based on a mathematical description of CROR rotor-alone and interaction tones (see Figure 11 for an example of far-field extrapolation).
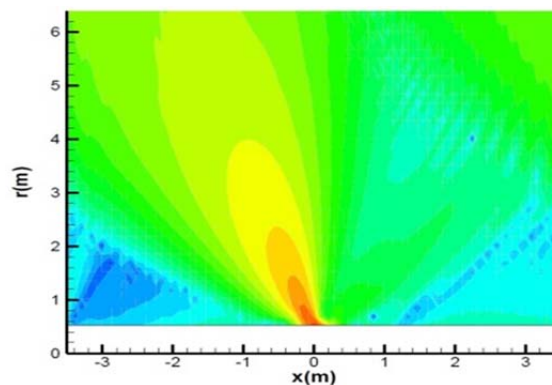

Figure 11. Far-field Directivity of the Front rotor BPF tone

A study on the sensitivity of near- to far-field extrapolations on the CROR source balance highlighted the necessity to determine the balance between steady loading and steady thickness noise so that the correct extrapolation procedure is used.

Adaptation of SOPRANO for en-route noise applications

SOPRANO is an aircraft noise prediction code originally developed in the SILENCE(R) project, that is now being been used in EU-funded projects as a common prediction platform.

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[2] N. Peake and W. Boyd, "Approximate Method for the Prediction of Propeller Noise Nearfield Effects," Journal of Aircraft, vol. 30, no. 5, 1993.

[3] H. Brouwer, "Analytic description of the noise radiation from single and contra-rotating propellers," pp. 1-6, 2010.

SOPRANO has been enhanced with additional capabilities so as to enable the prediction of single event noise level on the ground, generated by CROR in en-route conditions:

- Inclusion of new noise metrics, relevant for en-route noise impact
- Implementation of long range propagation models
- Adaptation to tonal character of CROR noise

<u>CROR en-route noise level predictions (single event)</u>

Experimental data points from the far-field source noise database derived earlier, were matched with corresponding CROR operating conditions for a number of points on a realistic CROR aircraft flight trajectory (Figure 12). The processed acoustic data from these points was fed into the whole aircraft noise prediction code SOPRANO and en-route noise levels at ground level were calculated.
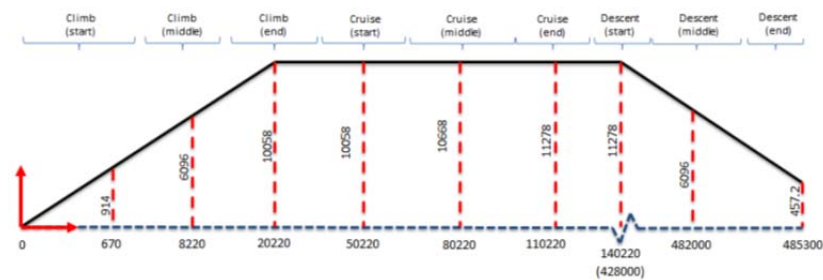

Figure 12 : Flight Trajectory for CROR Aircraft

Since these calculations do not take installation effects into account, a second study was performed by including the additional noise source which is produced by the interaction of the wake from an upstream pylon with the front rotor of the CROR engine.

A parametric study was conducted to investigate the effects of CROR design, operation and atmospheric propagation on the en-route noise produced by a CROR aircraft. It was shown that significant reductions in en-route noise can be obtained by improvements in CROR design and operation.

The work performed successfully addressed Challenge 2:

A tool chain to predict CROR en-route noise levels on the ground is now available

2.3. Challenge 3: Assessment of en-route noise impact

In order to assess the viability of CROR aircraft as far as en-route noise is concerned, the noise impact has to be assessed. The single event noise levels provided by the tools developed as part of Challenge 2 constitute a necessary element, but the noise impact must be considered in a wider context. Aircraft when en-route will fly over highly populated areas (e.g. agglomerations), but also over much quieter areas (e.g. national parks); the en-route noise levels will be perceived in a different manner in these different areas. The impact model has to be able to address these specific characteristics of en-route noise.

Development of en-route noise impact model

Based on an extensive literature review a list of metrics, relevant for en-route noise, was elaborated.

