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NEEDED

Next-generation data-driven reference European models and methods towards silent and green aircraft operations around airports

Horizon Europe | HORIZON-CL5-2022-D5-01-12

Preliminary methodology for customizing NPD tables and preliminary NPD tables for near-future aircraft technologies

This project receives funding from the European Union's Horizon Europe research and innovation programme under grant agreement no. 101095754 (NEEDED).

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2 PROJECT ABSTRACT

NEEDED responds to the second and third bullets of the “expected outcome” of the HORIZON-CL5-2022-D5-01-12 topic, delivering the next generation data-driven reference European models and methods to estimate present and future aircraft emissions (pollutants and noise), achieving TRL 4 at the end of the project. To do so, NEEDED will advance the state of the art by:

- improving the accuracy of the reconstruction of aircraft operations by using real-world ADS-B data,
- advancing emission inventories for current and future aircraft technologies, while delivering more accurate pollution dispersion models,
- extending the applicability of the ECAC Doc. 29 noise model towards future aircraft technologies,
- performing more accurate estimation of the number of people affected by local air transport operations by using dynamic population maps.

These activities are complemented by (i) local air quality (LAQ) and experimental noise measurements performed at Rotterdam The Hague Airport and Larnaca Airport, (ii) validation of the NEEDED toolchain in a 30-week pilot study involving three airports, and (iii) delivery of a methodology to optimize the flight patterns for minimum detrimental impact on the population in present and future scenarios. The project aims to function as a technology enabler, laying the methodological groundwork for facilitating the entry into service of transformative aircraft technologies while capitalizing on the potential of ADS-B data. The enabler role of NEEDED to the future Air Traffic Management (ATM) regulation and policies is facilitated by the direct involvement of EUROCONTROL.

The consortium combines a wide portfolio of competences from 11 partners from 8 different EU member states (Austria, Belgium, Italy, Sweden, The Netherlands, France, Spain and Cyprus) plus 1 non-EU Country and it is coordinated by AIT Austrian Institute of Technology. NEEDED is scheduled to run from January 1st, 2023, to December 31st, 2026, for a total duration of 48 months and has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement no. 101095754. A full list of partners and funding can be found at: https://cordis.europa.eu/project/id/101095754

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3 LIST OF ABBREVIATIONS

Acronym / Short Name	Meaning
NPD	Noise-Power-Distance
RTHA	Rotterdam The Hague Airport
NMT	Noise Monitoring Station
ANP	Aircraft & Performance
BPF	Blade Passage Frequency

4 EXECUTIVE SUMMARY

This report expands on a preliminary methodology towards increasing the accuracy of modelled noise predictions, creating a robust workflow such that the best available source for each of the key inputs (mainly distance and thrust) is used. This approach also facilitates updates to the Noise-Power-Distance tables. This deliverable presents the preliminary work conducted by TU Delft in collaboration with partners RTHA and ANOTEC in response to Task T4.1 - Noise measurements and the development of innovative analysis techniques and T4.2 - Constructing new parameterized NPD model with trajectory and noise data for future aircraft technologies. Within T4.1, the section 5.2 of this report describes the first version of the methodology to obtain the most accurate model input. This methodology is applied to a first set of measurements performed near RTHA to verify the predicted noise levels with the current Doc.29 method. This is followed by proposing a measurement-based method for quantifying the attenuation caused by interference due to the presence of the ground in section 5.3. T4.2 is elaborated in section 6. The different approaches that can be taken toward constructing a new parameterized NPD model with trajectory and noise data for future aircraft technologies are proposed.

5 NOISE MEASUREMENTS AND THE DEVELOPMENT OF INNOVATIVE ANALYSIS TECHNIQUES

5.1 CASE STUDY – RTHA

5.1.1 Air traffic

The average number of passenger flights running per month is 1600, 70% of which are of aircraft type Boeing 737-NG, and 75% of the flights are run by TRANSAVIA airline. The three aircraft types investigated in this project are Embraer 190, Boeing 737-700, and Boeing 737-800.

5.1.2 Status of Noise Monitoring Stations

Rotterdam The Hague Airport has six noise monitoring stations (NMTs) around the airport, as seen in Figure 1. However, most of them cannot be used to obtain sufficient spectral information and noise levels. This is due to their locations near high-road traffic or residence regions. The only appropriate NMT that has been investigated is highlighted in red and white circles in Figure 1.

