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

Nico VAN OOSTEN[1]; Dominique COLLIN[2]

[1] Anotec Engineering, Spain

[2] Snecma, France

ABSTRACT

The potential introduction of aircraft fitted with advanced counter-rotating open rotor (CROR) engine power plants should 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, could be considered 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 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

This paper presents the main results of NINHA and gives recommendations for future work on CROR en-route noise.

Keywords: Open rotor, CROR, en-route noise, aircraft noise I-INCE Classification of Subjects Number: 13.1

1. INTRODUCTION

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 have not been not standardized and the ability to predict en-route noise so far quite limited. NINHA addressed this limitation.

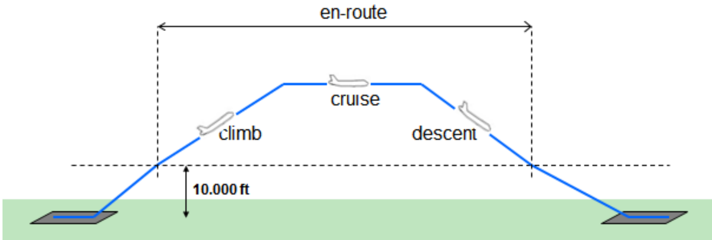

Figure 1 - Definition of “en-route”

[1] nico@anotecengineering.com
[2] dominique.collin@snecma.fr

The project was organized 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, including turboprops

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 had to be 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. 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 then 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 had to be 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 (varying CROR share). Communication of the project results to rulemaking bodies was also addressed.

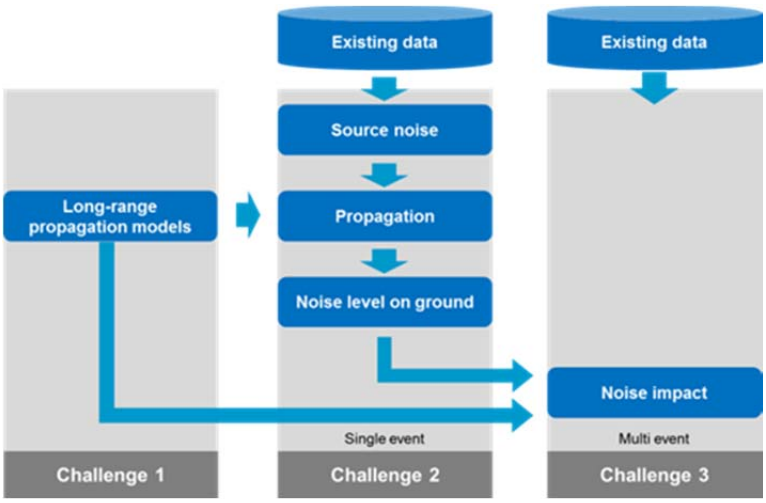

Figure 2 - NINHA main challenges and related project structure

2. DESCRIPTION OF KEY TECHNICAL ACHIEVEMENTS

2.1 Challenge 1: Long-range propagation modeling

2.1.1 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 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.

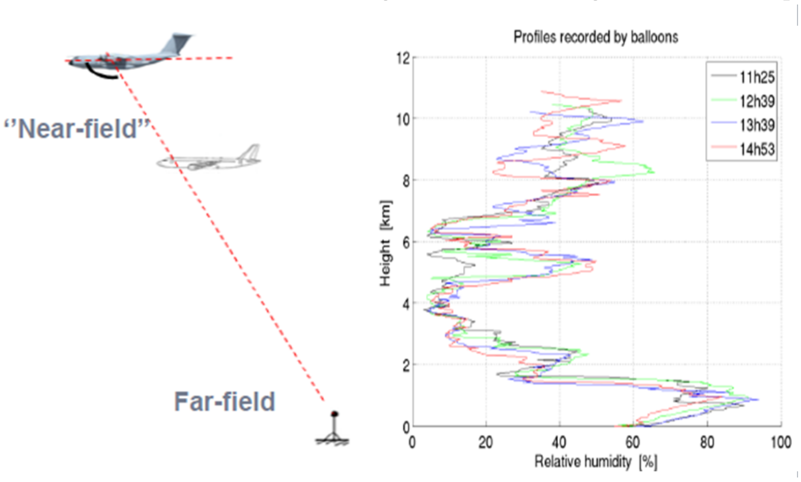

Figure 3 - A400M flight test

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.