The development of the noise impact model consisted of three main parts:
- Air traffic model
- Noise model
- Scenario generator

For the air traffic model operational data was obtained for Spain, Netherlands and Romania, 3 countries with significantly different topography and population densities, representative for different areas in Europe. For the latter country actual radar data was provided by ROMATSA, whereas for the first two countries ADS-B receivers were used. The air traffic model consists of a database, representing a 3D grid with cells. For each movement, relevant data (aircraft id, geometrical info, etc) is stored for each of the cells through which it passed.

The noise model is based on a 2-D grid, fixed to the ground and compatible with the abovementioned traffic grid and also with the background noise grid determined in the EASA BANOERAC project. For each movement in each cell of the traffic grid, the distance to each observer cell (within 20km distance) is calculated. From the noise-distance relationship provided by BANOERAC (for turbofans), from the measurements of turboprops (see hereafter)) or from the predictions of SOPRANO (for CROR), the relevant single event metrics can then be determined for each operation.

One of the specific issues of en-route noise was found to be the significant scatter observed from measurements. An important part of this scatter is attributed to variations in the atmospheric propagation over the large distances involved. The engineering model developed for Challenge 1 has been implemented in the impact model to account for this in a pseudo-random manner.

This procedure is then repeated for each of the operations defined in the air traffic scenario. For each cell of the receiver grid the contributions of all single events within it are then combined so as to obtain the overall noise metrics.

The Scenario Generator module was developed in order to be able to insert a certain amount of CROR aircraft into the air traffic. To this end typical Short-Medium Range Aircraft in the

fleet are substituted by 2012 generation CROR equipped aircraft. However, since it is unknown which of the operations in the traffic model would be replaced by CROR, a random substitution is performed. In order to avoid biased results, also with respect to the uncertainties due to atmospheric propagation as mentioned above, it was shown that after averaging 10 random simulations a stable value is obtained for all relevant metrics.

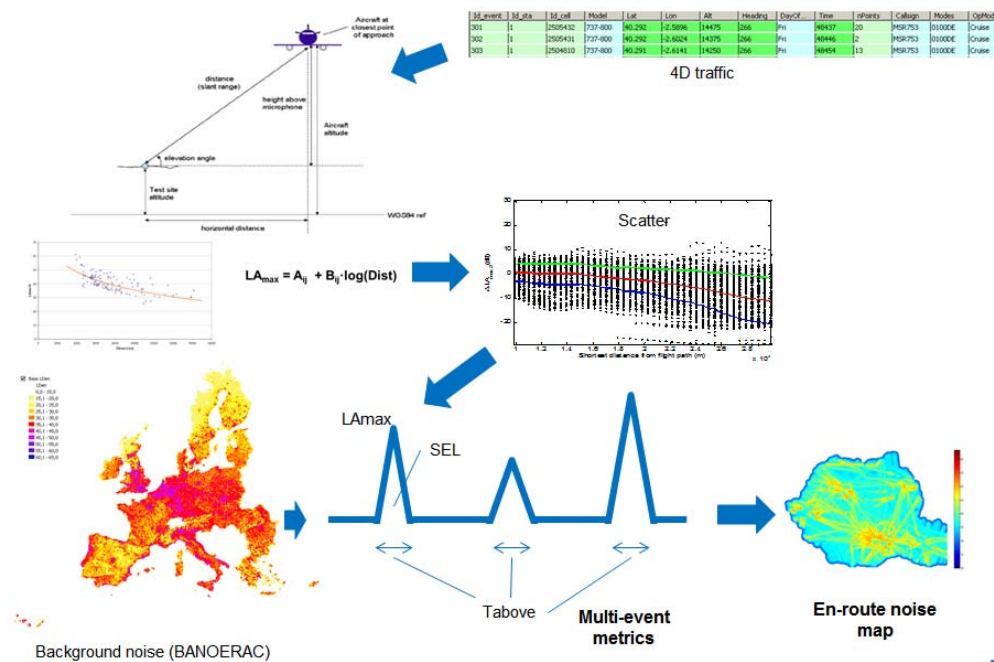A schematic overview of the en-route noise model is provided in Figure 13.

