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Airport Noise and Emission Modelling Methodology

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Summary

The objective of Sourdine II project was to propose and evaluate new, innovative procedures for reducing the impact of aircraft noise on the ground, otherwise known as Noise Abatement Procedures (NAPs). Based on single event noise assessments, a set of NAPs (both approach and departure procedures) have been selected to be further analysed from an operational point of view, in the context of four European airports: Paris Charles de Gaulle, Amsterdam Schiphol, Madrid Barajas and Napoli Capodichino.

The global environmental impact of these selected procedures – in terms of noise and emissions – had also to be evaluated at these airports. This document presents the modelling developments which have been carried out to enable such airport-scale analyses of the selected SII NAPs.

For noise assessments, an airport noise modelling system, derived from the FAA's Integrated Noise Model (INM), has been specifically developed, enabling refined airport noise assessments of the selected SII CDAs. Its main characteristic is to better account for the effect of aircraft configuration (flaps/gear) and speed on the noise produced during approach, through the use of configuration and speed-based noise data. These data, which represent a "generalised" form of standard INM noise data (NPDs), have been produced by Airbus and Boeing for twelve specific aircraft types.

It was originally planned to use the output (the 4-D trajectories) of the fast-time simulations carried out in WP4 for the four airports (capacity assessments of the different NAPs) as a means to account for the actual noise impact that would result from implementing the NAPs under operational conditions. But the fast-time simulations could not produce data with the level of details required by the noise modelling system. Therefore, the airport noise modelling methodology described in this document uses only the ground tracks produced by the fast-time simulations. For the description of the vertical flight profiles, the methodology uses a SII-specific flight profile database, which has been developed as part of the noise modelling system. This database includes mostly manufacturer-supplied data.

The thus-developed noise modelling system, along with its specific noise and performance datasets, remains a prototype which goes beyond standard modelling methods given in current SAE, ECAC and ICAO guidance documents. In particular, due to the experimental and proprietary character of the specific datasets, using this system outside the SII project is not considered appropriate and would in any case require a specific agreement from Airbus and Boieng.

Moreover, the use of this noise modelling system to evaluate the SII NAPs in the context of the four selected airports does not allow to capture all the airport-specific operational conditions. Therefore, noise contours produced with this system should be considered as notional. In particular, the noise impact resulting from each SII NAP has to be evaluated in a relative way, against a baseline/reference procedure. Additionally, differences in the noise results from one airport to another result mainly from differences in the total number of operations (i.e. the size of the airport), and their distribution per aircraft type and route/runway.

For the emission assessments of the SII NAPs, a specific tool called TBEC (Thrust Based Emission Calculator) has been developed. This tool calculates aircraft emission levels associated to a given INM-like flight profile, on the basis of the ICAO Engine Exhaust Emissions Data Bank. However, this tool remains a prototype with several limitations. Further investigations need to be carried out in order to refine and validate its modelling principles. Emission results produced with such a tool should therefore be taken with caution and analysed in a relative way (i.e. relative variations of emission levels between the SII procedures and a baseline/reference procedure).

Table of Contents

1. Introduction

1.1. Context

The first phase of Sourdine II has consisted of designing and optimising different Noise Abatement Procedures (both approach and departure procedures), based on single event noise impact assessments (using SEL and LAmax metrics). The results of these single event noise assessments, presented in the Sourdine II D5.3 deliverable [D5-3], have been produced by Airbus for two specific aircraft (A320-211 and A340-313), using the manufacturer's in-house noise and performance modelling facilities.

Based on the results of these single event noise assessments, four CDA variants and two NADPs (the most "promising" procedures in terms of noise benefit), have been selected to be further analysed from an operational point of view, through the fast-time simulations carried out in WP4.

Additionally, it was also required to evaluate on an airport-scale the global environmental impact – both in terms of noise and emissions - of these selected SII procedures. As far as the noise impact is concerned, the purpose was to evaluate the potential and global noise benefit of the procedures in terms of noise contour area reduction, using the airport noise metrics L_{DEN} and L_{night}.

Such evaluations had to be carried out in the context of four European airports: Paris Charles de Gaulle, Amsterdam Schiphol, Madrid Barajas and Napoli Capodichino, which provide different local characteristics (in terms of number of movements, fleet-mix, runway configurations, etc.).

These airport-scale noise and emission assessments have required developing (or adapting existing) modelling facilities, along with defining a methodology for their application to the four airports.

1.2. Noise modelling developments

It has been logically proposed to perform the airport-scale noise impact assessments on the basis of the US FAA's Integrated Noise Model (INM), given that this tool represents a *de facto* 'standard' in the domain of airport noise contour modelling. This tool is widely used throughout the world and incorporates current modelling 'best practice'. In particular, the INM 7.0 version which has been used for Sourdine II complies with the recently revised ECAC Document 29 guidance [D29_3].

However, for the specific needs of Sourdine II, a new approach noise calculation module has been specifically designed and integrated in the standard version, enabling to better account for the airframe noise component when evaluating the global noise impact of CDAs. This module uses configuration and speed-based noise data, which have been specifically produced by Airbus and Boeing for twelve aircraft types.

This new noise calculation module, along with its specific noise dataset, remains a prototype which goes beyond standard guidance given in current SAE, ECAC and ICAO guidance documents. In particular, due to the experimental and proprietary character of the noise dataset (along with the SII-specific performance dataset – see 1.3), using such data outside the SII project is not considered appropriate, and would in any case require getting a specific agreement from Airbus and Boeing.

Chapter 2 of this document gives an overview of the modelling principle applied by INM in its standard version. This chapter describes in particular the standard noise data (NPD data) and the associated "segmentation" process, which are used to calculate the noise levels produced by a single flight operation.

Chapter 3 reminds the different flight parameters contributing to the noise impact of a procedure, which should be taken into account by the noise modelling system when evaluating the SII NAPs.

Chapter 4 describes the approach noise calculation module which has been developed to meet the Sourdine II requirements specified in Chapter 3. Chapter 4 describes in particular the principle of configuration and speed-based NPD data, and the different modifications which have been applied to the standard noise calculation method (described in Chapter 2) to support this new type of noise data.

1.3. Input data - aircraft performance modelling

The initial objective of the airport-scale studies at the four airports was to evaluate the actual environmental benefit which would result from applying the selected SII procedures to a “real” fleet mix, under airport-specific operational conditions and constraints.

In order to account for the operational conditions/constraints (along with the effect of fleet mix) in the noise and emission assessments, it was foreseen – as described in the Sourdine II D5.1 document [D5-1] - to use the output of fast-time simulations, in terms of flight trajectories, as input of the INM. However, this initial objective would have required having traffic simulators which could produce – with the required level of details and accuracy – 4-D trajectories reflecting both the specificities of the studied procedures when applied to different aircraft types (through a sophisticated aircraft performance model) and the airport-specific operational constraints.

Unfortunately, the fast-time simulators (TAAM and Simmod) could not offer such a level of sophistication. Therefore, only the ground tracks produced by theses simulators have been used in the airport noise assessments. The vertical flight profiles, required to construct the 4-D trajectories, have been taken from a SII-specific INM flight profile database. This database includes mainly manufacturer-supplied flight profiles for the different selected SII NAPs (along with baseline procedures) and for the twelve aircraft types, for which configuration-based noise data have been produced (see 1.2). Additionally, some of these profiles include fuel flow data as well, for the calculation of the emission levels produced by the different procedures. These manufacturer-supplied profiles were used at the four airport studies, generally without being modified to account for local specificities.

The SII-specific flight profile database, to be used both for noise and emissions analysis, is described in Chapter 5. The application of the developed noise modelling system to the airport studies is described in Chapter 6.

1.4. Emission modelling developments

For the local emission assessments of the SII procedures, an application called TBEC (Thrust Based Emissions Calculator) has been specifically developed. This tool calculates aircraft emission levels on the basis of the ICAO Engine Exhaust Emissions Data Bank, for flight profiles providing altitude, speed and thrust information along the travelled ground distance. During the project, TBEC has been adapted to use manufacturer-supplied fuel flow data included in the input flight profiles, in order to produce more reliable results.

Chapter 7 of this document describes the modelling principle of this tool.

1.5. Acknowledgements

Along with the contribution of Airbus – as a member of the Sourdine II consortium – to the production of configuration-based noise data and SII-specific flight profile data, the work carried out by the FAA, with Volpe Labs and ATAC, on the modifications of the INM source code to meet the specific requirements of SII was fundamental.

Additionally, the provision by Boeing of similar data for a series of aircraft types (i.e. configuration-based noise data and SII-specific flight profile data) was particularly valuable, contributing to the production of airport-scale noise assessments for more representative fleets. The work performed by Boeing for the needs of Sourdine has been sponsored by NASA.

1.6. Glossary

Term	**Description**
NAPs	Noise Abatement Procedures
NADPs	Noise Abatement Departure Procedures
CDA	Continuous Descent Approach
SPL	Sound pressure level (dB)
LA_{max}	A-weighted maximum sound pressure level (dBA)
L_E	Single event sound exposure level (dB)
SEL	A-weighted sound exposure level (dBA)
L_{eq}	Equivalent sound level over a 24-hour period (dBA)
L_{DEN}	Day-Evening-Night Level (dBA)
L_{night}	Night-time L_{eq} (dBA)
INM	Integrated Noise Model
NPDs	Standard INM noise-power-distance data
Multi-Configuration NPDs	Noise-power-distance data for different approach configurations and speeds (also called *configuration and speed-based NPDs*)
TBEC	Thrust-Based Emissions Calculator
FMS	Flight Management System
MLW	Maximum Landing Weight
MTOW	Maximum Take-Off Weight
FPA	Flight Path Angle
FAS	Final Approach Speed
IFS	Intermediate Flap Speed

1.7. References

Short Reference	**Author / Organisation, Title, Edition, Date and Reference**
[AIR]	Society of Automotive Engineers: *Procedure for the Calculation of Aircraft Noise in the Vicinity of Airports*. SAE AIR-1845 (1986).
[ARP]	Society of Automotive Engineers: *Standard values of atmospheric absorption as a function of temperature and humidity*. SAE ARP 866A (1975).
[D29_3]	European Civil Aviation Conference (ECAC): *Report on Standard Method of Computing Noise Contours around Civil Airports. Volume 2: Technical Guide*. ECAC.CEAC Doc.29, 3rd Edition (2005).
[TM6]	Jeffrey R. Olmstead, Gregg G. Fleming, John M. Gulding, Christopher J. Roof, Paul J. Gerbi, Amanda S. Rapoza: *Integrated Noise Model (INM) Version 6.0 Technical Manual*. U.S. Department of Transportation, Federal Aviation Administration, Report No. FAA-AEE-02-01 (January 2002).
[D9646]	International Civil Aviation Organization: *ICAO Engine Exhaust Emissions Data Bank*, ICAO Doc. 9646, 1st Edition (1995).
[AEM]	Eurocontrol Experimental Centre: *The Advanced Emission Model (AEM3) Version 1.5 - Appendices A, B and C to the Validation Report* EEC/SEE/2004/004 (2004).
[D5-1]	Sourdine II, D5-1: *Noise and Emission Modelling Requirements*.
[D5-3]	Sourdine II, D5-3: *Single Event Noise Calculations*

2. Standard INM – Overview

2.1. Introduction

The FAA's Integrated Noise Model is an airport noise contouring tool whose modelling principle is derived from the methodology described in the AIR-1845 guidance [AIR], issued by the Society of Automotive Engineers (SAE) in the 80s. The INM algorithms have evolved since, incorporating in particular a segmentation process, not described in the original guidance. The INM algorithms are described in the INM6.0 Technical Manual [TM6]. The version 7.0 which has been used for Sourdine II incorporates additional updates (in particular an updated lateral attenuation model), making that version fully compliant with the recently updated ECAC Document 29 guidance [D29_3].

Along with the noise calculation engine (the 'heart' of the system), INM includes different modules to define the input data which are required to calculate noise levels – basically the 4-D flight path (i.e. 3-D position and speed) of each aircraft around the airport, along with an additional flight parameter characterizing the aircraft noise source state (the engine power settings).

The main steps of the process applied by INM to calculate the noise levels produced by a single event (i.e. a given aircraft type performing a given procedure) are described in section 2.2. The flight path definition is described in 2.3. Section 2.4 describes briefly how INM calculates L_{DEN} and L_{night} noise contours resulting from a given traffic operating at the airport.

2.2. Single-event noise calculation

2.2.1. Noise Power Distance data

The INM's noise calculation process relies on the use of tabulated Noise Power Distance (NPD) data, available in a database for a large series of aircraft models and variants. These provide, for different power settings, a set of noise event levels at ten specific propagation distances (200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, and 25000 feet). The noise levels are given for various single event noise metrics, including at least L_{Amax} and *SEL*. These NPD data are usually derived by manufacturers from noise certification data.

By definition, NPDs provide overall noise levels perceived underneath a notionally infinite straight horizontal flight path, flown at a constant specific speed (Figure 2-1).The different other flight parameters characterizing the noise source state (power settings and aircraft configuration in particular), are also assumed constant along this infinite flight path. Each of the ten distance values at which the noise levels are provided represent the shortest distance $\boldsymbol{d_i}$ between the ground receiver and the flight path (so the altitude at which the aircraft flies the infinite flight path).

Additionally, NPDs are normalized to the following standard reference conditions:

- Atmospheric pressure:	101.325 kPa (1013.25 mb)
- Atmospheric absorption:	for an 'average' atmosphere with attenuation rates[1] listed in [AIR]

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[1] These attenuation rates are arithmetic averages, which cannot be associated with a specific single atmosphere (i.e. with specific values of temperature and relative humidity). However, INM offers the possibility to adjust standard NPDs to user-specified temperature and relative humidity conditions, using spectral data stored in a 'spectral class' database, and attenuation rates calculated according to the SAE ARP-866A guidance [ARP] for the specific T and RH values. This process is described in [D29_3].

- Precipitation:	None
- Wind Speed:	Less than 8 m/s (15 knots)
- Local terrain:	Flat, soft ground free of obstacles
- Reference Speed (for exposure metrics):	160 knots

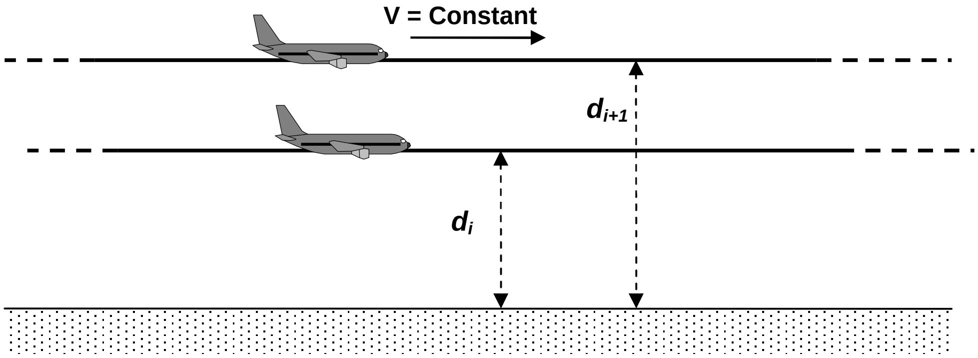


Figure 2-1: 'Infinite' flight path

The noise-related parameter in the NPD relations is the engine power setting (usually the corrected net thrust per engine F_n/δ), as the noise perceived on the ground is to a large extent - especially for departure operations - 'driven' by this parameter. It serves as a simple surrogate for the state of the aircraft and reflects the changes in the noise source as the aircraft/engine state changes. However, NPD data are distinguished by operating mode (approach or departure – see Figure 2-2) as, due to airframe effects, noise depends on the flight configuration as well as power setting during approach operations. Approach NPDs are therefore provided for lower (approach-specific) power settings, and for a specific – single – approach configuration, which is close to the final landing configuration (full flaps, gear down).

The power settings span normal operating values, both for approach and departures, in order to avoid the need for large modelling extrapolations.

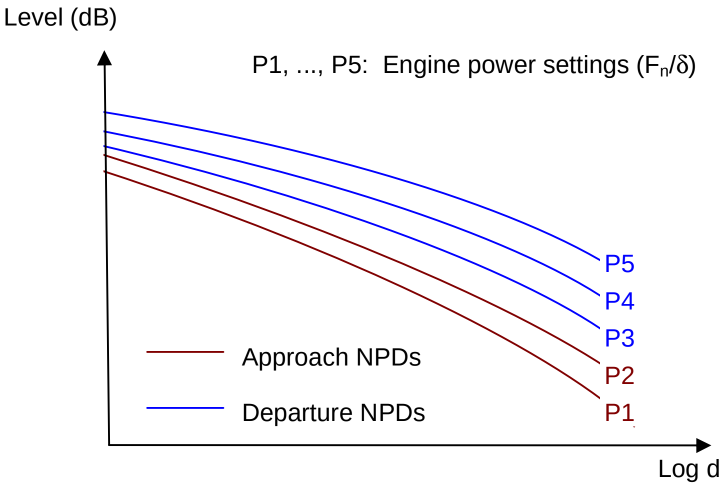


Figure 2-2: Standard NPD data

2.2.2. *The segmentation process*

The INM noise calculation principle consists of representing the aircraft trajectory (3-D flight path) by a series of finite straight segments, on each of which the variation of the different flight parameters (relevant for noise) are small. The noise contributions of the hence defined finite segments are calculated (as described in 2.2.2.1) and then 'combined' (see 2.2.2.3) to give the noise level produced by the flight event at a given ground receiver point. How the 3-D flight path is defined and sub-divided into finite segments is described in section 2.3.

2.2.2.1. Calculation of a segment event level L_{seg}

At a ground receiver point, INM calculates the noise contribution of a given finite segment of the flight path by applying adjustments to a 'baseline' noise level, obtained from the NPD tables. The adjustments are applied to account for differences between the actual source-to-receiver conditions for the finite segment of interest and the theoretical infinite flight path for which the NPD data are provided (and normalized).

These adjustments depend on the single-event noise metric to be calculated, which can be either a maximum noise level (Lamax) or an exposure noise level L_E (SEL), as described below.