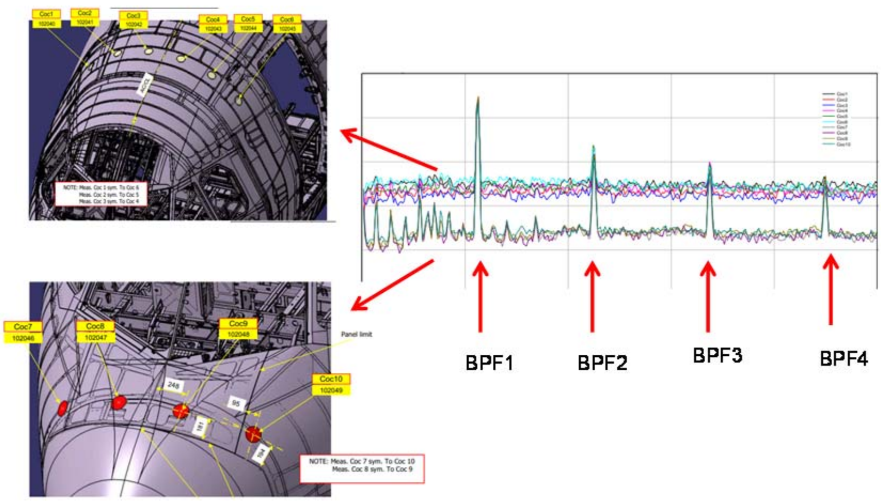

Figure 4 - Near-field measurement results

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.

2.1.2 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 minimize 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. Validation of these methods was done against the measured data from the A400M flight test (Figure 5).

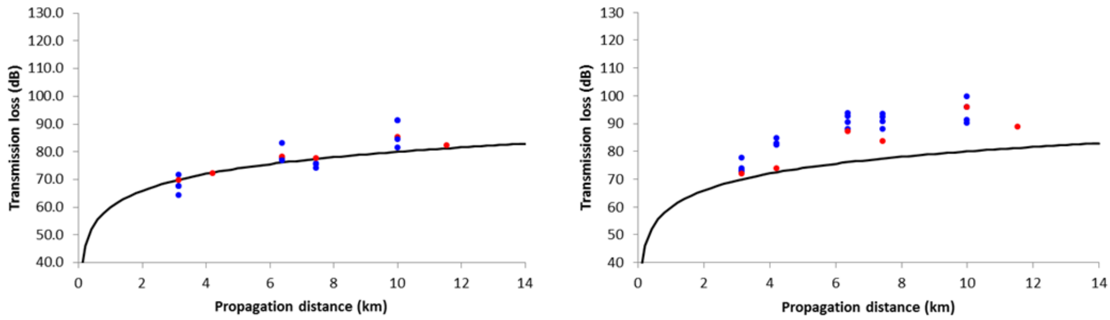

Figure 5 - Predicted (red) vs measured (blue) Transmission loss for 1 BPF (left) and 2 BPF (right)

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

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 6).