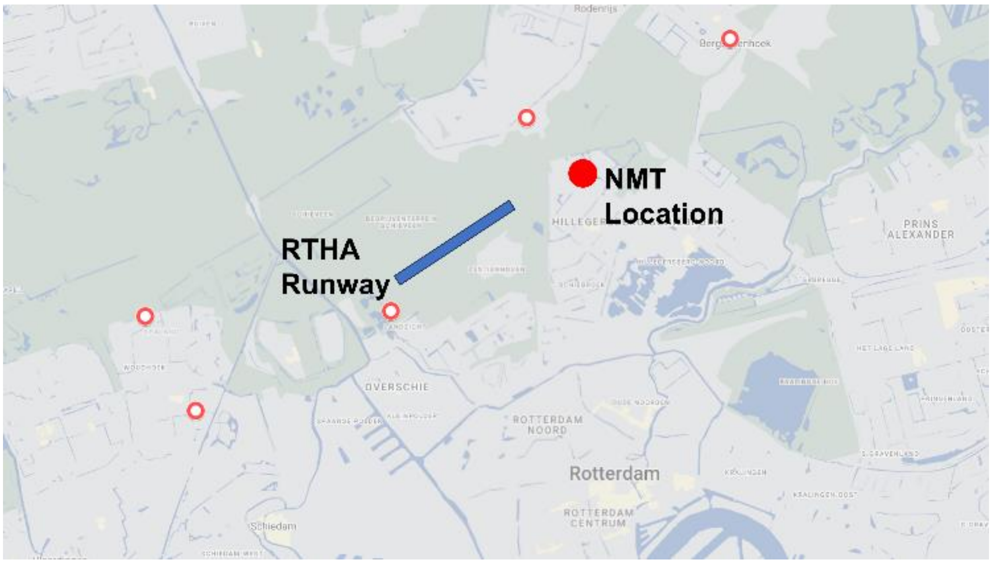

Figure 1 Noise Monitoring Stations around RTHA.

5.2 METHODOLOGY FOR OBTAINING KEY INPUTS

To improve and extend the prediction capabilities of Doc.29, the assumptions made must be verified, and the input must be validated and updated. The input consists of the distance between the aircraft and the receiver position, the angles of the aircraft towards the receiver position, and the aircraft thrust. This input is typically obtained from the Aircraft Noise and Performance (ANP) database. In addition, the ANP database contains the so-called Noise-Power-Distance (NPD) tables. These tables list noise levels as a function of thrust and distance between the aircraft and the receiver. So the ANP database allows for predicting noise levels for predefined procedures with specified aircraft locations and thrust. The NPD tables are curated and extrapolated for a cluster of similar aircraft types based on measurements taken during the aircraft certification process at various standard operation stages and atmospheric conditions.

When validating the Doc.29 predictions, it is important to ensure that the model input, i.e., power and distance, is accurate. The assumption of standard procedures can, therefore, not be made, and as such, the profiles from the ANP database cannot be used. Therefore, as shown in Figure 2, a robust workflow for obtaining accurate input for predicting single-event noise levels is established. For this phase of the project, a preliminary test campaign has been carried out, using two types of noise measuring equipment in addition to the noise monitoring station (NMT). These are a Munisense microphone and an acoustic microphone array, shown in Figure 3. The radar and ADS-B data are used to determine the distance between the aircraft and the measurement station. To retrieve the thrust settings, use is made of the measurements taken by the acoustic array.

The noise levels measured during a measurement campaign around Rotterdam The Hague Airport (RTHA) are compared with the predicted values. Furthermore, the applicability of the noise-measuring setups toward model-data comparisons for future steps is determined through qualitative and quantitative comparison.

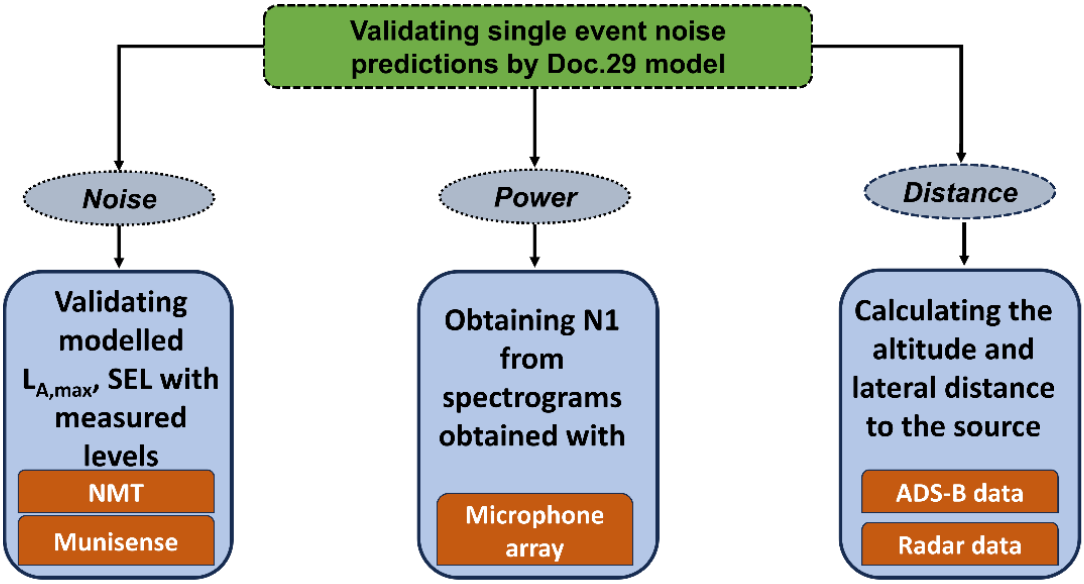

Figure 2 Each Key input, i.e., noise, power, and distance, is validated with measurements from different setups.

Figure 3 Munisense microphone (left) and 64-mic phased array (right).

5.2.1 Power

The engine setting required for noise prediction is the thrust setting or its related normalized fan rotational speed. Employing the equations given below the N1% is calculated from the fan's Blade Passing Frequency (BPF). The BPF and its higher harmonics are detected from spectrograms obtained from the microphone array [1] acoustic measurements.

$$n = 60 * \frac{BPF}{B}$$

$$N1\% = \frac{n}{n_{\{max\}}}$$

where *B* is the number of blades in the specific fan, *n* (rpm) is the fan rotational speed, and $n_{\{max\}}$ (rpm) is the maximum permissible rotational speed of the fan at 100% N1.