The maximum noise level from a specific segment $L_{max,seg}$ is expressed as:

$$L_{max,seg} = L_{max}(P,d) + \Delta_I(\varphi) - \Lambda(\beta,\ell) \tag{2-1a}$$

The contribution from one segment to the L_E is expressed as:

$$L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\varphi) - \Lambda(\beta,\ell) + \Delta_F \tag{2-1b}$$

$L_{max}(P,d)$ and $L_{E\infty}(P,d)$ are the 'baseline' noise levels, interpolated (or extrapolated) for distance d and power settings P from the NPD tables (respectively the Lamax and SEL NPDs). The NPD data interpolation/extrapolation process is described in 2.2.3.

Values of P and d depend on the receiver-to-segment geometry and the noise metric as well. How these values are specified is described in 2.2.2.2.

The correction terms in equations (2-1a) and (2-1b) account for the following effects:

Δ_V	*Duration correction:* the NPD data relate to a reference flight speed of 160kts. This correction term adjusts exposure levels to a segment-specific speed V (the specification of the value of V depends on the receiver-to-segment geometry – see 2.2.2.2). This duration correction is expressed as: $\Delta_V = 10 \cdot log(160 / V_{seg})$ (2-2) This adjustment is not applied to $L_{max,seg}$.
$\Delta_I(\varphi)$	*Installation effect:* this describes a variation in *lateral directivity* due to shielding, refraction and reflection caused by the airframe, engines and surrounding flow fields. The φ parameter is the depression angle between the wing plane and the propagation path. A full description of this adjustment can be found in Volume 2 of the updated ECAC Document 29 [D29_3].
$\Lambda(\beta,\ell)$	*Lateral attenuation:* significant for sound propagating at low angles to the ground, this accounts for the interaction between direct and reflected sound waves (ground effect) and for the effects of atmospheric non-uniformities that refract sound waves as they travel towards the observer to the side of the flight path. The β parameter is the elevation angle between the direct sound propagation path and the level ground line. The ℓ parameter is the lateral displacement of the observer from the ground track. A full description of this adjustment can be found in [D29_3].
Δ_F	*Noise fraction correction:* This correction term accounts for the finite length of the segment which obviously contributes less noise exposure than an infinite one. It is only applied to exposure metrics. A full description of this adjustment can be found in [D29_3].

Note: The above corrections mainly apply for airborne segments. In the specific case of ground-roll segments, additional or different adjustments are applied, which are fully described in Volume 2 of the updated ECAC Document 29 [D29_3]. These include in particular a start-of-roll directivity function for receivers located behind the takeoff start of roll.

2.2.2.2. Determination of the noise-related parameter values of a segment

The values of the noise-related parameters required to calculate the noise contribution of a segment at a specific location depend on the segment-to-receiver geometry, and the noise metric as well (i.e. maximum or exposure level).

These noise-related parameters are mainly the distance d (between the segment and the receiver) and the power setting P, required to determine the 'baseline' noise level (interpolated from the NPD tables). In the case of an exposure level L_E , the speed parameter V is also required, in order to apply the duration adjustment described in the previous section.

Along with the 3-D co-ordinates of its start and end points - S_1 and S_2 -, a segment is characterized by the P and V values at these points (respectively [P_1, V_1] and [P_2, V_2]). Depending whether the receiver point is located alongside or [behind, ahead of] the segment, the values of d, P and V used to calculate the noise contribution of the segment are determined differently.

Figure 2-3 illustrates the situation where the receiver is located alongside the segment.

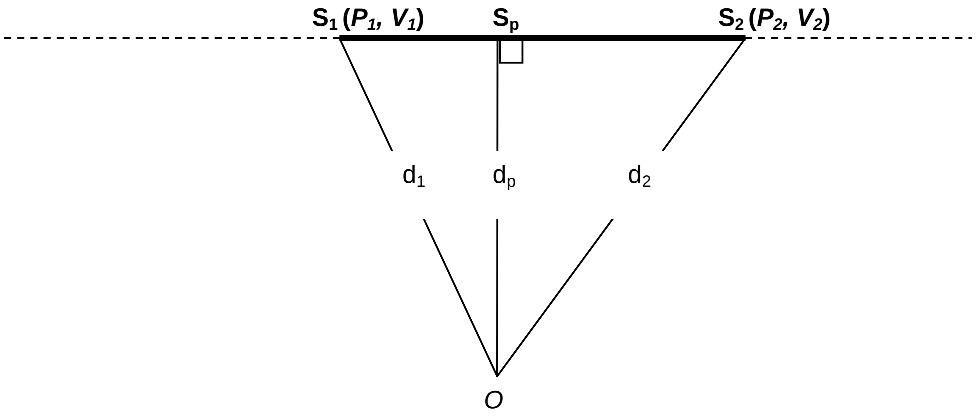


Figure 2-3: Segment geometry for observer alongside the segment

In that case, the value of the distance parameter d is the distance d_p between S_p and the observer, called the *minimum slant range* (i.e. the perpendicular distance from the observer to the segment).

The value taken by the power parameter P is the value at the point S_p on the segment that is closest to the observer. This value is interpolated between the segment-end point values (P_1, P_2), assuming that the power varies linearly with time between the two end-points.

In the case of an exposure level L_E , the value of the speed parameter V (required for the duration correction) is the value at the point S_p. This value is interpolated between the segment-end point values (V_1, V_2), assuming that the speed varies linearly with time between the two end-points.

Figure 2-4 below illustrates the situation where the receiver is located behind (or, in a similar way, ahead of) the segment:

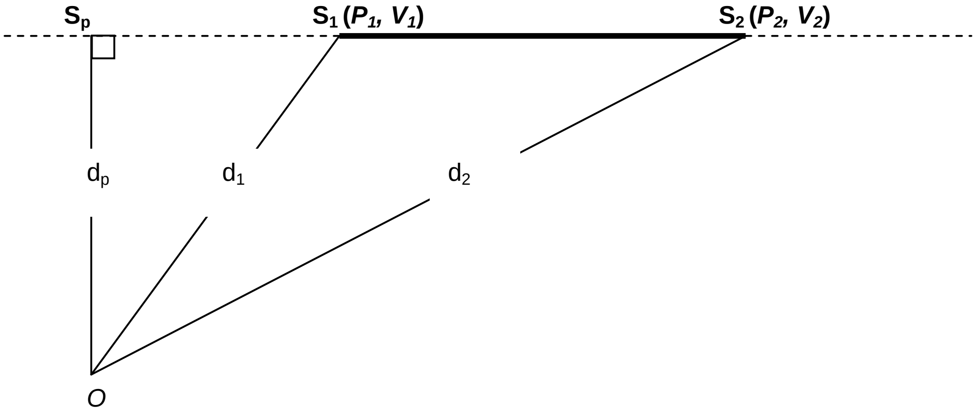


Figure 2-4: Segment geometry for observer behind (or ahead of) the segment

In that case, the value of the distance parameter *d* is defined as follows:

- When the noise metric is an exposure level L_E, *d* is the distance d_p between point S_p and the observer. This is the perpendicular distance from the observer to the extension of the segment (in other words to the hypothetical infinite flight path of which the segment is considered to be part).
- For maximum level metrics, *d* takes the value d_1, the shortest distance from the observer to the segment ($d = d_2$ in the case of a point located ahead of the segment).

The power parameter *P* takes the value P_1 at point S_1, the nearest point of the segment to the observer ($P = P_2$ in the case of a point located ahead of the segment).

In the case of an exposure level L_E , the speed parameter *V* takes the value V_1 at point S_1 , the nearest point of the segment to the observer ($V = V_2$ in the case of a point located ahead of the segment).

2.2.2.3. Calculation of the noise level produced by the flight event at a receiver

How the segment-event levels are ‘combined’ to determine the noise level produced by the flight event at a given ground receiver, depends on the noise metric, as described below:

Maximum Level L_{max} is simply the greatest of the segment values $L_{max,seg(i)}$:

$$L_{max} = Max(L_{max,seg(i)}) \qquad (2\text{-}3a)$$

Exposure level L_E is calculated as the decibel sum of the segment values $L_{E,seg(i)}$ from the N noise-significant segments of the flight path:

$$L_E = 10 \cdot log \left(\sum_{i=1}^{N} 10^{L_{E,seg(i)}/10} \right) \qquad (2\text{-}3b)$$

2.2.3. NPD interpolations

The 'baseline' levels $L_{max}(P,d)$ and/or $L_{E\infty}(P,d)$, required to calculate the noise contribution of each finite segment (see 2.2.2), are interpolated (or extrapolated) from the NPD data (using respectively LAmax and SEL NPD data).

A linear interpolation is used between tabulated power-settings, whereas a logarithmic interpolation is used between tabulated distances (Figure 2-5).

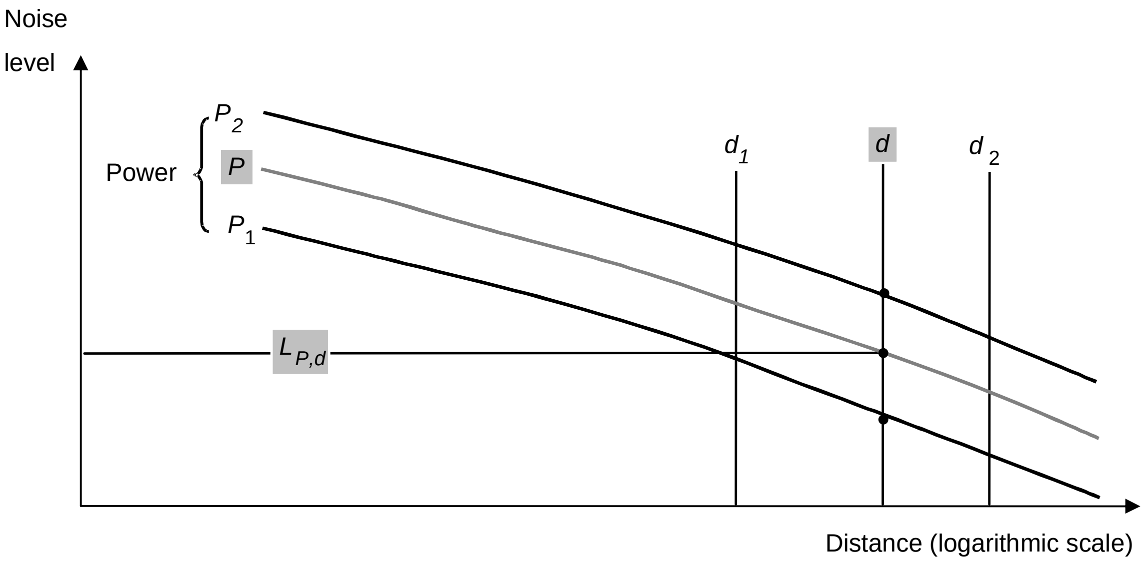


Figure 2-5: Interpolations in NPD curves

Interpolation or extrapolation of NPD data for departure operations is performed using the NPD curves designated as departure curves (see Figure 2-2). Similarly, interpolation or extrapolation of NPD data for approach operations, with one exception, is performed using the NPD curves designated as approach curves. The one exception occurs for the thrust reverse segment after aircraft touchdown. For this segment interpolation/extrapolation is performed using the departure NPD curves because of the higher noise levels associated with both departure and reverse thrust.

The interpolation of the noise level at a distance d (bounded by tabulated values d_1 and d_2) and for an engine power P (bounded by tabulated values P_1 and P_2) is performed as follows:

The noise level at engine power P_1 and distance d is given by:

$$L_{P1,d} = L_{P1,d1} + \frac{L_{P1,d2} - L_{P1,d1}}{\log d_2 - \log d_1} (\log d - \log d_1) \qquad (2\text{-}4a)$$

where

P_1 engine power value for which noise data are available in the NPD database,

d_1, d_2	distance values for which noise data are available in the NPD database,
$L_{P1,d}$	noise level at power P_1 and distance d,
$L_{P1,d1}$	noise level at power P_1 and distance d_1,
$L_{P1,d2}$	noise level at power P_1 and distance d_2.

The noise level at engine power P_2 and distance d is given by:

$$L_{P2,d} = L_{P2,d1} + \frac{L_{P2,d2} - L_{P2,d1}}{\log d_2 - \log d_1} (\log d - \log d_1) \tag{2-4b}$$

where

P_2	engine power value for which noise data are available in the NPD database,
d_1, d_2	distance values for which noise data are available in the NPD database,
$L_{P2,d}$	noise level at power P_2 and distance d,
$L_{P2,d1}$	noise level at power P_2 and distance d_1,
$L_{P2,d2}$	noise level at power P_2 and distance d_2.

Finally, the interpolated noise level at engine power P and distance d is given by:

$$L_{P,d} = L_{P1,d} + \frac{L_{P2,d} - L_{P1,d}}{P_2 - P_1} (P - P_1) \tag{2-5}$$

where

P_1, P_2	engine power values for which noise data are available in the NPD database,
$L_{P,d}$	noise level at power P and distance d,
$L_{P1,d}$	noise level at power P_1 and distance d , obtained from (2-4a),
$L_{P2,d}$	noise level at power P_2 and distance d , obtained from (2-4b).

The above methodology is used for extrapolations as well (i.e. when P and/or d do not lie between existing values in the NPD data).

Note: When noise levels are extrapolated to power settings below those represented by the NPD curves, INM limits the extrapolation to 5 dB below the lowest noise curve.

2.3. Flight path definition

As described in section 2.2, the calculation of the noise produced by a single event (a single flight operation) requires the description of its three-dimensional flight path and the varying engine power settings (the noise-related parameter in the NPD data) and speed (for noise exposure metrics only) along it. The segmentation process requires that the flight path is described by a series of contiguous straight segments. To construct this flight path, INM merges a user-defined ground track and a vertical flight profile (aircraft type-specific), taken from a *Standard profile* database and possibly modified by the user. These are described below.

2.3.1. Track data

The ground track is the vertical projection of the 3-D flight path on level ground. Aircraft ground tracks can be described either by an ordered series of coordinates in the (horizontal) ground-plane ("*Point tracks"*), or an ordered set of vectoring commands - straight and turn segments - ("*Vector tracks*").

Along with the definition of a backbone (or nominal) ground track, INM enables the definition of additional "sub-tracks", in order to account for the dispersion of trajectories which is likely to occur under operational conditions (as a result of ATC, airline-specific procedures, aircraft performance, meteorological conditions). When such sub-tracks are defined, INM distributes the total number of operations assigned to a given nominal track (or route) between the different sub-tracks, using a Gaussian distribution law.

Depending on the type of application and/or the type of available data, the backbone track and the sub-tracks can be defined in different ways. In the case of production of "historical" noise contours, and when relevant radar data are available, a reliable backbone track and suitable associated (dispersed) sub-tracks can be established by statistical analysis of these radar data. If such data is not available, or in the case of more theoretical "what-if" studies (modification of routes/procedures for instance), backbone tracks are usually constructed from appropriate procedural information, e.g. using standard instrument departure procedures from Aeronautical Information Publications. Some lateral dispersion can be added in a more theoretical way.

2.3.2. Vertical flight profiles

The vertical flight profile is a description of the aircraft motion in the vertical plane above the ground track, in terms of its altitude, speed, and thrust (the noise-related parameter in the NPD data), as a function of the travelled distance along the track. A vertical flight profile results from a flight procedure (i.e. a set of operating instructions, as flown by the crew), the aircraft type (through its performance characteristics) and operational conditions (aircraft operational weight, atmospheric conditions, etc.).

INM includes a *Standard profile* database providing flight profile information for each of its listed aircraft types and for different *standard* flight procedures (both approach and departure). In the case of departures, the database includes, for most of modern jet aircraft, the ICAO-A and ICAO-B procedures. Additionally, given that departure profiles highly depend on the aircraft takeoff weight, the database provides flight profile data for different 'typical' takeoff weights (associated to specific trip length ranges).

The flight profile information of the *Standard profile* database are available under two forms: either in the form of *procedural* profiles, or in the form of *fixed-point* profiles. Both options are presented below.

2.3.2.1. Procedural profiles

With the *procedural* profile form, the flight procedure is described by a set of successive procedural instructions/steps, as flown by the crew (ex: takeoff, climb, accelerate, descend, etc.). These procedural steps includes additional operational information such as the engine power settings, the flap settings, target speeds and rate of climb (for acceleration segments).

Using its aircraft performance model, along with appropriate aircraft performance coefficients (engine and aerodynamic coefficients, available in a database for most of modern aircraft), INM calculates the vertical profile (in terms of height, speed and thrust as a function of travelled ground distance, as required for the 3-D flight path construction) associated to the *procedural* profile. The calculated flight profile varies with the aircraft operational weight, meteorological conditions (temperature, pressure, wind speed) at the airport and procedure parameters (ex: flap settings schedule, thrust cutback, etc.), which can be adjusted by the user to meet local conditions.

The equations and algorithms of the INM aircraft performance model are described in the INM 6.0 Technical Manual [TM6].

2.3.2.2. Fixed-Point profiles

With the *fixed-point* profile form, tabulated values of height, speed and thrust at specific ground distances are directly provided by the database. They represent flight profiles resulting from standard procedures flown under standard conditions (standard atmosphere, airport at sea level, headwind less than 8 kts). These can not be automatically adjusted to account for other specific local conditions at the studied airport.

Usually, standard procedures are provided in the form of *fixed-point* profiles when the aircraft-specific performance coefficients are not available to calculate vertical profiles from the *procedural* definition of the procedure, or in the case of specific standard procedures where using the INM aircraft performance model would not be adequate because of some modelling limitations. For instance, approach procedures including idle thrust segments and/or level-off segments with deceleration are provided in the form of *fixed-point* profiles, because using the INM approach-specific thrust equation would over-estimate thrust levels associated to this kind of segments[2].

2.3.3. 3-D Flight path synthesis

INM merges a track and a vertical profile to construct the 3-D flight path as a series of contiguous straight flight path segments. If the ground tracks are defined using the *vector-tracks* option, INM first converts these in *point-tracks* before constructing the 3-D flight path. In a similar way, if the vertical profiles are defined in the form of *procedural* profiles, INM first converts these in *fixed-point* profiles (using its aircraft performance model).