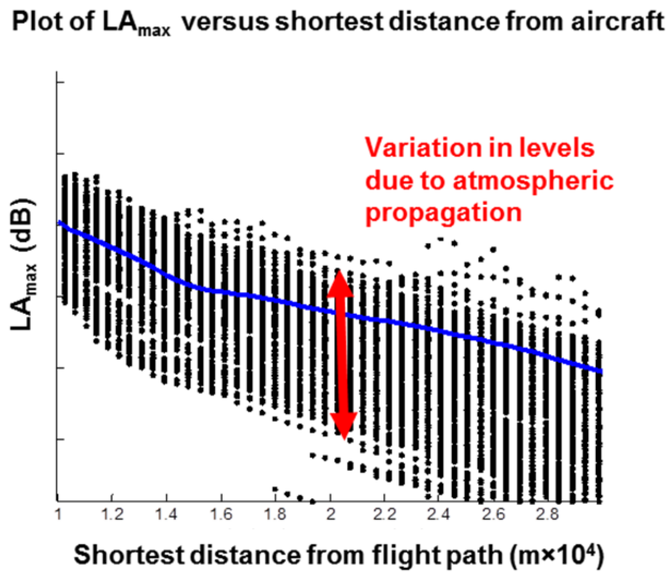

Figure 6 - Variation in ground noise levels due to atmospheric propagation

2.2 Challenge 2: CROR en-route noise levels

2.2.1 CROR source noise data

A large experimental database of near-field CROR noise, obtained in earlier research projects (DREAM, Clean Sky), was exploited (Figure 7).

Figure 7: 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 8).

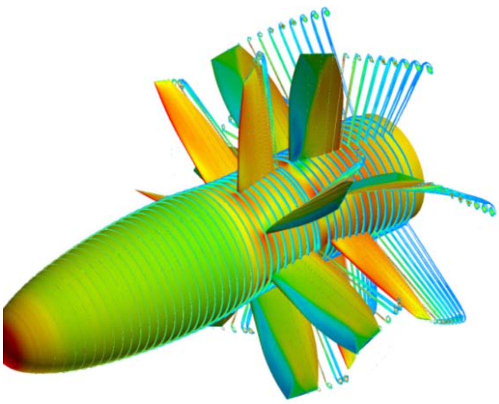

Figure 8. CFD simulation of CROR

2.2.2 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 (1), is very robust but potentially not as accurate as the second, based on a method developed by Brouwer (2). 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 9 for an example of far-field extrapolation).

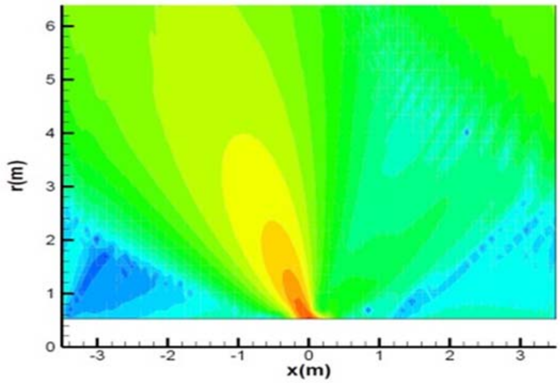

Figure 9 - Far-field Directivity of the Front rotor BPF tone

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.

2.2.3 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. 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

2.2.4 CROR en-route noise level predictions (single event)

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 10). 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.

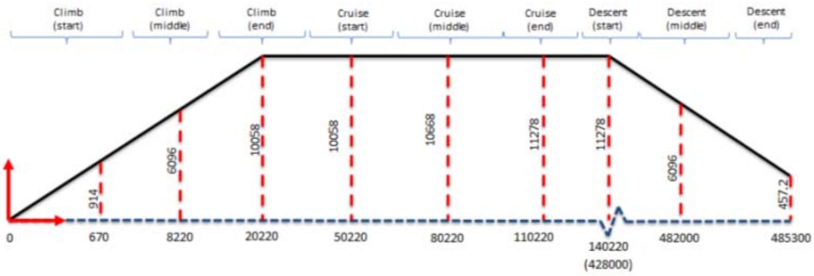

Figure 10 - Flight Trajectory for CROR Aircraft

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.

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.

2.3.1 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 11.