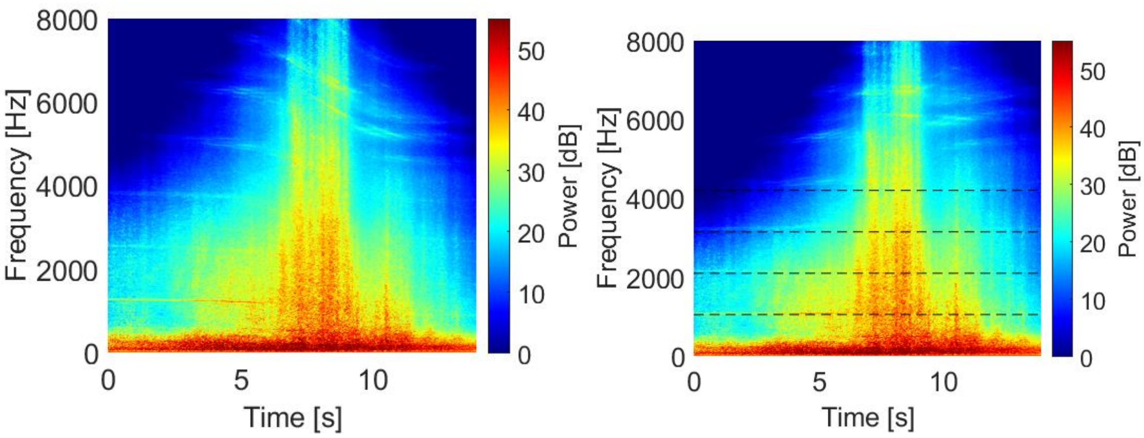

Figure 4 Intensity-averaged spectrograms of the landing of B737-700 without Doppler correction (left) and with Doppler correction (right), where dashed black lines represent the BPF and higher harmonics.

The spectral information is computed by averaging the power spectral densities as a function of time as calculated for selected microphones. For calculating the spectrograms, 5000 sampling points are taken per time block, and Hamming windowing is applied. The spectrograms for all the flyovers are studied, and since no significant spectral information in the range of 8 - 22 kHz is observed, only harmonics up to 8 kHz are considered. They are indicated by the dashed vertical lines in the right plot of Figure 4 where the BPF and its multiples/harmonics are shown. Typically, the presence of harmonics increased the accuracy of the BPF estimates. Once the N1% values are retrieved for the measured flyovers, the thrust of the aircraft can be derived to get the required input for the Doc.29 model. For the conversion of N1% to thrust, this research assumes a quadratic relation between the percentage of maximum rotational speed and the percentage of maximum thrust.

5.2.2 Distance

While investigating methods for improving each of these key input parameters, the accuracy and availability of the distance input is studied. Recognizing the necessity for having positional data of an aircraft for improved air traffic management, it is nowadays required for most aircraft to be equipped with an Automatic Dependent Surveillance Broadcasting System Out (ADS-B Out) [2]. ADS-B Out is a surveillance technique that broadcasts the identity of the aircraft and its position, determined by the Global Navigation Satellite System (GNSS), to ADS-B signal receivers set up on other aircraft and on the ground within a given range. The ground stations then transmit the signals to a surveillance processing unit managed by the OpenSky network [3], [4]. The system gives easy access to the positional data for individual aircraft, which is of importance for single--event noise prediction studies such as the work done by [5]. Despite its numerous advantages, there are a few limitations, such as inaccurate information, corrupted position data, or the lack of signal transponders [4]. Hence, it is advisable to create a quick and efficient alternative framework for localizing an aircraft, and one such method is studied. As with most acoustic source localization techniques that use the differences in time-of-arrival of the sound between different microphones in a phased microphone array, the traditional technique of conventional beamforming in the frequency domain (CBF) is applied. It is a robust method that computes the acoustic source levels in a predefined grid [6]; as such, applying an exhaustive search for identifying that location that provides an optimal agreement between measured and modelled differences in time of arrival. In addition to CBF, the global optimization (GO) technique is applied, where an exhaustive search is no longer carried out, but instead, a directed search through the search space is followed.

After retrieving and improving the accuracy of the input parameters, single-event noise predictions for each flyover were conducted. Two of these are shown in Figure 5. Along with the predicted noise levels, the curves exhibit the noise levels measured over a single flyover by the NMT and Munisense. The modeled trends are satisfactory. However, there are differences between the two measurement curves, represented by red and black dashed lines, for lower noise levels. This difference has been attributed to the vastly reduced sample frequency of the NMT (16kHz) compared to that of Munisense (50kHz) and the difference in attenuation due to the ground effect. The attenuation caused by the latter is addressed in the next subsection.