Each segment of the 3-D flight path is defined by the following data:

x_1, y_1, z_1	starting coordinates for the segment (ft, ft, ft),
u_x, u_y, u_z	unit vector directed along the segment,
L	length of the segment (ft),

---

[2] The new version of ECAC Document 29 [D29_3] includes updated and additional thrust equations which address the issue, but require using additional aircraft performance coefficients, which are still to be developed and supplied by manufacturers.

v_{T1}	speed (kt) at the starting point,
Δv	change in speed (kt) along the segment: $\Delta v = v_{T2} - v_{T1}$,
$(F_n/\delta)_1$	corrected net thrust per engine at the starting point,
ΔF	change in corrected net thrust per engine along the segment: $\Delta F = (F_n/\delta)_2 - (F_n/\delta)_1$,
ε_1	bank angle[3] at the starting point,
$\Delta\varepsilon$	change in bank angle along the segment.

During the construction of the 3-D flight path, INM inserts or removes points, in order to have a flight path which is described with an optimal level of details (i.e. small segments when variations of one or several parameters are large, and longer segments for phases of the flight with small variations of the parameters). More details on this process can be found in [TM6] and [D29_3].

2.4. L_{DEN} and L_{night} noise contour calculation

INM can produce noise contours for most of the usual airport noise metrics. It includes pre-defined metrics, and enables to create additional user-defined metrics, through the specification of the single-event noise descriptor, weighting factors and time-periods . The L_{DEN} and L_{night} metrics, for instance, have to be created by the user.

The way in which INM computes L_{DEN} and L_{night} is defined below:

$$L_{DEN} = 10\ Log\left(\sum_{i=1}^{N_{day}} 10^{\frac{SEL_i}{10}} + 3.162\times\sum_{j=1}^{N_{eve}} 10^{\frac{SEL_j}{10}} + 10\times\sum_{k=1}^{N_{night}} 10^{\frac{SEL_k}{10}}\right) - 49.37dB \tag{2-6}$$

where

L_{DEN}	Day-Evening-Night Level
N_{day}	number of operations during day-time period (12 hours)
N_{eve}	number of operations during evening-time period (4 hours)
N_{night}	number of operations during night-time period (8 hours)
$SEL_{i,j,k}$	single event Sound Exposure Level produced by flight *i* (day), *j* (evening) or *k* (night), calculated as described in section 2.2
49.37 dB	10 Log(T) for the 24-hour time period (T = 24 x 60 x 60 s)

---

[3] Used in INM7.0 only. The bank angle is taken into account when calculating the depression angle φ, required to determine the engine installation correction Δ_I (φ) (see 2.2.2.1). The bank angle is calculated based on the aircraft speed (taken from the flight profile) and the aircraft turn radius (directly obtained or calculated from the ground track data). More details can be found in the new version of the ECAC Document 29 [D29_3].

$$L_{night} = 10\ Log\left(\sum_{i=1}^{N_{night}} 10^{\frac{SEL_i}{10}}\right) - 44.59\,dB \qquad (2\text{-}7)$$

where

L_{night}	night-time L_{eq}
N_{night}	number of operations during night-time period (8 hours)
SEL_i	single event Sound Exposure Level produced by flight *i*, calculated as described in section 2.2
44.59 dB	10 Log(T) for the 8-hour night-time period (T = 8 x 60 x 60 s)

Definition (2-6) of L_{DEN} accounts for the 5dB and 10dB noise “penalties” (respectively for evening and night-time flights) through weightings of the number of movements. Hence, the 3.162 multiplier for evening-period flights corresponds to the 5dB penalty applied to the single-event noise levels during this period ($3.162 = 10^{5/10}$).

To compute L_{DEN} and L_{night} noise levels, INM calculates the single-event SEL_i produced by each of the flight operations occurring within the period of interest, using the method described in section 2.2. A given single flight operation is fully defined by:

- the operating aircraft type,
- the ground track followed by the aircraft,
- the flight procedure/profile along the track,
- The period of the day of the operation (day, evening or night-time).

In practice, several operations (*N* operations) of the same aircraft type may follow the same track with the same vertical profile. In that case, INM computes the single event noise levels produced by one movement, and then determines the noise contribution of the *N* movements by adding 10 Log (*N*) to the initially calculated noise levels.

3. Airport-scale noise impact assessment of NAPs: modelling requirements

3.1. Introduction

This chapter reminds the main parameters of flight procedures contributing to the noise perceived on the ground, on which NAPs are based to minimize the noise impact. The objective is to identify the limitations of using an airport-scale noise model like the INM for assessing the noise impact of the SII NAPs, and determine the required developments to have a noise modelling system which can properly evaluate the noise impact of these SII NAPs, when applied to a fleet mix on an airport.

There are several factors that contribute to the noise perceived on the ground that are important for designing noise abatement procedures. For a given aircraft type, noise perceived on the ground is a combination of the noise amplitude at the source, which varies with the aircraft operating ‘state’ (in terms of power settings, aerodynamic configuration and speed), and propagation effects, which depend on the source-to-receiver geometry.

In designing noise abatement procedures such as ICAO A and ICAO B the idea is to balance the tradeoffs of aircraft climb performance vs. engine power. Aircraft at full power that hold flap retraction will climb faster, albeit at with a noise source that is louder than an aircraft that has cutback. Approach NAPs will adhere to similar rules. Noise abatement strategies aim to keep the aircraft high at as low a power setting as possible and look to minimize noise both through increased source-to-receiver distance and engine power states that are close to idle power. However in the case of approach procedures, the overall noise perceived on the ground is also influenced by the aircraft aerodynamic configuration and speed, through their effect on the airframe noise source component. These parameters have therefore to be taken into account as well when evaluating the actual noise impact of approach NAPs.

Section 3.2 describes in more details the main operational parameters contributing to the overall noise perceived underneath the flight path.

Section 3.3 describes the feasibility and limitations of using an airport-scale noise model like standard INM to model the noise impact of NAPs.

3.2. Operational parameters influencing noise

3.2.1. *Approach procedures*

For a given aircraft type and weight, the following parameters are considered as main factors influencing noise impact underneath the approach flight path, affecting source noise and/or sound propagation losses:

- Height or source-observer distance,
- Engine power setting,
- Aerodynamic configuration (flaps/slats configuration, landing gear position, airbrakes),
- Airspeed,
- Descent angle.

Height determines the amount of propagation loss. Engine power setting determines the amount of engine noise together with airspeed. Aerodynamic configuration and airspeed are main drivers of airframe noise. The descent angle has indirect impact on noise through height profile and energy management (engine power setting, speed and drag requirements).

The ranking of parameters in terms of approach noise sensitivity per parameter depends on the aircraft type and the phase of the procedure. The airframe noise component may become the main contributor to the overall approach noise, especially for modern aircraft with modern quiet engine technology. However, on specific phases of the procedure, engine noise can remain the dominant factor. The following paragraphs describe the underlying mechanisms.

3.2.1.1. Height

Maximising height along the trajectory ensures maximum source-observer distance. The source-observer distance directly influences the amount of sound energy dissipated during the transmission from source to observer, due to following propagation phenomena:

- Spherical spreading: sound spreads out over an increasingly larger surface at increasing distance from the source. For a doubling of propagation distance spherical spreading accounts for a 6dB reduction in terms of sound pressure level (SPL).
- Atmospheric absorption of sound: sound energy is attenuated when travelling through the atmosphere due to friction and other molecular effects. The amount of dissipation (in dB) is defined per unit of distance travelled and depends on air temperature, relative humidity, and frequency. High frequencies are attenuated more than low frequencies.
- Lateral attenuation: excess attenuation of sound propagated in lateral direction due to ground effect and refraction/scattering.

Other propagation phenomena of which impact may increase with increasing source-observer distance are refraction of sound due to temperature and wind gradients and dissipation due to turbulence.

3.2.1.2. Engine power setting

The engine power setting N1 (the percent low pressure rotor speed) and the Mach number, determine together with ambient conditions the engine thermodynamic cycle and resulting engine noise. The spectral content and directivity of sound emitted by the different engine components such as fan, compressor, turbine and jet noise differ significantly. The spectral content of the overall engine noise varies therefore significantly with the emission angle.

In the case of approach procedures, thrust settings vary between idle thrust and adapted thrust along the stabilised final approach along the glide slope. Thrust levels and associated engine noise levels are therefore considerably lower than during departure. Engine noise levels during the approach can be lower than airframe noise levels (see below).

3.2.1.3. Aerodynamic configuration

The aerodynamic configuration of the aircraft – relative to the clean configuration used during cruise – is determined by the following parameters:

- Deflection angle of slats and flaps,
- Position of landing gear,

- Deflection of airbrakes/spoilers.

The graph of Figure 3-1 below shows approach noise levels as a function of speed for a number of slats/flaps deflection angles and landing gear positions for a modern long range four-engine jet aircraft. Engines setting is flight idle. Whilst the landing gear is retracted, the influence of slat/flap angle on noise is significant. A significant increase of 3.5dB between clean configuration (00/00) and first intermediate configuration (20/00) is observed. The graph shows that the landing gear becomes the dominant noise source as soon as it is lowered. This case must be considered as example. For other aircraft types the relative contribution of different sources may be different.

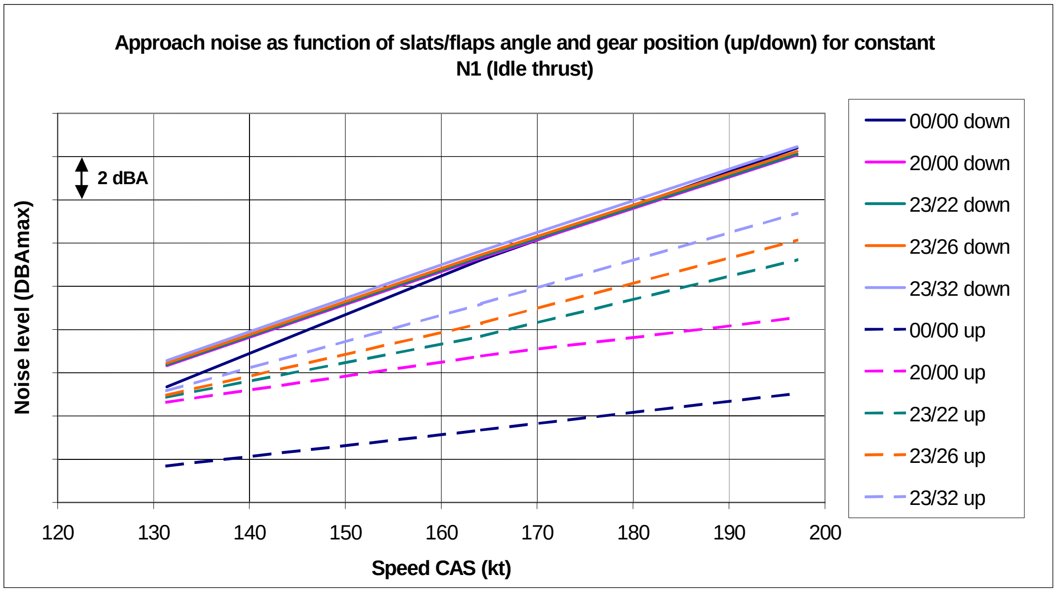


Figure 3-1: Configuration and speed effects on approach noise

The influence of airbrakes extension on airframe noise is considered significant although less data is available to quantify the impact.

3.2.1.4. Airspeed

The impact of airspeed on approach noise is twofold. The amplitude of airframe noise level is directly related to airspeed. During approach, airframe noise is an important noise component, as explained in the previous paragraph. The graph of Figure 3-1 shows the effect of speed on approach noise. The slope of the noise versus speed curve depends on the aerodynamic configuration.

Secondly, the airspeed determines the duration of the noise event and thereby the total noise exposure at a given ground location. Exposure metrics like SEL account for this duration effect together with the actual noise levels.

3.2.1.5. Descent angle

The selected descent angle for a given approach procedure has indirect but significant influence on noise below track, both through the resulting vertical profile and through its impact on energy management.

A steep descent enables a high vertical profile, which increases noise transmission losses between aircraft and observer.

Energy management includes management of thrust and high-lift devices with regard to the amount of speed (kinetic energy) and altitude (potential energy) along the trajectory.

Whereas an increased descent angle may lead to reduced thrust in certain conditions it can lead to decreased braking capability and additional drag requirements in other cases. Impact on noise in these situations is opposite as explained below.

In case an adapted thrust setting is used to maintain a constant speed along an imposed descent angle, a high descent angle requires less thrust than a low angle leading to a reduction in engine noise. However, throughout the part of the approach profile where idle thrust (or a fixed setting close to idle thrust) is used, the descent angle does not influence thrust and engine noise.

In other situations an increased descent angle can decrease braking capability of the aircraft and lead to requirement for additional drag. Additional drag by means of early slats/flaps, gear or airbrakes extension leads to more airframe noise. In general a steeper descent results in a longer deceleration distance and requires earlier activation of high-lift system of an aircraft.

3.2.2. Departure procedures

This section describes the main flight parameters to be taken into account in the development of noise abatement departure procedures.

During departure, engines are operated at ratings varying from takeoff to climb thrust. As a consequence engine noise is the dominant noise component.

For a given aircraft type and weight, the following parameters are considered as main factors of influence, direct or indirect, on noise level perceived at a specific observer position underneath the flight path:

- Height or source-to-receiver distance,
- Engine setting and thrust management,
- Airspeed,
- Takeoff speed and slats/flaps setting.

The following paragraphs explain their influence in more details.

3.2.2.1. Height

In the same way as for approach procedures, height directly influences the amount of noise energy that is lost during the propagation from the source to the receiver.

3.2.2.2. Engine power setting and thrust management

Engine noise is the dominant noise source during departures for existing jet aircraft. The engine setting directly determines the amount of source noise during departure and climb-out. In general an increase of thrust leads to an increase in engine noise.

The thrust management technique applied throughout the departure operation including takeoff ground roll, initial climb, acceleration and continued climb determines the departure climb performance. It has therefore a second - indirect - influence on noise exposure throughout the departure. A high amount of thrust in the initial phase leads to better climb performance in that phase than a reduced amount of thrust and as a consequence to a higher vertical profile and less noise underneath the subsequent part of the departure. The opposite is also true.

As part of thrust management technique the level, position and duration of the thrust cutback including the transition to climb power at the end of the noise reduction zone are main parameters.

Depending on the aircraft weight and performance constraints at a specific airport (runway length, presence of obstacles) the takeoff thrust rating can vary between derated- or flexible takeoff and full takeoff thrust. In real practice the operator applies the level that reduces engine wear and the takeoff thrust setting is therefore considered as fixed.

Sequence of acceleration and thrust cutback

The order in which acceleration and slats/flap retraction and thrust cutback take place has a first order impact on the area relative to the brake release point where noise reduction can be accomplished. Two types of noise abatement departure procedures are therefore distinguished.

Procedures for close-in noise reduction include a thrust cutback prior to acceleration and clean-up (slats/flaps retraction). Procedures for noise reduction at more distant areas include a thrust cutback after or during the acceleration and clean-up.

Cutback thrust level

The level of cutback thrust at a given position along the flight path determines the amount of acoustic energy emitted at that position and therefore the noise level directly underneath.

The standard cutback on wide body jet aircraft consists in selecting climb thrust. In addition to a Maximum Climb rating, derated climb ratings are normally available and can be selected if conditions allow it.

In addition to the standard climb rating, the minimum thrust level that allows regulatory climb performance in case of failure of one engine can be considered as cutback setting. Although not available on current aircraft, aircraft that will enter into service in nearby years will feature NADP functions based on this setting, allowing lower cutback levels than the climb rating for a range of operational weights. As a result lower source noise levels are obtained.

In case a deep cutback is applied during a part of the flight path where noise reduction is required, the restoration to maximum climb at the end of that phase can result in an increase of noise. As demonstrated in Sourdine II deliverable D5.3 [D5-3], this can be avoided by applying a gradual restoration of thrust. This function will be available on modern aircraft that enter into service in the nearby future.

Cutback thrust height

The minimum height for thrust cutback in current versions of ICAO PANS-OPS is 800ft. Given the drop in perceived noise underneath the flight path associated to the thrust reduction, the cutback height is an important parameter in the optimisation of noise abatement departure procedures.

3.2.2.3. Airspeed

At a given position along the departure flight path, airspeed influences the noise perceived mainly through the duration of the noise event. For a high speed the noise event will last shorter than for a low speed. As a result the airspeed has influence on noise exposure metrics.

Airspeed has also an indirect influence on noise through its effect on climb performance. For distant procedures, for which the initial acceleration and clean-up is performed early on, the target speed for this initial acceleration determines both length of the acceleration phase (performed at a lower rate of climb) and climb performance after this acceleration phase. This parameter therefore determines the shape of the noise profile and can be used as optimisation parameter.

3.2.2.4. Takeoff speed and flap setting

The takeoff flap setting and associated speed are usually determined in accordance with operational constraints such as aircraft weight, runway length and presence of obstacles underneath the flight path. These settings have influence on aircraft takeoff and climb performance, including initial climb-out speed, rate of climb and the subsequent acceleration phase, and therefore on noise below track.

3.3. INM limitations and resulting modelling requirements

3.3.1. *General requirements*

In order to properly evaluate the noise impact of NAPs on an airport-scale, i.e. on the basis of a fleet composed of different aircraft types, the noise modelling system has to account for the different acoustic effects/mechanisms (described in 3.2), which determine the overall noise produced by the NAPs and vary from one procedure to another, and from one aircraft type to another. In particular, given that the evaluation of the noise benefit of NAPs has to be done in a relative way (i.e. against a reference/baseline procedure), a fundamental requirement is to produce accurate noise level differences between different procedures. Achieving such a level of "relative" accuracy requires a good sensitivity of the model.

As the overall noise perceived on the ground is a combination of noise source characteristics (varying as a function of specific flight parameters) and propagation effects (directly linked to the source-to-receiver geometry), the noise modelling system has to meet two types of requirements:

- Ensuring that the noise calculation method (along with its associated noise database), properly accounts for the variations of the aircraft noise source state as the flight parameters directly influencing noise at the source vary (sensitivity requirement). This has to be achieved for each aircraft individually, as such variations are highly aircraft type-dependant.