Figure 13: Schematic overview of the en-route noise model

Measurements of en-route noise of heavy turboprop

The EASA BANOERAC study provides a comprehensive database of en-route noise of current jet aircraft. Although very extensive, this database is lacking sufficient information on heavy turboprop en-route noise. In order to fill this gap, measurements of en-route noise of heavy turboprop aircraft were performed in NINHA in a similar manner to that done in BANOERAC. Since the Romanian flag carrier TAROM operates a significant fleet of ATRs these measurements were performed in Romania. Based on the measured data an empirical noise model could be derived for heavy turboprops (Figure 14). It can be observed that the cruise noise levels of heavy turboprops are significantly higher than those for turbofan aircraft.
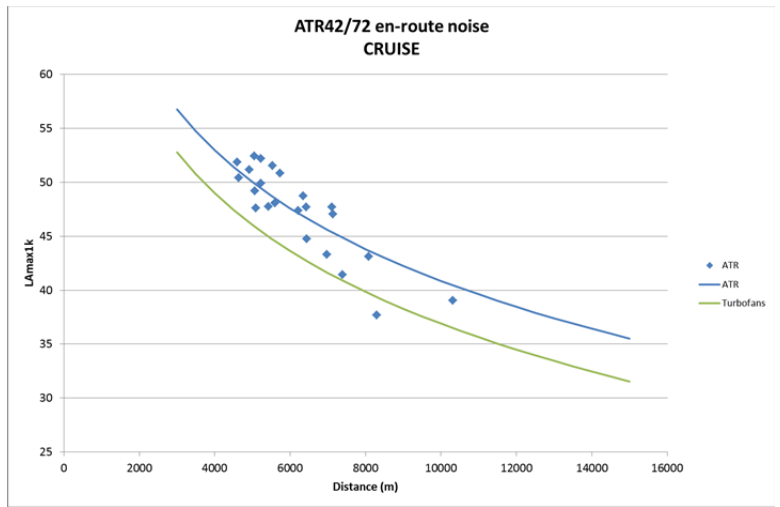
Figure 14. Measured data and empricial model for heavy turboprops in cruise.

Calculation and assessment of CROR en-route noise

The impact model has been executed for a variety of traffic scenarios, simulating different fleet compositions (aircraft/engine configurations, including different shares of CROR). The introduction of CROR was simulated in four scenarios:
- 0%CROR → baseline
- 25% CROR
- 50%CROR
- 100%CROR

Each of these scenarios represents the percentage of substitution of medium range aircraft (MR2) by CROR. In a first step the en-route noise maps were determined for the various scenarios (see Figure 15 for an example).
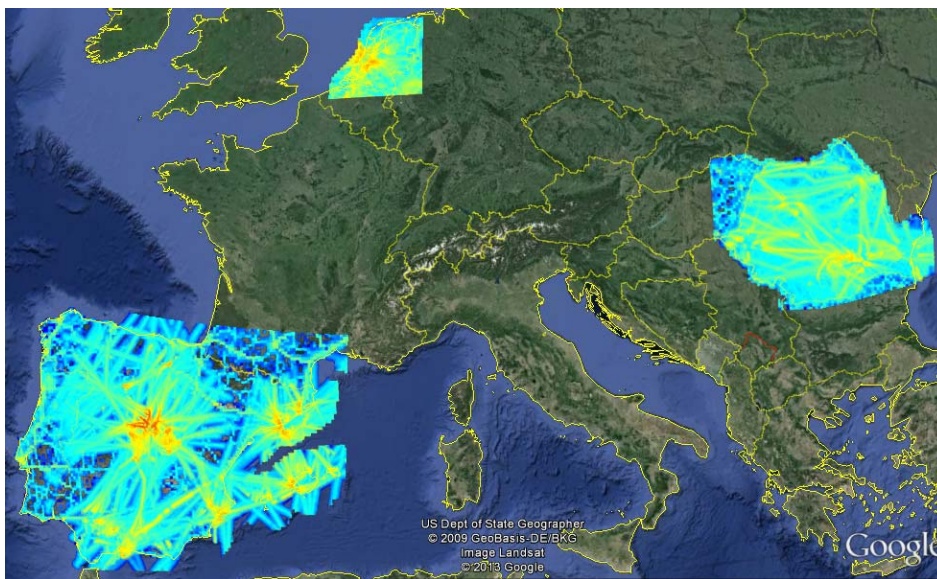

Figure 15: Example en-route noise maps for Netherlands, Spain and Romania

Although the en-route noise maps provide an understandable and visually attractive means of presentation of the en-route noise for a single scenario, its format is not appropriate to compare different scenarios. Therefore several additional methods have been explored to provide insight in the changes in noise impact due to the introduction of certain shares of CROR in the aircraft fleet. Each tool provides a partial indication of the effect of introduction of CROR into the aircraft fleet. No single indicator could be defined to cover all aspects of en-route noise impact.