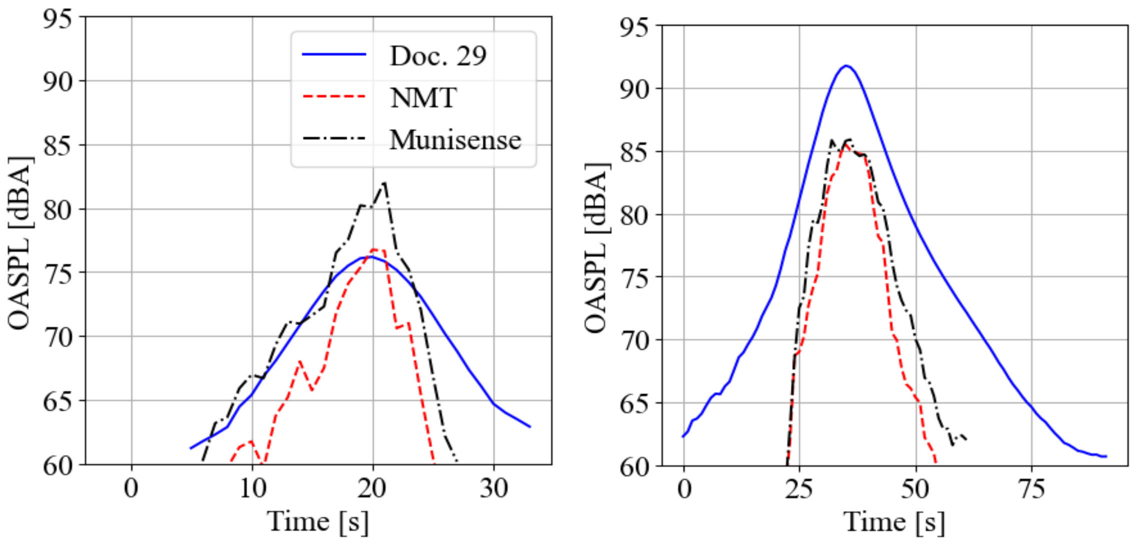

Figure 5 Landing of EMB190 (left) and take-off of B737-800 (right)

5.3 DATA ANALYSIS TOWARDS QUANTIFYING THE NOISE ATTENUATION CAUSED BY THE GROUND EFFECT

The Programme-Based Approach to Measuring Aircraft Noise (PAMV) studies conducted by RIVM reported a good correspondence between the modelled and measured noise levels in regions with L_{den} higher than 50 dB, but increasing differences between model predictions and measurements in low-noise regions [8, 10]. Unlike the noise levels measured in high-noise exposure areas, the agreement in low-noise regions is compromised by low signal-to-noise ratios and increased propagation effects (not fully accounted for in the model). To better allow for a valid comparison of modelled and measured individual flyover noise levels in these regions, it is thus necessary to ensure optimal quality of acoustic measurement conditions. Since the measurements performed for this study are flyover measurements, completely eliminating background noise is not feasible.

Apart from the atmospheric propagation of the noise, another significant physical phenomenon was observed in the acoustic measurements (unless a dedicated measurement configuration is used), i.e., the interference due to the ground effect. Ground effect is due to various acoustic propagation paths (often the direct and ground-reflected path), arriving at the microphone almost simultaneously. The effect of this is visible in the spectrograms of the measurements as wave reinforcement and canceling at certain frequencies [9]. To assess the effect of the ground effect for individual flyovers, the expected ground effect is analytically computed at different heights, 9 m and 1.75 m. Subsequently, the simulated frequency fringes are superimposed on a measurement obtained from the microphone array with no ground effect (beamformed with a focus on the aircraft location). Figure 6 and Figure 7 show the comparison between the measured ground effect and the simulated spectrograms. After matching the fringes, the deltas obtained from the simulated ground effect will be added/subtracted to the final noise levels for each flyover.

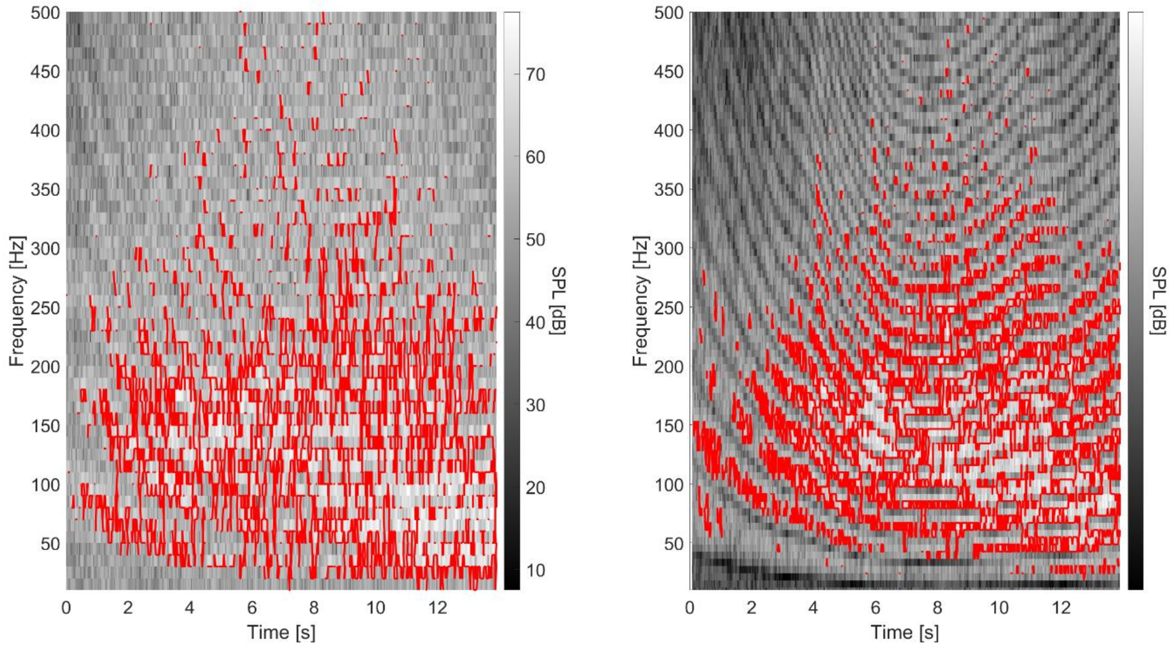

Figure 6 The measured ground effect by NMT set up at 9m height (left) and superimposed ground effect for a take-off procedure of B737-800 (right).