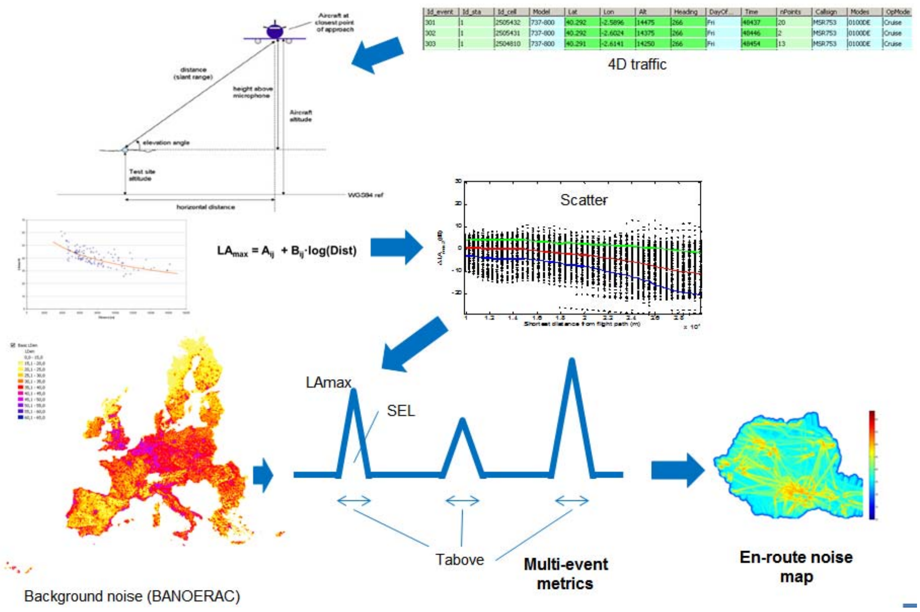

Figure 11 - Schematic overview of the en-route noise model

2.3.2 Measurements of en-route noise of heavy turboprop

The EASA BANOERAC study (3) 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 (4). 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 12). It can be observed that the cruise noise levels of heavy turboprops are significantly higher than those for turbofan aircraft.

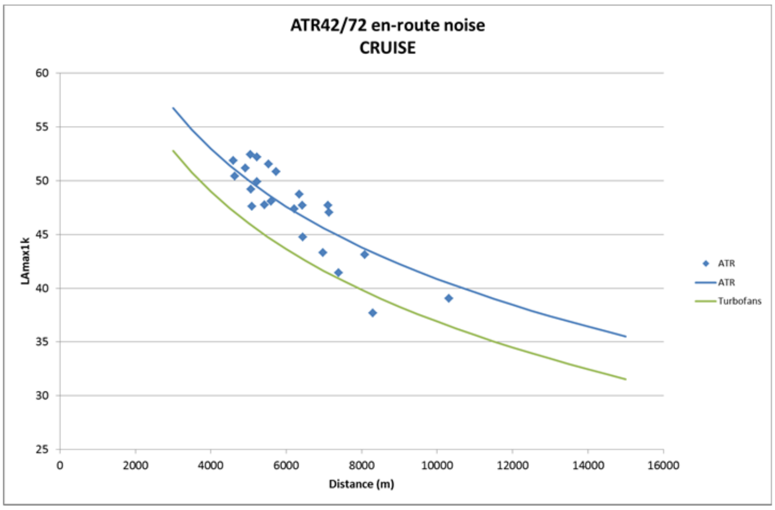

Figure 12 - Measured data and empirical model for heavy turboprops in cruise

2.3.3 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%, 50% and 100% CROR.

Each of these scenarios represents the percentage of substitution of medium range aircraft by CROR. In a first step the en-route noise maps were determined for the various scenarios (see Figure 13 for an example).