- Ensuring that the input flight path information needed by the noise calculation module (3-D position of the aircraft for the definition of the source-to-receiver geometry, along with all the required flight parameters to determine the noise source state), correctly reflect the behaviour of each aircraft type when operating the NAPs, especially in terms of vertical flight profiles. Indeed, for a given NAP, the resulting flight profile depends on the aircraft performance characteristics and other operational parameters like its operating weight.

As discussed in the following paragraphs, the required developments/adaptations of the INM to meet these general modelling requirements, differ with the type of procedures (approach or departures).

3.3.2. *Departure procedures*

During departure procedures, the noise source state varies mainly with the engine power settings, as the engine component is the dominant source. Therefore, standard departure NPDs, which provide overall noise levels for tabulated power settings spanning normal operating values, provide a good representation of how the noise source state varies during departure operations.

As discussed in 3.2, NADPs are based on different operational techniques aiming at increasing the source-to-receiver distance (higher attenuation of sound) and/or setting the engine power to a minimum value (noise reduction at the source). The resulting noise impact on the ground of a given NADP can be properly estimated by standard INM, provided that a detailed and accurate description of the resulting vertical flight profile – in terms of height, speed and thrust values along the ground distance – is available: height (combined with the ground track) determines directly the source-to-receiver geometry, speed affects the duration of the noise event (through the duration correction term – for exposure metrics only), whereas thrust determines the noise source state.

The INM aircraft performance model enables to calculate accurate vertical profiles associated to a set of standard departure procedures (based on their *procedural* definition). The calculation process accounts in particular for operational parameters like aircraft takeoff weight, airport elevation, atmosphere and wind conditions. INM provides a series of procedural step options enabling to create user-defined procedures or modify standard ones (these include for instance a "minimum thrust" option, specifying that a step/segment is flown using calculated thrust levels based on the one-engine-out procedure). Even if the *procedural* form, combined with the INM performance model, could be reasonably used to generate the vertical profiles associated to the SII NADPs (close-in and distant procedures), it seemed however preferable (for reliability reasons) to use as far as possible flight profiles directly calculated by manufacturers.

3.3.3. Approach procedures

As explained in Chapter 2, standard approach NPDs implicitly take into account an airframe noise state, associated to a specific approach configuration (and speed value). It has to be noted in particular that its contribution to the overall noise levels provided by the approach NPDs is significant, as the specific approach configuration associated to these NPDs is close to the final configuration with gear down, whereas the tabulated thrust values correspond to low – approach-specific – engine power settings.

However, this integrated airframe noise component is fixed as it is given for a single – fixed – configuration and speed value. With standard approach NPDs, the only parameter describing how the noise source state varies during approach remains the thrust parameter, exactly in a same way as for departure NPDs.

When using these approach NPDs to model the noise impact resulting from a given approach procedure, the estimated noise levels reflect changes of the engine noise component as thrust varies (through interpolations between the NPD data, provided for different tabulated approach thrust values) but cannot account for any change of the airframe noise component resulting from configuration and/or speed changes. In other words, the predicted noise levels depend only on the flight path geometry and the power setting (along with speed, as far as the duration of the noise event is concerned). The varying configuration and speed parameters during the procedure are only taken into account indirectly, through their effect on the resulting engine power settings (to balance the other forces).

Given that the aircraft approach configuration (flap/gear) and speed can have a very significant effect on the overall noise perceived on the ground (as shown in Figure 3-1), using INM with its standard approach NPDs to evaluate different CDAs is likely to give only a partial indication of their actual noise impact, and could even lead to erroneous noise level differences between different procedures. For the specific needs of Sourdine II project, it has been therefore proposed to develop a modified version of the INM, which accounts for the variations of the airframe noise component as a function of the aircraft approach configuration and speed variables. This is achieved through the use of configuration and speed-based NPD data, as described in Chapter 4.

Another difficulty when assessing on an airport scale the noise impact of advanced approach procedures like those studied in Sourdine II, deals with the detailed definition of the vertical flight profiles associated to each aircraft type, when flying the procedures. Indeed, the generic definition of the SII approach procedures (both baseline and CDAs) result in variable altitude, thrust and/or speed profiles from one aircraft to another, as these depend on the aircraft performance characteristics and other operational parameters or constraints. Additionally, the flap settings along the flight profiles have also to be known, as the aircraft configuration is an additional input parameter for the new noise calculation module mentioned above. Again, the flap setting schedule depends highly on the aircraft type, as flap/slat deflection to next position is usually performed at specific speed values, which vary from one aircraft type to another.

As explained in Chapter 2, the INM aircraft performance model, which calculates vertical profiles associated to *procedural* profiles, has some limitations in the case of approach procedures. In particular, it does not perfectly model thrust values associated to flight segments with deceleration and/or idle thrust. Additionally, the *procedural* definition of flight procedures requires anyway the specification of aircraft configuration and speed information on some of the segments, which can only be provided by manufacturers for each aircraft type.

Therefore, for an accurate description of aircraft-specific flight profiles associated to the different SII procedures, it appeared easier to build directly a *fixed-point* profile database, including data calculated and supplied by manufacturers. These *fixed-point* profiles provide altitude, speed, thrust and configuration data as a function of the ground distance to touchdown.

4. SII-specific noise modelling system development

4.1. Overview

In order to meet the modelling requirements described in Chapter 3, a specific noise modelling system has been developed, on the basis of the INM7.0 version. Its main characteristic is to better account for the airframe noise component (which varies with aircraft configuration - flaps/gear - and speed) during approach procedures, through the use of multi-configuration and multi-speed NPD data.

The different elements of this noise modelling system are illustrated in Figure 4-1 below:

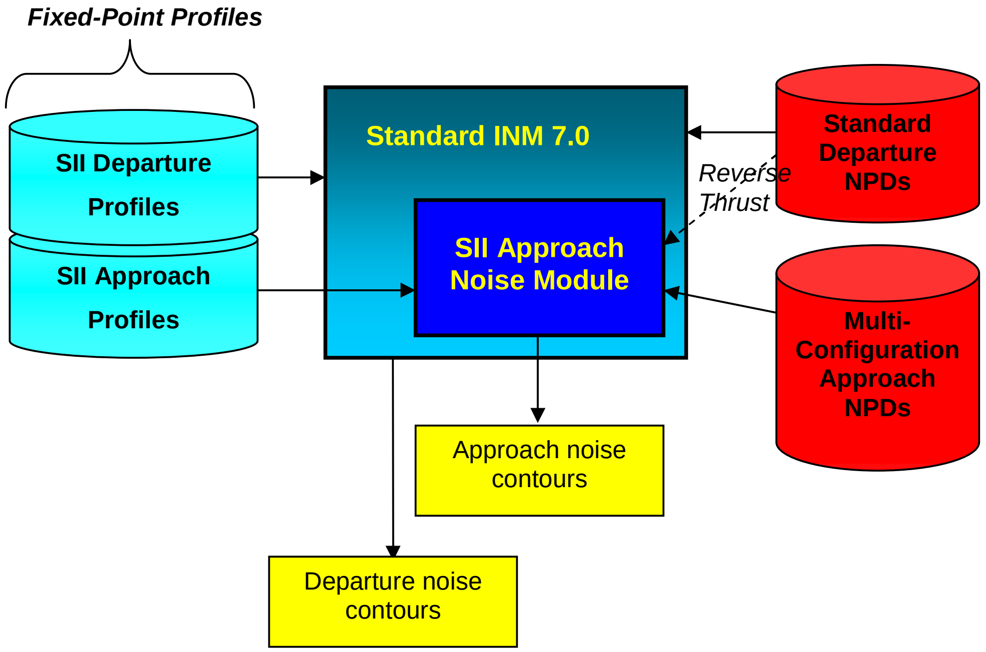


Figure 4-1: The SII noise modelling system

As shown in this figure, the standard noise calculation method of INM (i.e. based on standard departure NPDs) is used for the evaluation of NADPs, given that standard NPDs properly cover the different states of the aircraft noise source during departure operations (engine noise being the dominant component).

For the evaluation of the SII CDAs, the system includes a specific approach noise calculation module, which uses a database of configuration and speed-based approach NPDs (*Multi-configuration approach NPD* database). This module, along with its specific noise database, improves the sensitivity of the noise modelling system to the configuration and speed variables (by accounting for their direct effect on the airframe noise component). As shown in Figure 4-1, there is one exception where the *Multi-configuration approach NPD* database is not used, which is for the reverse thrust segment after aircraft touchdown: in the same way as for standard INM, the noise contribution of this segment is calculated using standard departure NPD curves instead, because of the higher noise levels (resulting mainly from engine noise) associated with reverse thrust.

FAA, in collaboration with Volpe Labs and ATAC, have modified the INM stream code to implement this approach noise calculation module, based on the Sourdine II specifications. In support of the new modelling method, Airbus and Boeing have produced a set of configuration and speed-based NPD data for twelve aircraft types (eight Airbus and four Boeing), using their in-house modelling facilities.

Additionally, in order to have input flight path data describing with the required level of details how different aircraft types actually fly the different SII procedures, the noise modelling system includes a SII-specific flight profile database. This database incorporates mainly data supplied by manufacturers (Airbus and Boeing) for the twelve aircraft types for which multi-configuration NPD data have been produced. For each aircraft type, flight profile data are available in the form of *fixed-point* profiles, for all the studied SII procedures (both CDAs and NADPs) and for baseline procedures as well (see Chapter 5).

This chapter describes in more details the developed SII approach noise calculation module. In particular, section 4.2 describes the concept of configuration and speed-based NPD data, and the dataset which has been produced by Airbus and Boeing. Section 4.3 presents the modifications of the INM noise calculation process to support this new type of noise data. It includes in particular a description of the associated noise data interpolations.

4.2. Configuration & speed-based approach NPD data

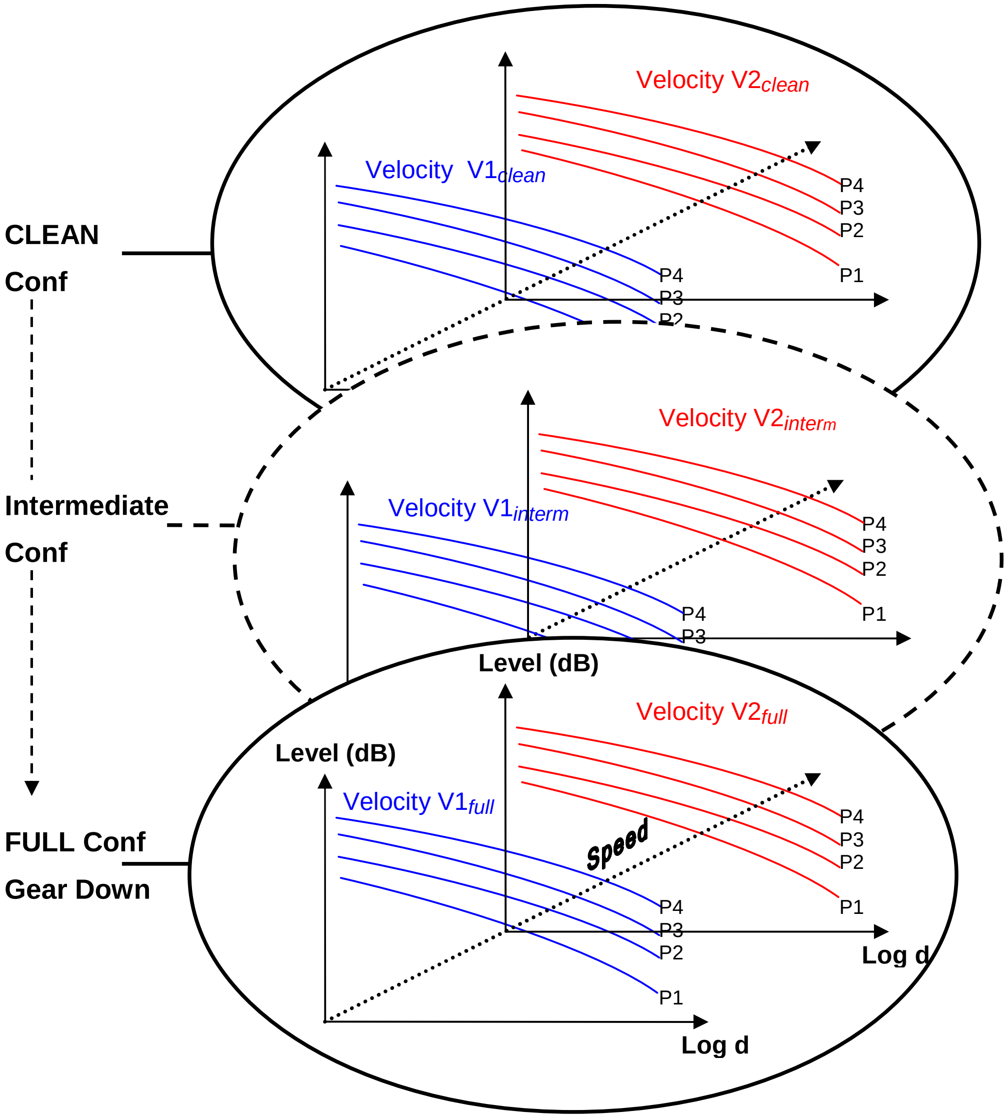
4.2.1. Principle

The configuration and speed-based NPD data represent a generalised matrix of conventional NPD data, which covers more aircraft noise source states, as a function of speed, aircraft configuration and engine power.

The use of these multi-configuration NPD data in the form of curves that represent overall aircraft noise levels as a function of source-observer distance for different thrust values is compatible with current practice and requires relatively minor modifications to the INM source code. The resulting modified INM version can use both these new configuration and speed-based NPD data and conventional NPD type data. It allows the manufacturer, as data developer, to add similar data in a similar format as provided in the current situation for additional parameter values (i.e. aircraft configuration and speed). Additionally, as the power parameter (corrected net thrust) remains one dimension of the “matrix”, these NPD data implicitly account for the variations of the relative contributions of the airframe and engine components to the overall noise.

An alternative method, in which engine and airframe components would have been delivered in separate tables and added up to overall noise in INM, would have required additional information on spectral content for correct summation of the different components. This would have required a too significant adaptation of INM source code and data requirements to handle within the timeframe of the Sourdine II project.

Figure 4-2 below illustrates the concept of configuration and speed-based NPD curves, as a generalised form of standard NPDs (illustrated in Figure 2-2).



P1, …, P4: Engine power settings (corrected net thrust)

Figure 4-2: **The multi-configuration/multi-speed approach NPD data matrix**

Whereas conventional approach NPDs are provided for a single – specific – configuration and speed value, the configuration and speed-based NPD matrix provides NPDs for the different configurations likely to be used by the aircraft during approach, from clean configuration (with gear up) to final landing configuration (with gear down), and for several (configuration-specific) approach speed values (at least two speed values, in order to enable an additional speed interpolation/extrapolation, described in 4.3.3). Figure 4-2 illustrates how this multi-configuration NPDs matrix is accessed during the noise calculation process (described in 0): for each segment of the flight path, INM identifies the configuration in which the segment is flown, and then selects the subset of NPD curves associated to that configuration, in order to perform the required noise interpolations.

The subset of NPD data associated to a given configuration and approach speed value are similar to standard NPDs and, as such, represent noise levels perceived underneath a notionally infinite straight flight path, flown at constant speed; this constant speed being the tabulated approach speed value to which the NPDs are associated. Additionally, these are normalised to the same standard conditions[4] as conventional NPDs (see 2.2.1), except for the reference speed in the case of exposure metrics (see next paragraph).

Unlike standard NPDs, the configuration and speed-based NPDs for exposure metrics (SEL) are not normalised to the 160 knot reference speed, meaning that each NPD curve includes the noise duration effect associated to the configuration-specific tabulated speed value for which it has been derived. Before performing interpolations in these NPDs (described in 4.3.3), INM will preliminarily normalise all the NPD data of the database to the same 160 knot reference speed, such as they all include the same duration effect, whatever their associated tabulated speed value is.

4.2.2. Production of a configuration and speed-based NPD database

Airbus and Boeing have produced configuration and speed-based NPDs for twelve specific aircraft, using their in-house modelling facilities. These aircraft types are listed in Table 4-1 below:

Manufacturer	***Airframe***	***Engine***
Airbus	A319-111[*]	CFM56-5B5/P
	A320-211	CFM56-5A1
	A320-214[*]	CFM56-5B4/P
	A320-232	V2527-A5
	A321-211[*]	CFM56-5B3/P
	A321-232	V2530-A5
	A330-301	CF6-80E1A2
	A340-313[*]	CFM56-5C4
Boeing	B737-300	CFM56-3B-1
	B737-800	CFM56-7B26
	B757-200	RB211-535E4
	B777-200	GE90-90B

Table 4-1: List of aircraft with configuration and speed-based NPDs

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[4] Unlike for standard NPDs, configuration and speed-based NPDs can not be adjusted to user-specified temperature and relative humidity conditions. Therefore, airport noise studies using configuration and speed-based NPD data deliver noise contours for standard atmosphere only.

[*] For these aircraft, Airbus has also produced standard departure NPD data, as these aircraft are not available in standard INM. These additional departure NPD data are needed to evaluate the noise impact of the SII NADPs and to model the noise contribution of reverse thrust segments for approach procedures.

The configuration and speed-based noise data have been derived using the manufacturer-specific computerised methods enabling the calculation of standard NPD data according to the SAE AIR-1845 guidelines. Such methods calculate aircraft noise levels at an observer position for a given aircraft type, flight trajectory (including the specification of power settings, aircraft configuration and speed) and source-observer geometry. Engine and airframe sound pressure level spectra are usually calculated separately and added logarithmically, to obtain the overall aircraft noise spectrum perceived at the observer position. The observed noise spectra are calculated as a function of time, on basis of which maximum and exposure based noise metrics are calculated.

The engine noise spectra are usually calculated by projection of noise data obtained from static engine tests into flight conditions. The method and data are adjusted using noise data obtained from certification flight tests. In a similar way, airframe noise spectra are calculated using semi-empirical methods, calibrated on the basis of results of airframe noise flight tests.