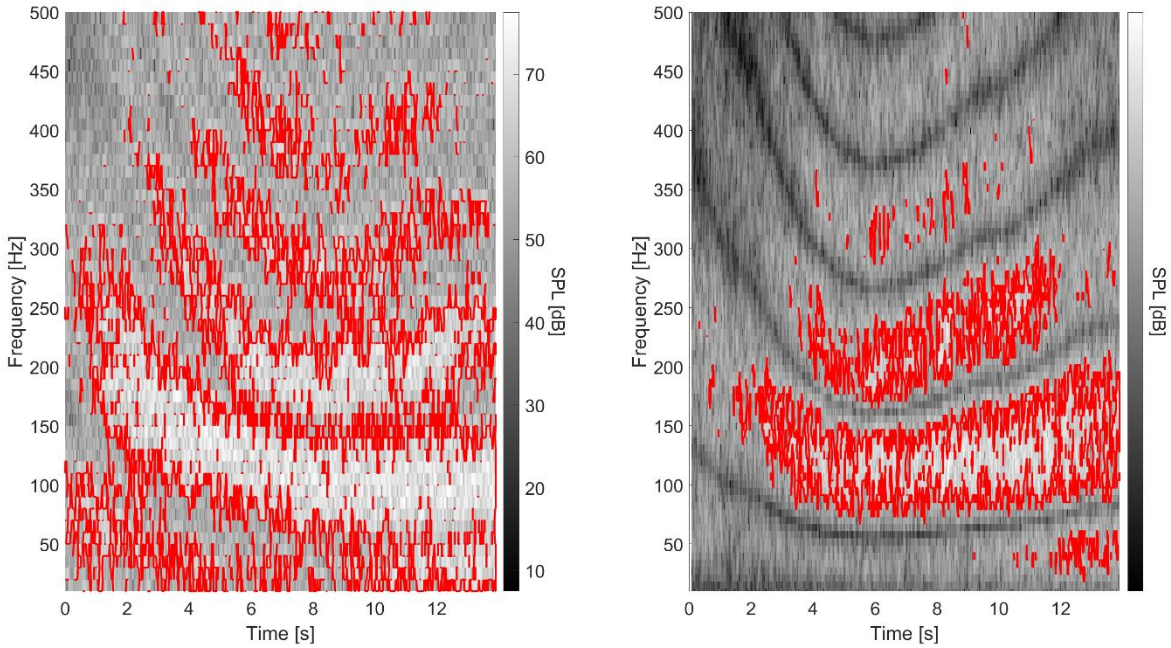

Figure 7 The measured ground effect by NMT set up at 1.75m height (left) and superimposed ground effect for a take-off procedure of B737-800 (right).

5.4 CONCLUSIONS

- Before updating the NPD tables, the noise predictions made by the best-practice model are computed by establishing a smooth workflow of input data. This is done for 3 aircraft types: Embraer 190, Boeing 737-700, and Boeing 737-800.
- Innovative data analysis techniques for reducing background noise and other factors affecting noise levels, such as interference due to ground effect, are studied.
- Predictions will be validated with measurements taken at varying distances to better understand noise propagation for the current aircraft types. After updating the NPD tables for these types of low-noise regions, the knowledge of general trends obtained will be applied to create NPD for future aircraft technologies.

6 CONSTRUCTING NEW PARAMETERIZED NPD MODEL WITH TRAJECTORY AND NOISE DATA FOR FUTURE AIRCRAFT TECHNOLOGIES

In this task a methodology is being developed to generate NPD entries that represent new aircraft configurations (new propulsion systems, new airframe designs, etc.). To be able to predict the noise levels of such future aircraft configurations, several options exist:

1. prediction of the noise from scratch, with existing semiempirical methods that make use of engine and airframe data of the new design
2. generation of NPD levels for the new configuration by means of a noise difference (ΔdB), applied to the NPD values for an existing baseline configuration (such as those derived in T4.1).
3. use of a noise level database, which may come from advanced modelling techniques and/or experimental activities, for each individual noise source, for the engine and airframe separately or the full aircraft. Also engine installation effects (e.g. wing shielding) are considered here.

As a basis, the single event aircraft noise prediction platform SOPRANO, developed by ANOTEC, will be used. A general overview of the SOPRANO platform is given in Figure 8. More details on SOPRANO are provided in Appendix 1.