The calculation results have been presented and discussed in a final workshop with international experts, contributing to the assessment of the en-route noise of CROR. Consensus was reached on the following main conclusions:

The NINHA project has established that at cruise the noise of Contra Rotating Open Rotors with today's technology will be significantly reduced from that of the UnDucted Fan of the 1980s. The maximum noise level (when the aircraft is overhead) will be equivalent to that of today's TurboProps. Further reductions in Open Rotor noise are expected to be forthcoming before they enter service in the late 2020s

The impact model was fully developed for three "test" countries for which traffic data was available (Spain, Netherlands, Romania). This allowed preliminary investigation of a series of representations and metrics. The project partnership welcomed these successful developments and felt that more work would be needed to clarify the usage conditions of such tools (such as identification of acceptability criteria, quantification of uncertainties,…)

In a complementary approach, this assessment also provides recommendations for future work aimed at addressing beyond the NINHA achievements the issues, shortcomings, gaps and needs identified with respect to the development of a fully effective predictive framework aimed at en-route noise impact assessment.

Liaison with rulemaking authorities

Currently, the issue of en-route noise is not included in the workprogramme established towards the next CAEP plenary meeting (CAEP/10, February 2016). However, in the previous CAEP cycle, the question was referred by the Working Group 1 (Noise Technical) Rapporteurs to the Independent Experts Panel (IEP2) involved in the 2nd ICAO Noise Technology Review. The IEP2 predictive assessment presented at the CAEP/9 meeting (WP/16, February 2013) appears to be in line with the findings of NINHA for the CROR 2012 generation.

Following recommendations made during the NINHA final workshop, including EASA's feedback, it has been decided to provide an information paper at the occasion of the next CAEP Working Group 1 meeting (May 2014), within the framework of its Technology Task Group. This paper will in particular put forward the elements of conclusion described above.

The work performed successfully addressed Challenge 3:

A model to assess ground noise impact of CROR re. conventional powerplant is now available

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3. Potential impact and main dissemination activities and exploitation results

3.1. Potential impact

The novel engine architectures based on CROR concepts provide 10-15% reductions in the specific fuel consumption compared with turbofan engines of equivalent technology, but their noise remains an important issue around airports as well as potentially en-route. The project assessed if the en-route noise impact is acceptable for aircraft with 2012 technology CROR engine configurations.

Relatively little research had been conducted on en-route aircraft noise since the 1990s. To address this shortfall, NINHA developed a complete tool chain enabling the calculation of en-route noise as received on the ground, and generated by a fleet of aircraft/engine combinations, including CROR. NINHA demonstrated that it is possible to calculate a variety of metrics, related to community annoyance. During the project, however, it became clear that a knowledge gap exists with respect to acceptability criteria.

Previous studies have demonstrated that en-route noise could be a potential problem, and that risks could be difficult to control due to the variations in meteorological conditions, but these conclusions have been reached based on limited data for old designs. Furthermore an ICAO report in 2007 concluded that annoyance is due to the cumulative impact of a large number of over flights rather than to the level of noise of a single flight. NINHA demonstrated that it is possible to take into account uncertainties in the assessment process.

NINHA provided valuable data that will inform the technical discussions that will be continued beyond Europe to get an international consensus on the understanding of en-route noise and its annoyance impact. This could result in new standards and certification processes.

3.2. Main dissemination activities and exploitation results

The project developed three types of results:
- Knowledge and capabilities such as computation models and experimental processes enabling assessment of aircraft en-route noise impact
- Data from measurements and computations allowing assessment of the en-route noise impact of specific aircraft fleets
- Assessments and Management Guidelines for potential annoyance resulting from high altitude operations of future airplanes.

The first two types of results have been and will be disseminated mainly through presentations and contributions to scientific workshops and conferences.

Beyond this, the NINHA results will contribute to the discussions on the need to develop new advisory material and/or standards regarding the noise impact from aircraft high altitude operations. To this end a specific dissemination is required to relevant policy and rulemaking bodies. These bodies include but may not be limited to EASA, ICAO Committee of Aviation Environmental Protection (CAEP) and ECAC. A dedicated workshop has been organised at the end of the project, involving main international experts and stakeholders, initiating this process.

4. Contact details

For further information on NINHA please contact the Project Coordinator:

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