As configuration and speed-based NPDs represent a generalised form of standard approach NPDs (i.e. a larger set of approach NPDs covering more aircraft states in terms of configuration and speed), they have been derived using these computerised methods in a same way, each subset of NPDs being produced for a specific (fixed) configuration and speed value.

For each of the aircraft listed in Table 4-1, NPD data have been hence produced, both for SEL and LA_{max} metrics. For each metric, NPD curves (one curve being a set of noise levels at the ten tabulated distances, associated to a given combination of configuration, thrust and speed values) have been generated for:

- 4 or 5 approach thrust values,
- 5 or 6 aerodynamic configurations (from clean-gear up to full landing-gear down configurations),
- 3 to 6 configuration-specific speed values.

The above number of tabulated values (of thrust and speed) and aerodynamic configuration states depend on the aircraft type. The different aerodynamic configurations for which NPD curves are provided cover most of the aircraft states during normal approach operations. The time at which the landing gear is extended is aircraft type dependent, and is generally associated to a specific intermediate configuration. For this particular configuration, NPDs are provided both with the gear up and gear down options. The configuration-specific airspeed values cover, as far as possible (see the limitations in 4.2.3), the operational speed ranges which are likely to be associated to each of the configurations.

4.2.3. Limitations

The development of configuration and speed-based approach NPD data (as standard approach NPDs) is more complicated than the development of departure NPD data, for several reasons. As the flight trajectories used to calculate these NPD data differ significantly from the certification and airframe noise flight trajectories, a part of the methodology to calculate source noise and propagation effects relies on extrapolations as the computerised methods are used outside their domain of validity. In particular, the low thrust levels require usage of data at the lower limit of the available engine noise data. Moreover, for exposure-based NPDs (such as SEL, EPNL), the emitted sound pressure levels being relatively low, the 10dB-down periods[5] may be extremely long, requiring a significant amount of extrapolations, especially for the lower thrust levels combined with zero/intermediate flap settings and retracted landing gears.

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[5] The period during which the instantaneous perceived sound pressure level is higher than the maximum perceived noise level (LA_{max}) minus 10dB. Practically, integrating instantaneous sound pressure level over such a defined period accurately represents the sound energy level produced by a single flight event.

The NPD data points for large source-observer distances (16000ft and 25000ft) have been obtained using simplified extrapolation procedures (accounting mainly for spherical spreading of sound and air absorption). However, the noise levels associated to these tabulated distance values are normally not used when producing approach noise contours starting at L_{DEN} 55 or L_{night} 50.

As a consequence, the most extrapolated noise level data may be less reliable than the others. This occurs notably for noise levels associated to:

- Large sauce-to-receiver distances (but this is not a critical issue, as already explained above),
- Lowest tabulated thrust values, especially when combined with clean and intermediate configurations (with gear up).
- Highest tabulated speed values associated to clean configuration with gear up.

4.2.4. Control of NPD extrapolations for high speeds

Initial segments of approach procedures are usually flown with clean-configuration (and idle thrust) combined with high speed values, quite above the highest tabulated speed values for which NPDs could be reasonably derived. INM will have therefore to extrapolate noise levels to these operational speed values from the configuration and speed-based NPDs (see 4.3.3). Such extrapolations are likely to produce uncontrolled excess of noise far from touchdown (due to increasing airframe noise). To avoid this situation, it has been decided to “saturate” the extrapolations above 220kts, through the addition of a NPD dataset for 250kts, which is identical to the dataset associated to 220kts (this results in “horizontal” extrapolations).

4.3. Modifications of the INM single-event noise calculation method

4.3.1. Introduction

As already discussed in 4.2.1, configuration and speed-based NPDs consist of a wider set of NPD data (covering more general states of the aircraft noise source). Using these data require therefore relatively minor modifications to the INM source code. Mainly, these modifications deal with considering an additional parameter (the aircraft configuration) in the calculation of the noise contribution of each finite segment of the flight path, and performing modified interpolations in the configuration and speed-based NPDs.

4.3.2. Modification of the INM segmentation process

To calculate the noise contribution of a given finite segment of the flight path, the segmentation process considers the aircraft configuration in which the segment is flown as an additional parameter, used to select the subset of NPD data associated to that configuration. It has to be noted that the aircraft configuration (flaps/gear state) is treated as a single, discrete state throughout the entire segment (Figure 4-3). In particular, the method does not model any transition between two configuration states (i.e. the fact that in reality, flaps deployment takes several seconds to be complete): configuration changes are here assumed to be instantaneous.

The noise contribution of a finite segment flown with configuration *Conf_N*, is determined using variants of equations (2-1a) and (2-1b) (respectively for maximum and exposure metrics), provided below:

The maximum noise level from a specific segment $L_{max,seg}$ is expressed as:

$$L_{max,seg} = L_{max}(Conf\_N, P, V, d) + \Delta_I(\varphi) - \Lambda(\beta, \ell) \qquad \text{(4-1a)}$$

The contribution from one segment to the L_E is expressed as:

$$L_{E,seg} = L_{E\infty}(Conf\_N, P, V, d) + \Delta_V + \Delta_I(\varphi) - \Lambda(\beta, \ell) + \Delta_F \qquad \text{(4-1b)}$$

The only modified terms in the above equations (compared with the standard ones) are the ‘baseline’ noise levels L_{max} *(Conf_N, P, V, d)* and $L_{E\infty}$ *(Conf N, P, V, d)*, which are defined using *Conf_N* and speed *V* as additional input parameters. In particular, all the correction terms applied to the ‘baseline’ noise levels remain unchanged.

The above ‘baseline’ noise levels are interpolated for distance *d,* power settings *P* and speed *V* from the subset of NPD data associated to *Conf_N* (using respectively the LA_{max} and *SEL* NPDs). This new NPD data interpolation process is described in 4.3.3.

Values of *P*, *d* and *V* are computed exactly in the same way as described in 2.2.2.2 (for standard INM), as a function of the receiver-to-segment geometry (i.e. observer alongside or behind/ahead of the segment) and the noise metric (see also Figure 4-3).

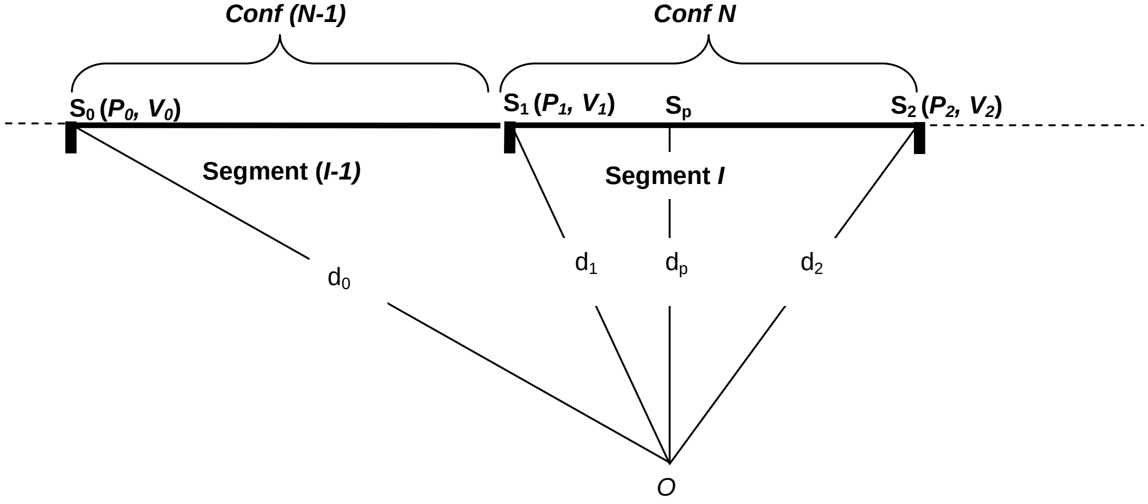

Figure 4-3: Multi-configuration NPD data segment geometry

4.3.3. Interpolations in configuration and speed-based NPD data

The 'baseline' levels $L_{max}(Conf\_N, P,V,d)$ and/or $L_{E\infty}(Conf\_N, P,V,d)$, required to calculate the noise contribution of each finite segment, are interpolated from the configuration and speed-based NPD data, using the subset of NPD data associated to the configuration *Conf N* at which the segment is flown.

As for standard NPDs, a linear interpolation is used between tabulated power-settings, whereas a logarithmic interpolation is used between tabulated distances.

An additional interpolation is applied between tabulated speed values for which the configuration-specific NPDs are provided (at least two values in order to enable the interpolations/extrapolations). This speed interpolation is linear, in a same way as for power settings.

In the case of SEL (exposure metric) data, the noise calculation module preliminarily normalises all the NPDs of the database to the same 160 knot reference speed (by adding $10.\log(V/160)$ to the original noise levels), before performing the interpolations[6]. The hence normalised NPDs include all the same duration effect (corresponding to the theoretical 160 knots reference speed), whatever their associated tabulated speed value is. Therefore, the above speed interpolation captures only the variations of the noise source state as a function of speed (through variations of the airframe noise component).

Additionally, whatever the speed effect on the overall noise (the decibel sum of the engine noise and airframe noise components), this linear interpolation may be considered as a reasonable assumption,

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[6] This normalisation is required to be consistent with equation (4-1b), which applies the duration correction term ΔV to 'baseline' noise levels (interpolated from NPDs) including a duration effect associated to 160 knot. It can be noted that a more simple solution could have been to directly normalise the NPD data to 160 knot in the database.

given that the tabulated speed values for which the noise data are available are sufficiently close to each other. Moreover, large – uncontrolled – extrapolations for high speed values (associated to clean configuration) are limited, through the use of "duplicated" NPDs – see 4.2.4)

How the noise level associated to a power *P*, speed *V* and distance *d* is interpolated between tabulated values of these parameters, is illustrated in Figure 4-4. The different steps are described below.

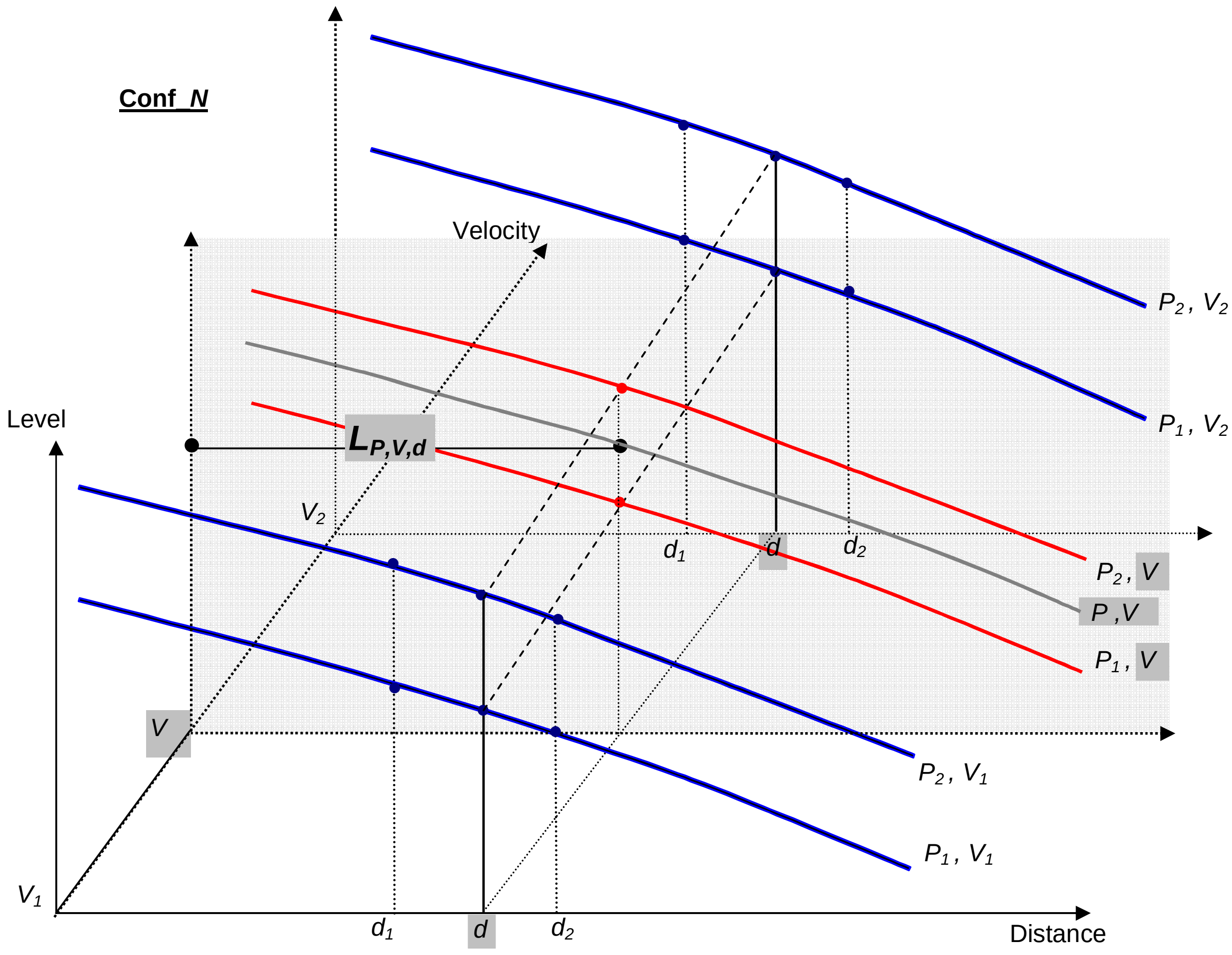

Figure 4-4: Interpolations in configuration/speed-based NPD curves

4.3.3.1. Interpolations at distance *d*

The noise level at engine power P_1 , speed V_1 and distance d is given by:

$$L_{P1,V1,d} = L_{P1,V1,d1} + \frac{L_{P1,V1,d2} - L_{P1,V1,d1}}{\log d_2 - \log d_1} (\log d - \log d_1) \qquad (4\text{-}2a)$$

where

P_1	engine power value for which noise data are available in the database,
V_1	speed value for which noise data are available in the database,
d_1, d_2	distance values for which noise data are available in the database,
$L_{P1,V1,d}$	noise level at power P_1 , speed V_1 and distance d,
$L_{P1,V1,d1}$	noise level at power P_1 , speed V_1 and distance d_1,
$L_{P1,V1,d2}$	noise level at power P_1 , speed V_1 and distance d_2.

The noise level at engine power P_2 , speed V_1 and distance d is given by:

$$L_{P2,V1,d} = L_{P2,V1,d1} + \frac{L_{P2,V1,d2} - L_{P2,V1,d1}}{\log d_2 - \log d_1} (\log d - \log d_1) \qquad (4\text{-}2b)$$

where

P_2	engine power value for which noise data are available in the database,
V_1	speed value for which noise data are available in the database,
d_1, d_2	distance values for which noise data are available in the database,
$L_{P2,V1,d}$	noise level at power P_2 , speed V_1 and distance d,
$L_{P2,V1,d1}$	noise level at power P_2 , speed V_1 and distance d_1,
$L_{P2,V1,d2}$	noise level at power P_2 , speed V_1 and distance d_2.

The noise level at engine power P_1 , speed V_2 and distance d is given by:

$$L_{P1,V2,d} = L_{P1,V2,d1} + \frac{L_{P1,V2,d2} - L_{P1,V2,d1}}{\log d_2 - \log d_1} (\log d - \log d_1) \qquad (4\text{-}2c)$$

where

P_1	engine power value for which noise data are available in the database,
V_2	speed value for which noise data are available in the database,
d_1, d_2	distance values for which noise data are available in the database,
$L_{P1,V2,d}$	noise level at power P_1 , speed V_2 and distance d,
$L_{P1,V2,d1}$	noise level at power P_1 , speed V_2 and distance d_1,
$L_{P1,V2,d2}$	noise level at power P_1 , speed V_2 and distance d_2.

The noise level at engine power P_2 , speed V_2 and distance d is given by:

$$L_{P2,V2,d} = L_{P2,V2,d1} + \frac{L_{P2,V2,d2} - L_{P2,V2,d1}}{\log d_2 - \log d_1} (\log d - \log d_1) \qquad \text{(4-2d)}$$

where

P_2	engine power value for which noise data are available in the database,
V_2	speed value for which noise data are available in the database,
d_1, d_2	distance values for which noise data are available in the database,
$L_{P2,V2,d}$	noise level at power P_2 , speed V_2 and distance d,
$L_{P2,V2,d1}$	noise level at power P_2 , speed V_2 and distance d_1,
$L_{P2,V2,d2}$	noise level at power P_2 , speed V_2 and distance d_2.

4.3.3.2. Interpolations for speed V

The noise level at engine power P_1 , speed V and distance d is given by:

$$L_{P1,V,d} = L_{P1,V1,d} + \frac{L_{P1,V2,d} - L_{P1,V1,d}}{V_2 - V_1} (V - V_1) \qquad \text{(4-3a)}$$

where

P_1	engine power value for which noise data are available in the database,
V_1 , V_2	speed values for which noise data are available in the database
$L_{P1,V,d}$	noise level at power P_1 , speed V and distance d,

$L_{P1,V1,d}$	noise level at power P_1 , speed V_1 and distance d , obtained from (4-2a),
$L_{P1,V2,d}$	noise level at power P_1 , speed V_2 and distance d , obtained from (4-2c).

In a similar way, the noise level at engine power P_2 , speed V and distance d is given by:

$$L_{P2,V,d} = L_{P2,V1,d} + \frac{L_{P2,V2,d} - L_{P2,V1,d}}{V_2 - V_1}(V - V_1) \tag{4-3b}$$

where

P_2	engine power value for which noise data are available in the database,
V_1 , V_2	speed values for which noise data are available in the database
$L_{P2,V,d}$	noise level at power P_2 , speed V and distance d,
$L_{P2,V1,d}$	noise level at power P_2 , speed V_1 and distance d , obtained from (4-2b),
$L_{P2,V2,d}$	noise level at power P_2 , speed V_2 and distance d , obtained from (4-2d).