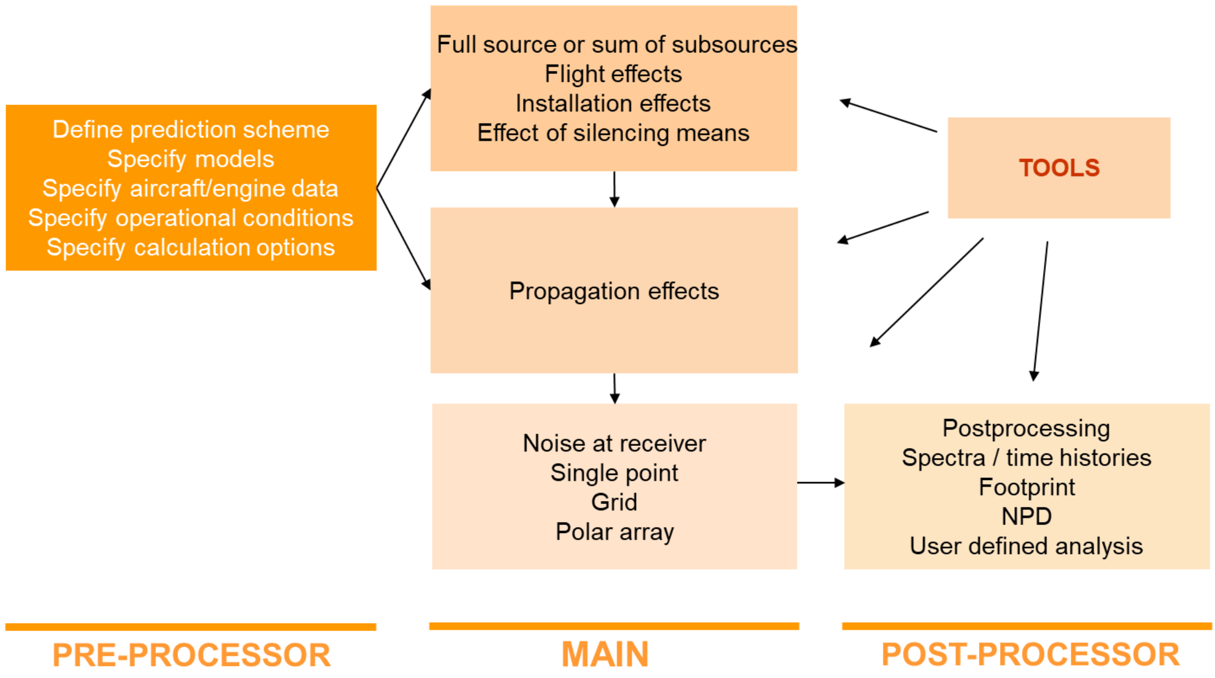

Figure 8 General overview of the SOPRANO aircraft noise prediction platform.

SOPRANO can handle a variety of prediction models, from semi-empirical to lookup tables generated by external advanced computational tools or databases of measured source, component or full aircraft/engine noise (see Figure 9). Deltas can be applied at the different stages so as to simulate the insertion of noise reduction technologies. Propagation and installation effects are applied, after which the noise at observer positions on the ground can be determined.

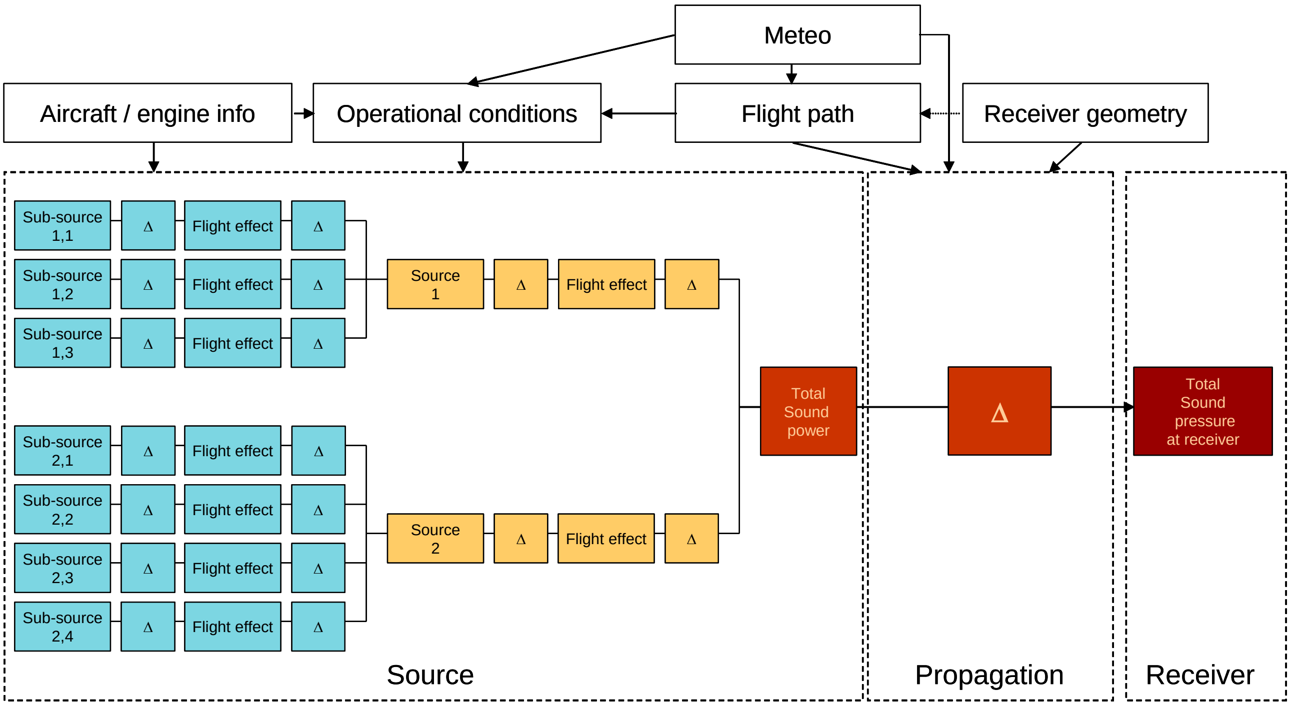

Figure 9 Structure of the MAIN module of SOPRANO.