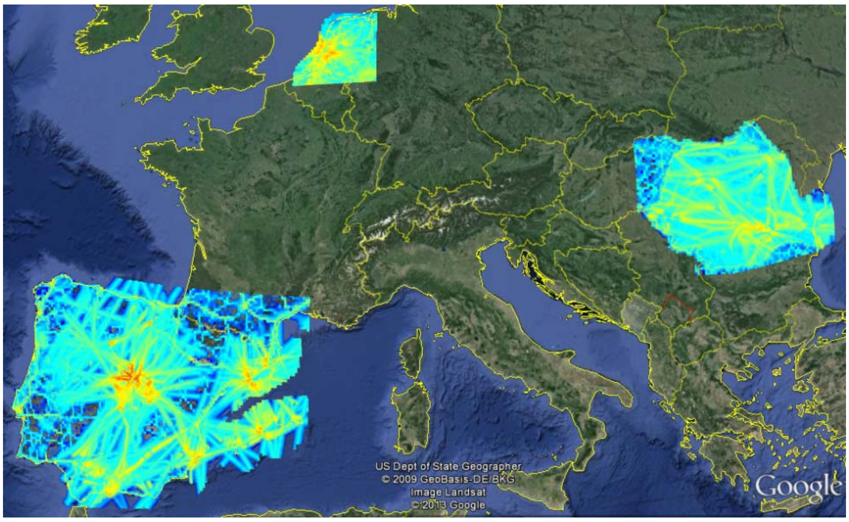

Figure 13 - Example en-route noise maps for Netherlands, Spain and Romania

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.

3. CONCLUSIONS AND IDENTIFICATION OF FUTURE RESEARCH PRIORITIES

Based on improved long-range propagation models and 2012 CROR technology capabilities, an updated vision statement on en-route noise levels of CROR configurations has been put in perspective with respect to initial efforts carried out around 1986-1988 by NASA and the industry as well as the recent assessment carried out by the CAEP 2nd Independent Experts panel.

This has been made possible thanks to a key NINHA achievement, in the form of a single-event prediction tool chain covering CROR configurations, current TurboFans and TurboProps:

- The exploitation of the most recent high speed wind tunnel data representative of “2012 CROR technology” coupled with improved long distance propagation models validated by means of a dedicated noise fight test performed on the A400M has allowed to develop a single event en-route noise prediction model for CROR configurations.
- The EASA BANOERAC study, performed in 2009, provides a comprehensive database of en-route noise of current jet aircraft. This database is EASA property. EASA confirmed that the database could be used in NINHA for the purpose of developing a TurboFan en-route noise model
- A TurboProp en-route noise prediction model was fully developed based on a series of dedicated measurements performed within the project.

Through use of these three complementary prediction models, a comprehensive picture of single event en-route noise levels has been established for:

- 2012 Technology CROR engines fitted on a typical Short-Medium Range Aircraft
- Average current TurboProps (also called Gen. 2 in reference to the previous TurboProp technology assessed in the original FFA en-route study from 1984 (5))
- Average current TurboFans (all aircraft types)

On a single-event noise levels basis, , 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

In a complementary approach, recommendations for future work aimed at addressing beyond the NINHA achievements the issues, shortcomings, gaps and needs identified have been formulated. Their aim is to facilitate the development of a fully effective predictive framework aimed at en-route noise impact assessment. The following activities are recommended through research framework and transatlantic collaboration:

- Benchmark of US-EU propagation models
- Assessment of uncertainties for all steps of predictive process
- Altitude reference acoustic source experiment
- Investigation of acceptability criteria
- Definition of standard atmospheric profile
- Further exploitation of BANOERAC and NINHA TurboProp data bases

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under Grant Agreement nº 266046.

REFERENCES

1. N. Peake and W. Boyd, “Approximate Method for the Prediction of Propeller Noise Near-field Effects” Journal of Aircraft, vol. 30, no. 5, 1993
2. H. Brouwer, “Analytic description of the noise radiation from single and contra-rotating propellers,” pp. 1-6, 2010.
3. http://easa.europa.eu/document-library/research-projects/an074-banoerac
4. L. Hossu and N. van Oosten, "Measurement of en-route noise of heavy turboprops", Euronoise Prague 2012
5. M. Linde et.al., "Measurement of noise from aeroplanes travelling at heights 3500-11000m", FFA TN 1986-21, March 1986