4.3.3.3. Final interpolation at engine power *P*

The noise level at engine power P, speed V and distance d is finally obtained by:

$$L_{P,V,d} = L_{P1,V,d} + \frac{L_{P2,V,d} - L_{P1,V,d}}{P_2 - P_1}(P - P_1) \tag{4-4}$$

where

P_1 , P_2	engine power values for which noise data are available in the database,
$L_{P,V,d}$	noise level at power P , speed V and distance d,
$L_{P1,V,d}$	noise level at power P_1 , speed V and distance d, obtained from (4-3a),
$L_{P2,V,d}$	noise level at power P_2 , speed V and distance d, obtained from (4-3b).

Note: The methodology described above can be used for extrapolations as well (i.e. when *P, V* and/or *d* do not lie between tabulated values in the NPD data. However, extrapolations for high speed values (in clean configuration) are avoided, through the use of the “duplicated” NPDs (4.2.4).

4.3.4. *Modification of the input flight path definition*

The modified single-event noise calculation method uses the aircraft configuration in which each finite segment is flown as an additional parameter characterizing the aircraft noise state. As standard INM flight profiles do not contain flap/gear state explicitly (given that this type of information is not required in the standard INM noise calculation process), the format of *fixed-point* profile[7] data has been modified to include flap/gear state as additional input parameter. With this modified format, the vertical profile database provides the configuration state of the aircraft at each point of the profile. All flap/gear labels used in the profile points definition must match the configuration labels used in the multi-configuration NPD database.

The 3-D flight path synthesis (where INM merges ground tracks and vertical profiles – see 2.3.3) has been adapted to account for this additional parameter. In particular, during the calculation of the contiguous straight flight path segments, each segment is assigned a single configuration (flaps/gear) label, treated as a discrete state throughout the entire segment.

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[7] Noise impact studies performed with configuration and speed-based NPDs must use *fixed-point* profile information to define the input flight path data. The *procedural* form is not supported.

4.4. Validation of the noise modelling concept

In order to validate the configuration and speed-based NPD methodology/concept, comparisons have been made between noise levels estimated using this method and those produced by Airbus's noise prediction tools. The graph of Figure 4-5 shows, for a specific aircraft type, comparisons of noise levels (LA_{max} under the flight path) associated to a "standard" procedure (including a level segment at 3000ft followed by a 3-degree glide slope).

The SII modelling system reproduces well the behaviour of noise as a function of configuration and speed changes, if not necessarily in terms of absolute values. It has to be noted that the manufacturer's model takes into account the transition period between two configuration states, whereas the SII modelling system assumes an instantaneous flap change, occuring when the flap change is complete. As a consequence, the manufacturer's model tends to predict noise increase starting earlier, as soon as the flap deployment to next position starts (which can lead also to higher noise levels, when speed at the start of flap deployment is higher than at the end, on deceleration segments). In order to better match manufacturer's noise predictions with the SII modelling system, a simple solution has consisted of specifying earlier flap changes (to next position) in the flight profile.

The above comparisons have been made only on a few examples, and only for a specific aircraft type. Such comparisons demonstrate mainly the validity of the modelling principle. In particualr, the quality of the results strongly depends on the reliability of the configuration and speed-based NPD data. There was no mean to verify and validate systematically all the NPDs of all the aircraft types of the list. Keeping in mind the limitations inherent to the production of configuration and speed-based approach NPD data (described in 4.2.3), further investigation, consisting of more detailed analysis of the noise data, should be therefore required, in close collaboration with manufacturers.

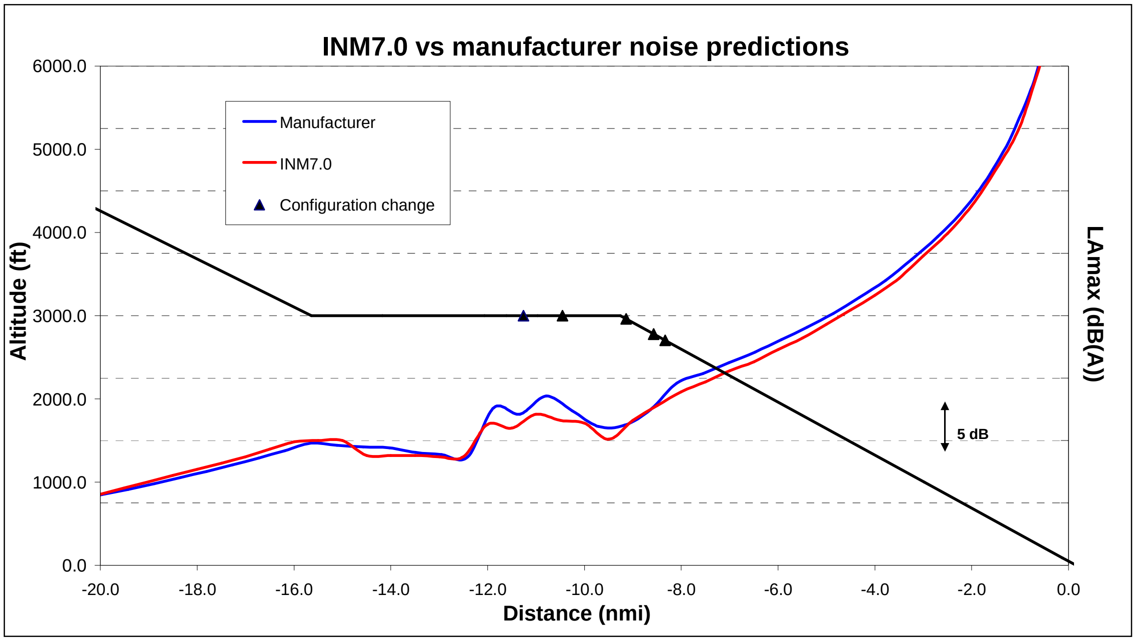

Figure 4-5: Validation against manufacturer-predicted noise levels

4.5. Improved sensitivity – worked examples

4.5.1. Single-event example

The example below illustrates the improved sensitivity of the noise modelling system - compared with standard INM - to the approach configuration and speed parameters.

Noise levels resulting from two procedures flown by a same aircraft type have been compared, using respectively standard INM (i.e. with standard approach NPDs) and the configuration/speed-based NPD method. These procedures include both a level-off segment at 3000 ft before intercepting a 3-degree glide. They differ by their deceleration profile and their flap setting schedule (one procedure having delayed deceleration and flap deployment sequence), as illustrated in Figure 4-6 below:

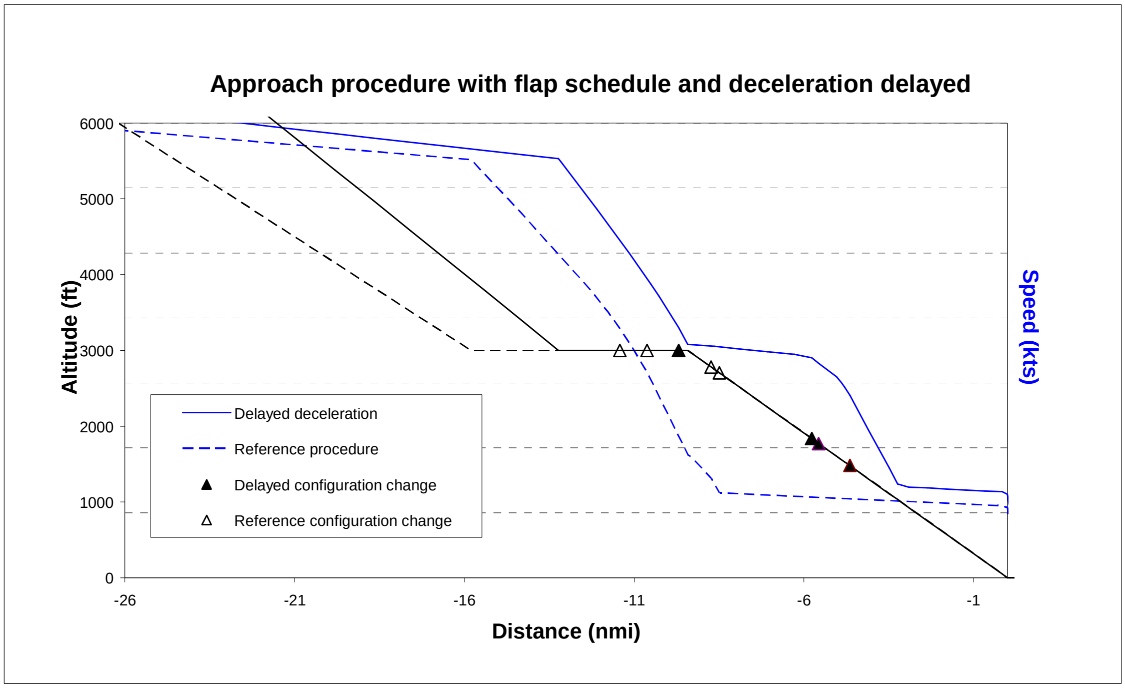

Figure 4-6: Reference and "delayed" procedures description

The following graphs (Figure 4-7 and Figure 4-8) compare noise levels (LA_{max} under the flight path) resulting from these two procedures, when calculated using respectively standard NPDs and the configuration/speed-based NPD method. With the standard NPDs, there is nearly no difference between the two procedures, the slight difference coming from differences in the thrust profiles (as, in this example, standard INM can only reflect the thrust differences between the two procedures). The noise levels produced with the new method show clearly the additional sensitivity of the system to the speed and configuration variables. In particular, the procedure with delayed deceleration involves final flap deployment at higher speeds, which results in a noticeable noise increase, via the airframe noise component.

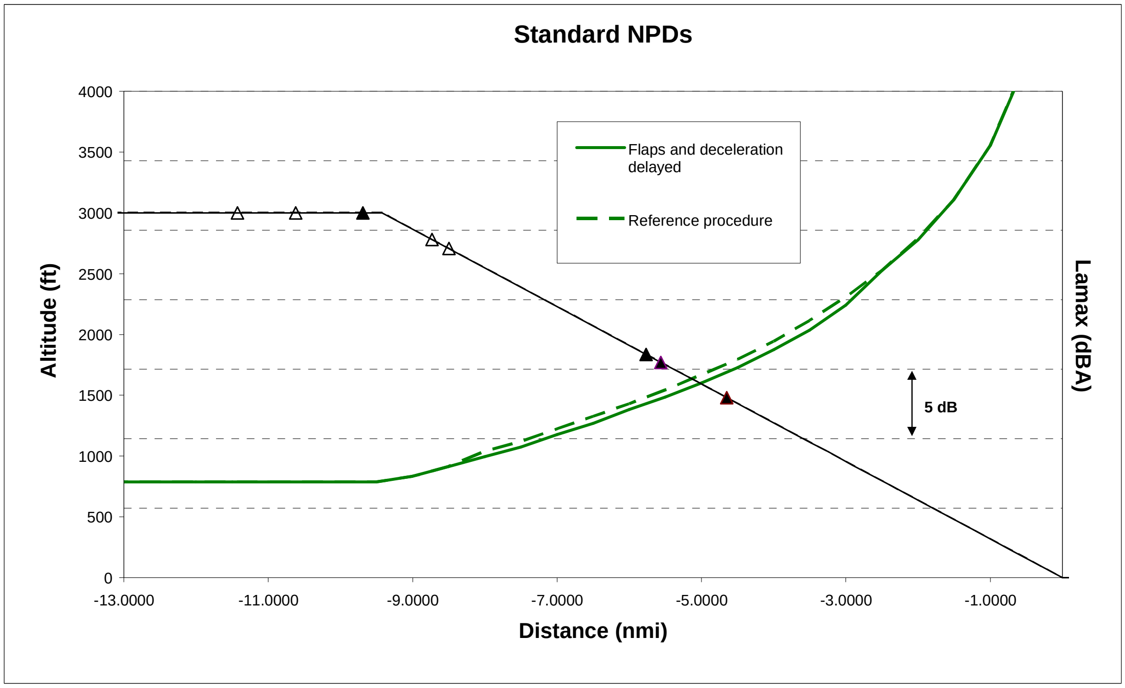

Figure 4-7: Noise level comparisons using standard INM

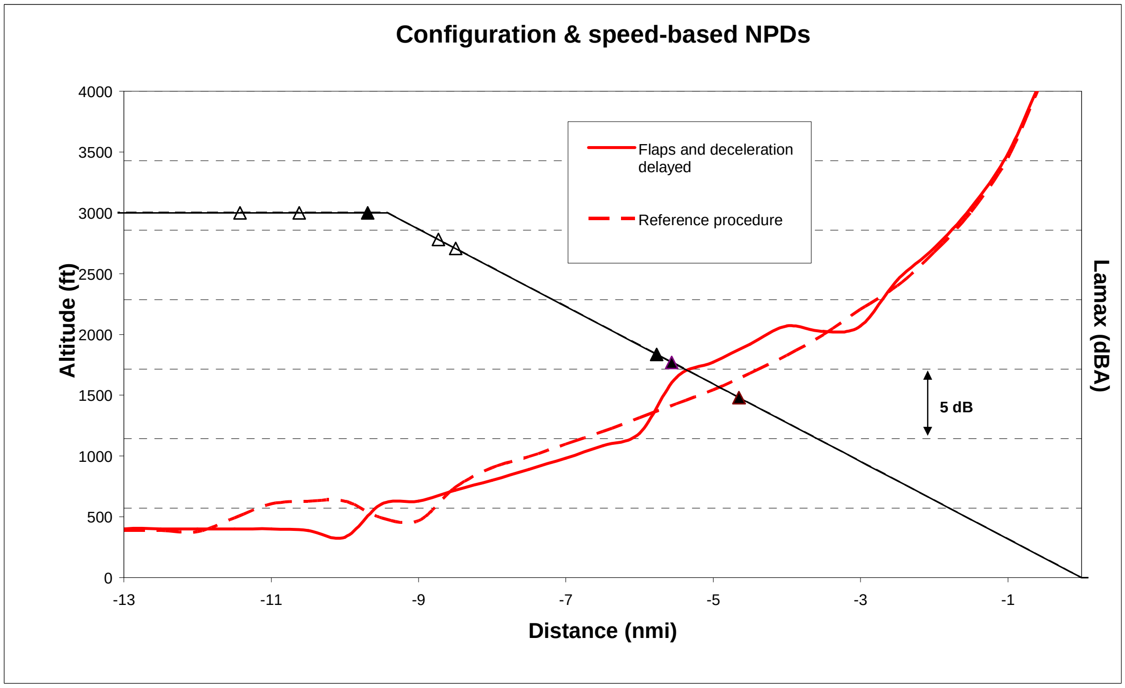

Figure 4-8: Noise level comparisons using configuration and speed-based NPDs

4.5.2. *Airport-scale noise contour examples*

The following examples compare, on an airport-scale, noise contours produced using respectively the standard and multi-configuration NPD methods. The purpose is to evaluate the actual effect on the shape and size of L_{DEN} contours (starting at 55 dBA) of better accounting for the airframe noise component, as a function of speed and configuration.

Contours have been calculated for three SII procedures (baseline, Procedure III and Procedure V - see Appendix A for their definition), applied to about 450 movements of a theoretical fleet. The graphs below compare, for each procedure, contours produced with the two methods.