In the first period of the project, ANOTEC has enhanced SOPRANO, so as to facilitate the noise predictions for any of the three options and any combination of them. A parametric study ("sweep") can be performed on both power and distance, thus enabling the generation of NPDs in a single execution of SOPRANO (see Figure 10).

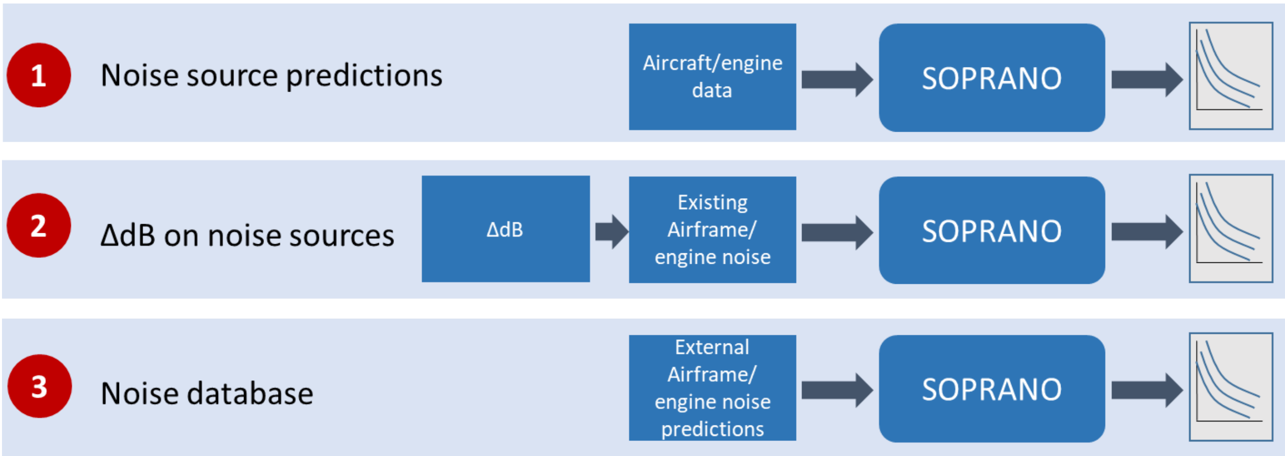

Figure 10 Implementation of the 3 options.

In Figure 11 an example is given of Option 1: Direct noise source predictions with the modules implemented in SOPRANO. As an example of the second option, Figure 12 shows a future aircraft design (Blended Wing Body) for which the installation effects (especially wing shielding) have been calculated with an advanced external tool, providing ΔdB with respect to a baseline aircraft. Option 3 is very similar to Option 1, except that here external databases, created with advanced external tools, are used to predict the noise of the different sources.

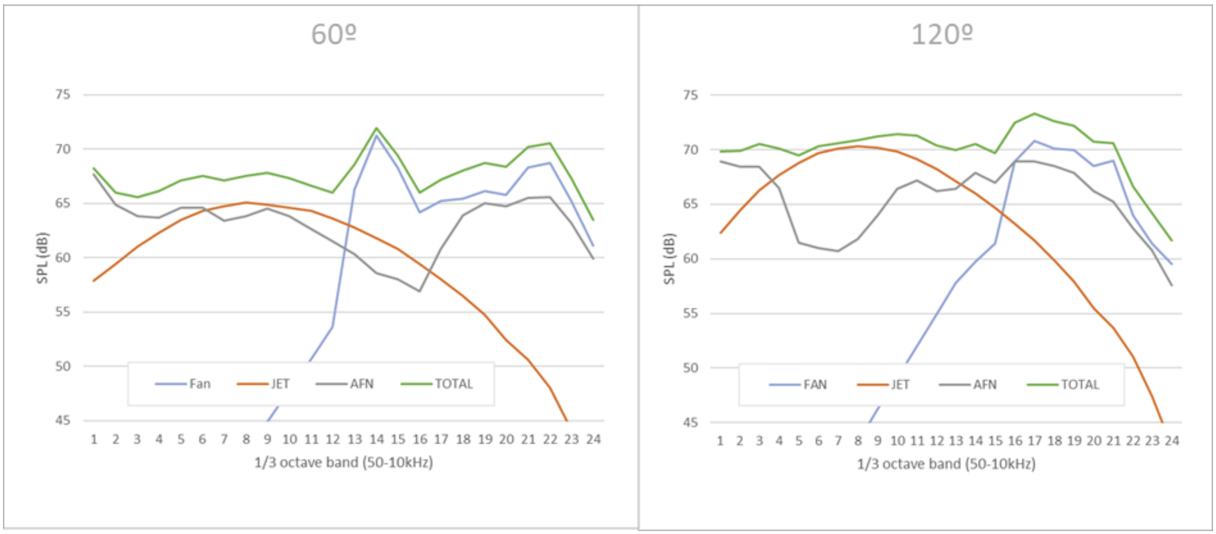

Figure 11 Example of a direct noise source prediction (here for 2 directivity angles).

Figure 12 Future aircraft design with predicted installation effects relative to a baseline aircraft

Some initial predictions have been made with SOPRANO with the mentioned sweep function to generate an NPD. The main objective of this was to verify that the resulting NPDs, calculated by SOPRANO, can be used by ECAC Doc29 compatible airport noise models.

In the second reporting period some future aircraft platforms will be defined for which noise predictions will be made so as to generate the corresponding NPDs. Depending on the available information for these platforms the optimal calculation method (Option 1, 2 or 3) will be selected and used. In addition, the methodology for the determination of the performance database for these future aircraft platforms will be developed. This work will be reported in D4.3.