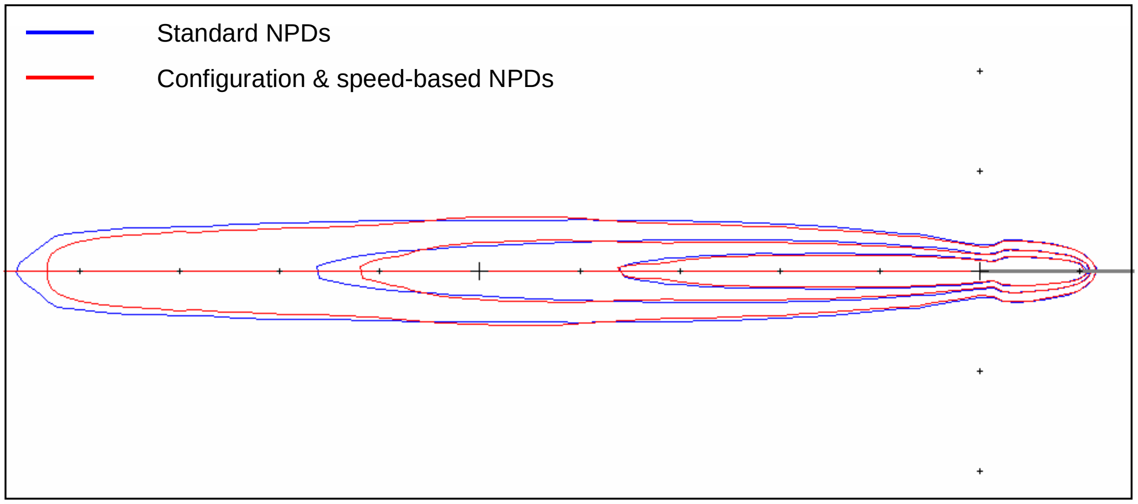

Figure 4-9: L_{DEN} contours (55 to 65 dBA) for the SII baseline procedure

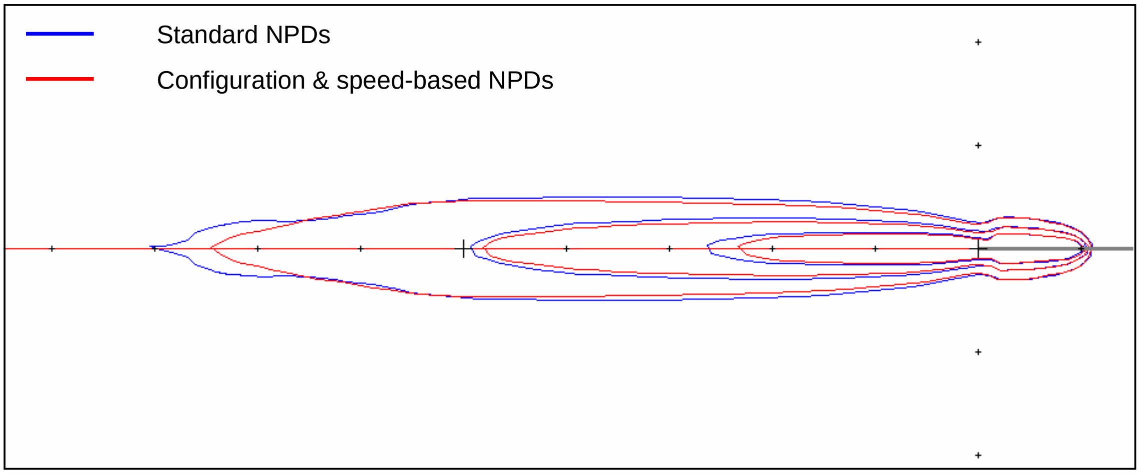

Figure 4-10: L_{DEN} contours (55 to 65 dBA) for SII Procedure III

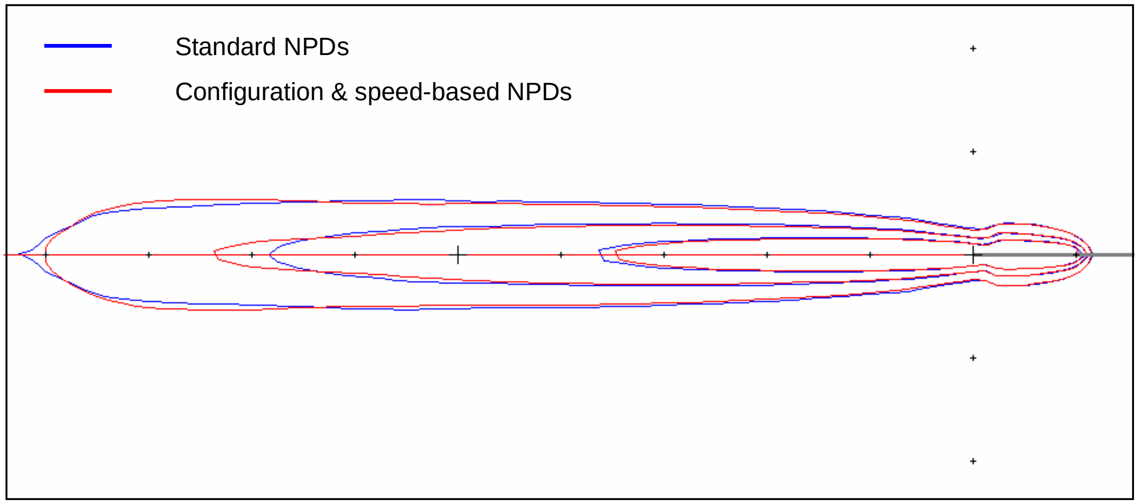

Figure 4-11: L_{DEN} contours (55 to 65 dBA) for SII Procedure V

As shown in Figure 4-9 and Figure 4-10, the use of multi-configuration NPDs instead of standard ones tends to reduce the length of contours, both for baseline procedure and Procedure III. This phenomenon is due to the fact that some aircraft types of the list have standard approach NPDs which have been derived for a configuration close to the final landing configuration with gear down, but for the 160 knot reference speed, which is a high speed value for that kind of configuration. The airframe noise component associated to such an aircraft state (and implicitly captured by standard approach NPDs) is rather conservative and tends therefore to over-estimate the actual airframe noise likely to be produced under the circumstances of these two procedures.

However, it can be noticed that the contour size reduction (resulting from using the multi-configuration NPDs) depends on the noise level threshold of interest and, even more important, on the procedure. As a consequence, the evaluation of the noise benefit of Procedure III, compared with the baseline (in terms of relative contour area reduction) gives different results, as indicated in Table 4-2, depending on the method used to produce the contours. In this example, the multi-configuration method predicts a better noise reduction than the standard method.

For Procedure V, the trend is even different: for L_{DEN} 60, the multi-configuration NPD method predicts a “longer” noise contour as compared with the standard INM method. This comes from the characteristics of the procedure, in which flaps and gear are extended earlier (i.e. at higher altitudes), and at higher speed values (above the reference speed value for which standard NPDs have been derived). In this case, the actual airframe noise contribution becomes higher than the one which is implicitly captured in standard NPDs. In the case of this procedure, the noise impact results (compared with the baseline procedure) depend on the modelling method used to produce the contours: for the L_{DEN} 55 for instance, whereas standard INM method predicts a (slight) reduction of around 5%, the multi-configuration NPD method shows that Procedure V does not provide any noise benefit in this situation, compared with the baseline procedure (Table 4-2).

	Procedure III		Procedure V	
	Standard NPDs	Multi-configuration NPDs	Standard NPDs	Multi-configuration NPDs
55 dBA	-26.4%	-28.0%	-4.8%	+1.0%
60 dBA	-26.3%	-32.0%	+1.8%	+5.1%
65 dBA	-28.2%	-34.3%	-5.6%	-3.7%

Table 4-2: Relative contour area variations Vs baseline procedure

5. SII flight-profile database development

5.1. Overview

As the fast-time simulations (performed in WP4) could not fully meet the requirement of producing flight profiles which accurately reflect how different aircraft types would actually fly the different selected SII NAPs, with the level of details required by the SII noise modelling system, a SII-specific aircraft flight profile database has been developed, as part of the noise modelling system. This database, which includes mainly manufacturer-supplied data, is used in the airport noise studies, instead of the the fast-time siumlated flight profiles.

For each of the twelve aircraft (for which multi-configuration NPD data have been produced – see Table 4-1), the database provides flight profiles associated to both the SII CDAs and NADPs (along with baseline procedures). The flight profiles are provided in the form of *fixed-point* profiles, which is the most appropriate and direct way for manufacturers to produce reliable data. Additionally, the *fixed-point* profile format (as far as approach procedures are concerned) is the only format supported by the SII-specific approach noise calculation module.

For each procedure, Airbus and Boeing have used their in-house aircraft performance modelling facilities to calculate the vertical profiles as flown by each aircraft type along a “virtual” straight ground track aligned with the runway. The profiles have been calculated for the following conditions:

- Atmosphere: ISA conditions,
- Runway at mean sea level,
- No wind.

When necessary, these manufacturer-supplied profiles have been converted (time-to-distance conversions, unit conversions, data reduction, etc.) to produce *fixed-point* profiles in accordance with the required INM format.

The flight profiles supplied by Airbus provide also fuel-flow data (kg/s) at each point of the profiles. This additional parameter is used for the emission calculations with TBEC (see chapter 1).

There is however one exception where manufacturer-supplied profiles have not been directly used, which is for the NADP profiles of the Boeing aircraft. Indeed, toward the end of the project, the SII NADPs (both close-in and distant procedures) have required new calculations of the associated flight profiles. Whereas Airbus has been able to produce such updated flight profiles, it has not be possible to ask Boeing to re-calculate new profiles within the remaining timeframe. Therefore, for the four Boeing aircraft, the INM *procedural* profile option, combined with the INM aircraft performance model, has been used to generate the required *fixed-point* profiles. This is described in more details in section 5.3.

5.2. Approach Profiles

Approach *fixed-point* profiles consist of a series of altitude, speed and thrust values as a function of ground distance to touchdown. Additionally, they provide the aircraft configuration state (flaps/gear) at each point of the profiles, as required by the SII-specific approach noise calculation module. The start altitude is 7000ft for all the profiles.

All the profiles have been calculated for aircraft operational weights corresponding to 90%MLW (Maximum Landing Weight).

Approach profiles have been produced for the basline procedure and the four SII CDAs, which are listed below:

- Baseline procedure (Procedure I), which includes a level deceleration segment at 3000ft, followed by a 3-degree glide slope,
- Procedure II, a basic CDA with a 2-degree initial flight path angle (FPA),
- Procedure III, a CDA with a 2-degree initial FPA and increased final glide slope
- Procedure IV, a CDA with constant speed, variable FPA segment at landing configuration
- Procedure V, which has a constant speed, variable FPA segment at intermediate configuration.

A detailed description of these procedures is provided in Appendix A.

It has to be noted that these calculated *fixed-point* profiles reflect how the aircraft would fly the procedures under standard conditions, according to the “generic” manufacturer specifications. In particular, the flap setting schedules and speed profiles do not capture any local speed constraints, which could be imposed at specific airports.

Additionally, the *fixed-point* profiles associated to the different procedures have all the same (aircraft-specific) rolling segment (after touchdown), including in particular the same reverse thrust and deceleration distance to reach taxi speed.

5.3. Departure Profiles

Departure *fixed-point* profiles consist of a series of altitude, speed and thrust values as a function of ground distance from brake release. The final altitude is 10000ft for all the profiles.

All the profiles have been calculated for aircraft operational weights corresponding to 85% MTOW (Maximum Take-Off Weight).

Departure *fixed-point* profiles have been generated for the three following procedures:

- Baseline procedure, which is the ICAO-A noise abatement procedure,
- SII optimised close-in procedure,
- SII optimised distant procedure.

A detailed description of these procedures is given in Appendix A.

The profiles calculated by Airbus for the close-in and distant procedures include a climb segment performed with a deep thrust cutback, whenever it can be achieved, i.e. when the thrust cutback is lower than MaxClimb thrust (this depends on the aircraft type, weight and the procedure as well). The aircraft-specific cutback values correspond to the minimum thrust which, in case of one engine inoperative, ensures with the remaining engines a climb gradient of 1.2% for twinjet aircraft and 1.7% for 4-engine aircraft. Additionally, for aircraft/procedures with a thrust cutback lower than MaxClimb thrust, the profiles incorporate an additional climb segment with a gradual thrust increase to MaxClimb.

As mentioned earlier in this section, the *fixed-point* profiles associated to the close-in and distant procedures for the Boeing aircraft have been generated using the INM *procedural* profile form, combined with the INM performance model.

The deep thrust cutback segment has been modelled using a *procedural* climb segment flown with the engine-out “minimum thrust” option. With this option, INM assigns to the climb segment a calculated thrust value (per engine), which, with one engine inoperative, enables a climb gradient (at constant speed) of 1.2% for twinjet aircraft and 1.7% for 4-engine aircraft. INM then computes the average climb gradient associated to the segment, which results from having this thrust value delivered by all the engines. This process, described in [TM6], complies with the definition of the cutback in the SII close-in and distant procedures. However, it has to be noted that actual cutback values (under operational conditions) may be above this minimum.

The gradual thrust increase segment has been modelled by a series of short *procedural* climb segments flown with user-defined thrust values (constant over each segment), using the INM “UserCutback” option. Each segment makes the aircraft climb 500ft. The user-defined thrust value on each segment corresponds to the value of the previous segment, incremented by a given thrust step. The increments start from the engine-out “minimum thrust” cutback value, and stop when reaching a thrust value corresponding to MaxClimb.

Additionally, for each aircraft type and procedure, an optimal value of the thrust increment (thrust step) has been determined (through “manual” iterations and single-event noise calculations), which allows to extend the noise reduction area compared with the case of instantaneous thrust restoration, and minimise the noise increase at longer distances (as illustrated in the example of Figure 5-2).

<u>Note</u>: For the other *procedural* segments (takeoff and acceleration segments), values of the related parameters have been derived from the profiles which had been initially calculated by Boeing for these NADPs (in particular: configuration, speed and climb rate schedules for acceleration segments).

An example of resulting flight profiles is given in Figure 5-1, for the close-in procedure, with and without gradual thrust increase segment.

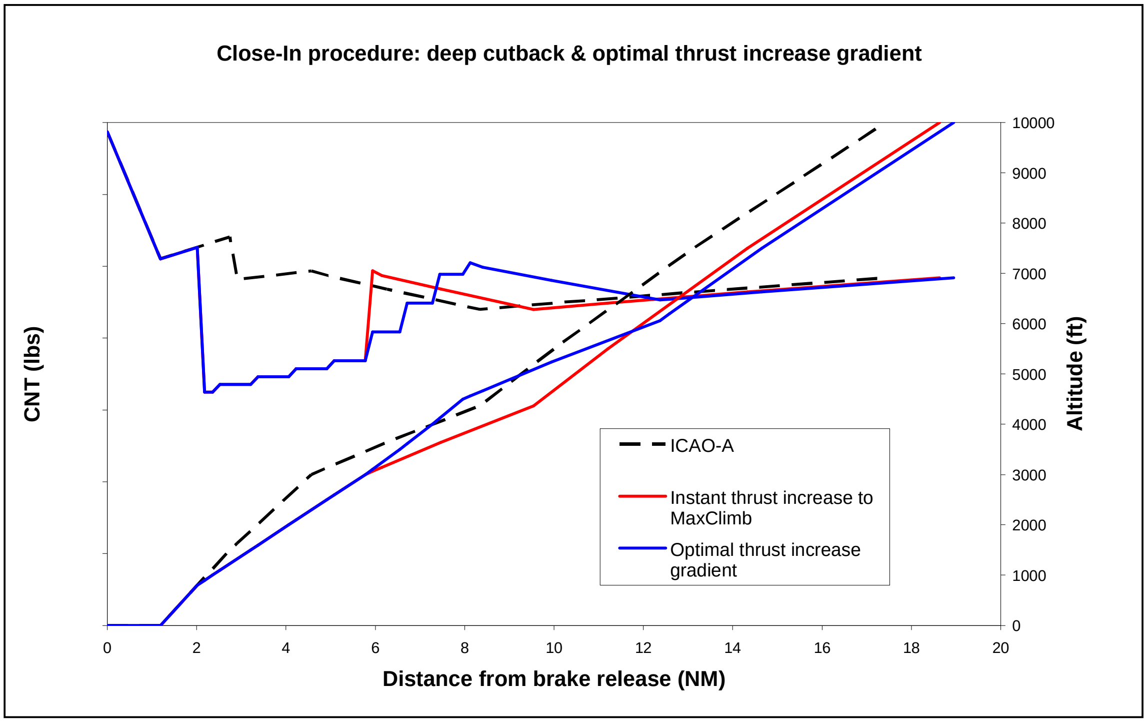

Figure 5-1: Close-in procedure with and without thrust increase gradient

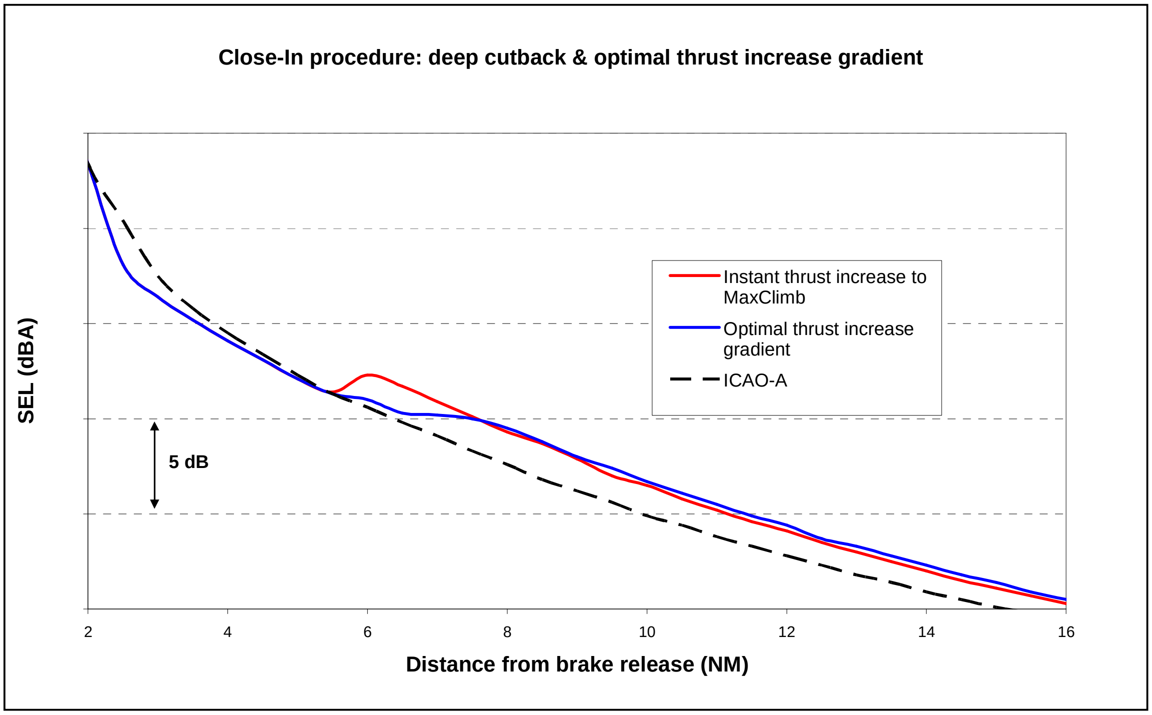

Figure 5-2: Additional noise benefit with an optimal thrust increase gradient

6. Application to the airport-scale noise studies

6.1. Introduction

This section describes briefly how the developed SII noise modelling system has been used to evaluate the noise impact of the SII procedures at the four airports. In particular, the different modelling assumptions are presented, along with the resulting limitations of the produced noise results.

6.2. Aircraft substitutions

The airport-scale noise assessments of the SII procedures require representing “in-service” aeroplanes operating at the studied airports by substitutes, i.e. the aircraft types for which the SII noise modelling system database provides specific noise and flight profile data.

In general, substitution techniques are used to represent actual fleet by a (necessarily) limited number of aircraft types (those available in the database of the model), with the goal of ensuring that calculated noise contours reflect the actual noise load produced at the airport. This is particularly required for the production of “historical” noise contours, where the estimated noise levels (absolute values) have to correlate as much as possible with noise measurements.

Making appropriate aircraft substitutions is not an easy process, given that noise footprints produced by individual movements are a mix of noise source characteristics and aircraft performance (i.e. through the resulting flight profiles, which define the source-to-receiver geometry, and the aircraft state along the trajectory). The most appropriate substitution tetechnique relies on the concept of "equivalencies": one movement of an unlisted aircraft is replaced by an equivalent number of movements of a proxy aircraft (available in the database). The proxy aircraft must have similar characteristics to the unlisted aircraft (closest weight, same number of engines and installed thrust-to-weight ratio). The equivalent number of movements of the proxy accounts for differences in the noise source characteristics between the proxy and the unlisted aircraft. This number is calculated based on the certication noise level differences between the two aircraft.

However, in the specific case of the SII airport noise studies, using such a method is not really appropriate (no real added value), as the specific noise modelling system includes “only” twelve (large and heavy) jet aircraft types: for many “in-service” aeroplanes, it would not be possible to find appropriate proxy (according to the criteria specified above) within this limited list. Addtionally, as the noise impact of the SII NAPs has to be evaluated in a relative way (i.e. against baseline procedures), for a same (constant) fleet-mix and number of movements, there is less need to produce absolute noise contours which accurately represent the actual noise load produced by “in-service” fleet at the airports.