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APPENDIX 1. DESCRIPTION OF SOPRANO

SOPRANO (Silencer cOmmon PlatfoRm for Aircraft NOise calculations) is a single event aircraft noise simulation model. Originally developed in the EU SILENCER project as a technology evaluator, SOPRANO has been used and extended in a variety of other EU projects. SOPRANO contains a collection of semi-empirical source noise models for all main sources of a conventional jet and propeller aircraft. New methods, sources or engine/aircraft parameters can be easily added. Source noise can also be provided in the form of look-up tables. This allows SOPRANO to take advantage of the results from high-fidelity CFD/CAA tools and measurements to make accurate predictions and to extend its use to e.g. rotorcraft and Open Rotors. Filters can be applied to each noise source, so as to simulate noise reduction technology or to simulate other aircraft configurations.

In order to predict overall aircraft noise levels, the program can perform several different types of calculation. These can be broadly classified as follows:

- Individual noise sources
- Thermodynamic effects on noise sources (atmospheric conditions, altitude)
- Flight effects on noise sources
- Changes (‘deltas’) on noise sources
- Propagation effects
- Noise unit calculations

Noise sources

The semi-empirical noise source prediction methods and propagation methods included in the current version of the program are given in the following table.

Item	Ref.	Title
Jet noise	SAE ARP 876D	Gas turbine jet exhaust noise prediction
	Stone	J.R. Stone, D.E. Groesbeck, C.L. Zola: Conventional profile coaxial jet noise prediction, AIAA Journal (1983)
Core noise	SAE ARP 876D	
Fan noise	Heidmann 1979	M.F. Heidmann: Interim prediction method for fan and compressor source noise, NASA Technical Report TMX-71763, 1979
	Heidmann 1996	K. B. Kontos, B. A. Janardan and P.R. Gliebe NASA Contractor Report 195480, 1996
Turbine noise	NASA TM X-73566	E.A. Krejsa: Interim prediction method for turbine noise
	AIAA 75-449	S. B. Kazin and R. K. Matta: Turbine Noise Generation, Reduction and Prediction, 1975
Propeller noise	SAE AIR 1407	Prediction procedure for near-field and far-field propeller noise

Airframe noise	FAA-RD-77-29	M.Fink: Airframe noise prediction method, 1977
	DOBRZYNSKI	W. Dobrzynski: Almost 40 Years of Airframe Noise Research: What did we Achieve?, Journal of Aircraft, Vol. 47 (No. 2), pages 353-367, DOI: 10.2514/1.44457, March - April 2010
Landing gear	NASA-CR-2005-213780	R.A. Golub, Y.P. Guo: Empirical Prediction of Aircraft Landing Gear Noise
	FAA-RD-77-29	M.Fink: Airframe noise prediction method, 1977
	NASA-CR-2004-213255	R.A. Golub, Y.P. Guo, R. Sen: Airframe Noise Sub-Component Definition and Model
Atmospheric absorption	SAE ARP 866 A	Standard values of atmospheric absorption as a function of temperature and humidity
	Sutherland (ANSI S1.26)	L.C. Sutherland, J.E. Piercy and H.E. Bass: A method for calculating the absorption of sound by the atmosphere.
	NPL	Sound absorption in air at frequencies up to 100 kHz by E. N. Bazely NPL Acoustics Report Ac 74 National Physical Laboratory February 1976
	ISO 9613	Attenuation of sound during propagation outdoors
	SAE ARP 5534	SAE, Application of pure-tone atmospheric absorption losses to one-third octave-band data, ARP5534, 2013
Wing Shielding	Maekawa	Z. Maekawa: Noise Reduction by Screens. Memoirs of the Faculty of Engineering, Kobe University, Japan, vol. 12, 1966, pp. 472-479.
Ground Reflections	Chien and Soroka	C.F. Chien and W.W. Soroka (1980), “A note on the calculation of sound propagating along an impedance plane”, J. Sound Vib., 69:340-343
Lateral attenuation	SAE AIR 1751	Prediction method for lateral attenuation of airplane noise during takeoff and landing
	SAE AIR 5662	Society of Automotive Engineers: AIR-5662, update to AIR-1751 (2006)
Noise units	ICAO Annex 16	Noise units

Apart from the mentioned prediction methods, databases with static or in-flight measured or prediction noise levels may be used. To this end the program is capable of interpolating in necessary parameters in order to calculate noise levels at angles and engine powers or aircraft velocities between those included in the source database.

Changes (‘deltas’) on noise sources

It is possible to apply one or more deltas to the individual and total source noise levels. These deltas may be applied in order to account for:

- Thermodynamic effects on noise sources (atmospheric conditions, altitude)
- Cycle effects
- Some installation effects (e.g. wing shielding)
- Flight effects on noise sources (e.g. Doppler amplification)
- Noise reduction technology (e.g. liner effects)

Flightpath and operating conditions

The program can make calculations for a single point on a flight path (although not all noise metrics can be calculated for this case), or for a complete (two or three-dimensional) flight path. For each required calculation point, the operating conditions of aircraft and engine are determined by interpolation in the relevant data (e.g. engine deck).

Noise unit calculations

The program calculates noise levels as would be measured by free-field, ground level, or 1.2m microphones, or any user defined microphone height and at one or more observer positions. A variety of noise metrics is calculated. The results of the calculations are stored in an ASCII outputfile, for further processing by the post-processor.