A more basic and simple method is therefore proposed, using one-by-one substitutions (one movement of an unlisted aircraft is replaced by one movement of an aircraft available in the database). Table B- 1 of Appendix B provides a list of the main substitutions which have been used to represent fleet-mix likely to operate at the four airports in 2015. The proposed substitutions have been determined on the basis of either the closest aircraft MTWO, or the closest certification noise levels (using sideline EPNdB) when MTOW differences are too large. Four-engine aircraft like the B747-400 are substituted by the A340-313, the only available four-engine aircraft in the database. Turbo-prop and small jet aircraft have been discarded.

6.3. Input data definition

The definition of the input flight paths associated to each procedure to evaluate, is obtained by combining the procedure-specific *fixed-point* profiles, taken from the SII-specific flight profile database, with airport-specific ground tracks. These *fixed-point* profiles, produced for “generic” conditions, are normally not adjusted to reflect specific local conditions.

The SII noise modelling system enables (like standard INM) the definition of ground dispersion. However, in the SII airport noise analyses, aircraft are assumed to follow nominal tracks without any ground dispersion, for different reasons: firstly, it is assumed that aircraft will all perform R-NAV procedures in 2015, which should lead to minimum ground dispersion. Additionally, in the specific case of approach procedures, the noise contribution of single-events to the contours of interest (i.e. above 55dB for L_{DEN} and 50dB for L_{night}) is usually effective when the aircraft are aligned with the runway, so without ground dispersion of the trajectories.

Moreover, the ground tracks are assumed to be the same from one procedure to another. Only the distribution of traffic between the different tracks may be different (if this is required for operational reasons).

The input ground tracks and number of operations (per aircraft type, route and period of the day) are obtained from the fast-time simulations performed in WP4, through an automated process which has been specifically developed for this purpose. This process performs in particular the required aircraft substitutions.

6.4. Noise assessments - limitations

L_{DEN} and L_{night} contours are produced for ISA conditions, with no wind and for airports assumed at sea level (implicitly, through the use of the *fixed-point* profiles produced by manufacturers for these conditions). Terrain surrounding the airport is assumed to be flat, soft, free of obstacles (this corresponds to the standard conditions for which standard and multi-configuration NPDs have been produced).

Because of the above simplified assumptions, and because “in-service” fleet are represented by a limited set of twelve aircraft flying the procedures in a “generic” way, the produced noise contours should be considered as notional, and not representative of the actual noise load that would result from implementing the studied NAPs to a real fleet, under airport-specific operational conditions and constraints.

In particular, no guarantee can be given that aircraft types other than the eight Airbus and four Boeing aircraft taken into account by the model, would provide similar noise benefit when performing the SII NAPs. However, it is also believed that the twelve aircraft types which are taken into account in the the noise modelling process are a representative sample of popular aircraft, including different categories (large and heavy, twin and four-engine jet aircraft). The main weakness is probably the absence of the B747-400 in this list.

Additionally, differences in the noise results from one airport to another capture mainly the differences in the total number of operations (i.e. the size of the airport), and their distribution per aircraft type and route/runway.

7. Emission modelling

7.1. Introduction

The Sourdine project is primarily concerned with aircraft noise, not the pollutant emission produced. It is certainly not its role to perform a complete comparative local air quality study around the four Sourdine II airports. Such studies are very complicated and are still the subject of debate concerning the different methods used. In addition, such studies generally include all pollutant sources around an airport, not just airborne aircraft. The Sourdine II project must content itself with an analysis of the difference in pollutant production due to the different Sourdine II procedures.

This comparison can be broken down into two parts: fuel burn over the duration of the flight – which also gives us a comparison of CO_2 and SO_X production, both of which have global effects -, and the production of pollutants near to the ground that will have a noticeable effect on the quality of air around the airport.

This section describes the Sourdine II approach to these questions.

7.2. Fuel-burn, CO_2 and SO_X

For the study of fuel-burn, CO_2 and SO_X it is necessary to analyse all of the trajectories to be compared on the basis on equivalent change in energy, i.e. to/from equal height and speed from/to the equal height and speed (generally stationary on the ground). The data available in the Sourdine project do not fulfill this criterion, as can be seen in the following figure of Sourdine approach trajectories.

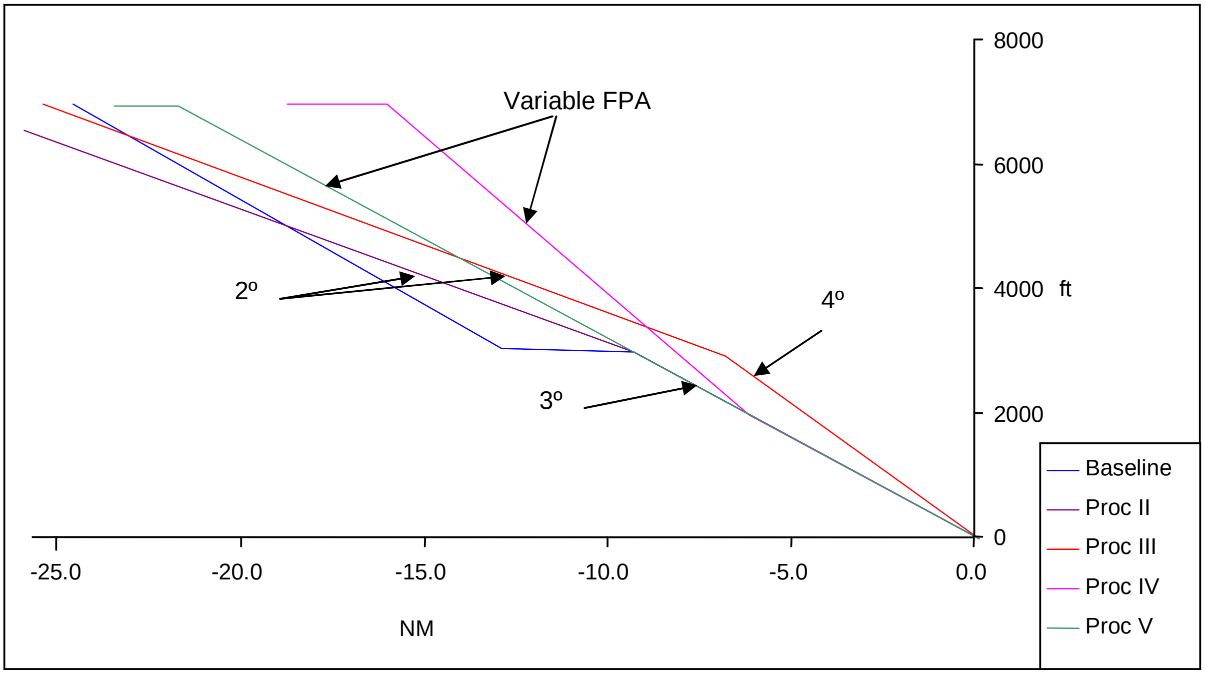

Figure 7-1: Vertical profiles of Sourdine II approach procedures

In order to perform a realistic fuel-burn analysis data would be required from a common point somewhere near the edge of the TMA. This is obviously well outside the scope of the present project.

Similarly, the Sourdine departure trajectories produce differing rates of climb and would have to be analysed up until some point, again near the TMA boundary.

A possibility initially considered for permitting such an analysis for approach procedures (and by analogy for departure procedures) was to consider that the Sourdine trajectories included a level segment at 7000ft from the point of intersection of this altitude with the trajectory that crosses it furthest out. This would obviously produce a bias towards Procedure II since it would have no level segment. Perfectly good procedures would be disadvantaged because of a level segment that does not, in reality, exist on which the plane would be considered to provide enough thrust to maintain constant speed. This would be compared with the baseline, whose level segment is used to reduce speed and has, therefore, minimal thrust. (Procedures IV and V are defined as having a level segment at 7000ft on which they decelerate to their respective initial approach speeds. These would not be, however, as long as required here.)

For this reason fuel-burn, and CO_2 and SO_X production, have not been analysed in the Sourdine II project. Future projects could perform this analysis by chosing a coincidental point on all trajectories. This is not, however, considered worthwhile in since the impact of these procedures on fuel-burn, and CO_2 and SO_X production, for the whole duration of even a short-haul flight is minimal.

7.3. Local Air Quality

Best practice methods consider that only that part of a flight below 3,000ft need be evaluated for pollutants that are a cause for concern in terms of their effects on the health of local populations. Analysis of these in Sourdine II has been, therefore, limited to sections of flight below this level. In order not to disadvantage the baseline procedure, which has a level segment at 3000ft, to an extent that comparisons become meaningless, this level segment has been ignored and analysis starts at the top of the final descent in this case.

The following sections describe the different steps of the local air quality analysis process used in Sourdine II in more detail.

7.4. Thrust-Based Emission Calculator

The Thrust-Based Emission Calculator (TBEC) is a Microsoft Access application which has been specially developed for Sourdine II in order to calculate aircraft emissions resulting from the different SII procedures. It uses the ICAO Engine Exhaust Emissions Data Bank [D_9646][8], which provides, for a large series of engine types, fuel flow (kg/s) and emission indices (g/kg of fuel) at four specific engine power settings (from idle to full take-off power). The overall principle of TBEC consists of calculating (by interpolations) emission levels, based on the actual thrust along the vertical *fixed-point* profiles associated to the SII procedures (see Chapter 5).

To calculate emission levels of different pollutants, it is necessary to have fuel flow information along the flight profiles. It was originally planned to approximate these by interpolations on input thrust values, as the ICAO databank provides fuel flow data associated to specific power settings (as described above). However, towards the end of the project, the International Civil Aviation Organisation Committee on Aviation Environmental Protection (CAEP)'s Modelling Working Group (WG2) considered that estimating fuel flow based on thrust was unsatisfactory without having a greater knowledge of individual aircraft/engine performance parameters, data that is not yet readily available.

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[8] The indicated reference corresponds to the paper version of the databank (first edition - 1995). Since, an electronic version of the databank database has been developed. It is hosted by the UK CAA, on behalf of ICAO, and updated at periodic intervals (data for new engines). TBEC uses the October 2004 version of the databank.

Consequently, realistic fuel flow data have been supplied by Airbus for all the studied SII procedures (along with the baseline procedures) and for the eight Airbus aircraft[9]. These fuel flow data have been incorporated, as an additional paramater, in the already produced *fixed-point* profiles (for the noise assessments – see Chapter 5). Based on the fuel flow and thrust values along the flight profiles, TBEC calculates total fuel burn (a straight forward process), and emission levels of different pollutants.

Calculation of arrival emissions stops at touchdown since the fuel-flow data available stop at that point. Reverse thrust emissions are not, therefore, taken into account. These would, of course, vary as a function of the landing speed of the aircraft, which is very slightly higher in the Sourdine II procedures than the baseline due to the different landing configurations used.

7.4.1. TBEC inputs

TBEC calculates fuel burn and emission levels for the *fixed-point* profiles of the SII flight profile database, which include the additional fuel flow parameter (Airbus aircraft only). As already described in Chapter 5, these input *fixed-point* profiles provide altitude (ft), speed (kts), corrected net thrust (lbs) and fuel flow (kg/s) as a function of the ground distance (ft) from brake release (for departures), or to touchdown (for arrivals).

7.4.2. TBEC outputs

For a given procedure (i.e. a flight profile), TBEC calculates total fuel burn and total emissions (in kgs) of the following components:

- Hydrocarbons (HC);
- Carbon Monoxide (CO);
- Oxides of Nitrogen (NO_x);
- Sulphur Dioxide (SO_2);
- Carbon Dioxide (CO_2);
- Water (H_2O);
- Volatile Organic Compounds (VOC);
- Total Organic Gases (TOG).

Note: VOC are Acetaldehyde, Acrolein, POM16PAH, POM7PAH, Styrene. TOG are Formaldehyde, Propianaldehyde, Toluene, Xylene, 1-3Butadiene, Benzene, Ethylbenzene.

The calculation of total fuel burn is a straight forward process: it is simply obtained by the time-integration of the input fuel flow data along the profile.

HC, CO and NO_x are obtained by linear interpolations in the ICAO databank, using as input data the corrected net thrust and the fuel flow on the successive segments of the profile. The calculation principle is described in details in the next section.

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[9] As this requirement was specified toward the end of the project, it was not possible to get similar data from Boeing within the remaining timeframe.

CO_2 , SO_2 and H_2O emissions are proportional to fuel burn (or fuel flow), and are obtained using emission coefficients (kg/kg fuel flow, or g/kg fuel flow for SO_2). The VOC and TOG emissions are obtained in a similar way from the calculated emissions of HC. All these emission coefficients are independent of the engine type.

7.5. Calculation principle

The flight profile is defined by a series of small segments, each segment being defined by two consecutive points of the *fixed-point* profile. The overall calculation principle consists of estimating the fuel burn and emission levels produced by each segment, and summing them (over the flight profile) to obtain the total fuel burn and emissions of each pollutant.

7.5.1. Fuel burn

The fuel burn on a segment FB_{seg} is calculated as follows:

$$FB_{seg} = \Delta T_{seg} * FF_{seg} \tag{7-1}$$

where

- ΔT_{seg} is the duration (in seconds) of the flight segment. ΔT_{seg} is calculated using the distance between the two end-points of the segment, divided by the average speed of the aircraft on the segment;
- FF_{seg} is the average fuel flow on the segment (kg/s), calculated using the input fuel flow values at the two end-points of the segment.

7.5.2. HC, CO and NO$_x$

The ICAO Engine Exhaust Emissions Data Bank provides emission indices (g/kg fuel flow) at four different power setting levels, namely: Take-Off, Climb-Out, Approach, and Idle. These four power states correspond to a percentage of F_{oo}, the maximum engine thrust available for take-off under normal operating conditions at ISA sea level static conditions [D9646]. By definition, the four tabulated power settings correspond respectively to 100%, 85%, 30% and 7% of F_{oo}.

The emissions of HC, CO and NO_x on a segment are calculated through a linear interpolation between the above tabulated emission data. The different steps of the process are described below.

The Emission Indices $EI(P_i)$ of each pollutant provided by the ICAO data bank at the four power settings are converted into segment-specific emission flow $EF_{seg}(P_i)$ as follows:

$$EF_{seg}(P_i) = EI(P_i) * FF_{seg} \tag{7-2}$$

where

- $EF_{seg}(P_i)$ is the emission flow for the segment associated to power setting P_i (in g/s)
- P_i is one of the tabulated engine power settings for which emission indices are provided in the data bank (7%, 30%, 85% or 100%)
- $EI(P_i)$ is the emission indices associated to power setting P_i (in g/kg of fuel)

- FF_{seg} is the average fuel flow on the segment (in kg/s), calculated using the input fuel flow values at the two end-points of the segment

The segment-specific power setting parameter P_{seg}, at which the emission levels will be interpolated, is approximated as follows:

$$P_{seg} = \frac{CNT_{seg}}{Max\,StaticThrust} * 100 \tag{7-3}$$

where

- P_{seg} is the segment-specific power setting (%)
- CNT_{seg} is the average corrected net thrust (lb) on the segment, calculated using the input CNT values at the two end-points of the segment
- $MaxStaticThrust$ is the engine-specific maximum sea level static thrust, available in the INM database (lb).

The following describes the interpolation process to estimate the emission level of a given pollutant on the segment (see Figure 7-2).

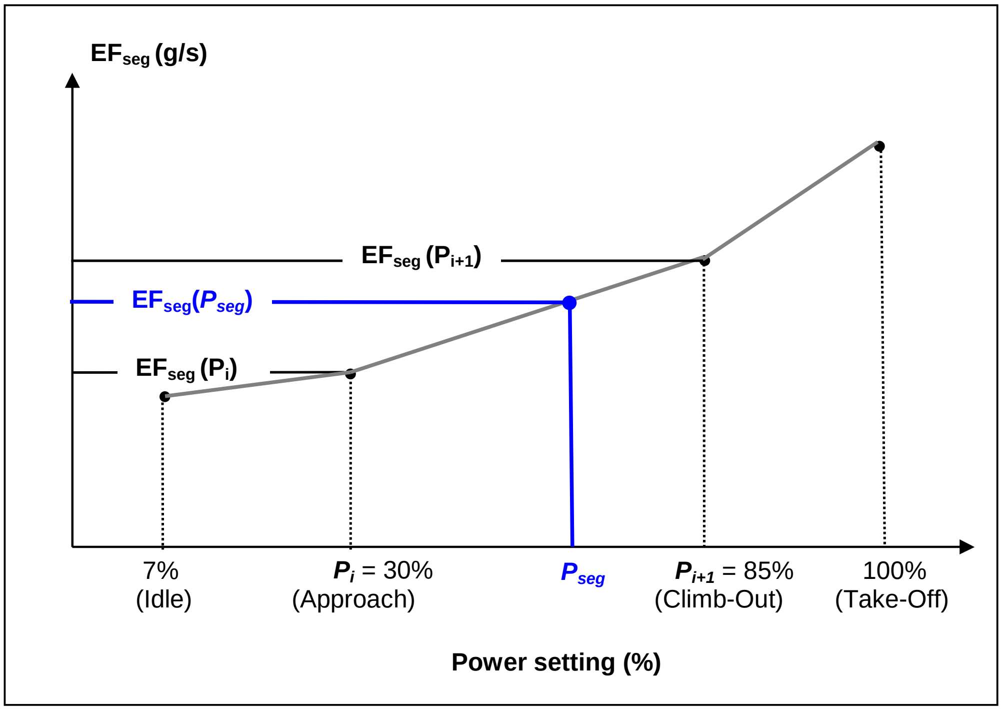

Figure 7-2: Emission Flow interpolation

The emission level of a given pollutant on the segment EL_{seg} is expressed as:

$$EL_{seg} = \Delta T_{seg} * \left[EF_{seg}(P_i) + \frac{P_{seg} - P_i}{P_{i+1} - P_i} \left(EF_{seg}(P_{i+1}) - EF_{seg}(P_i) \right) \right] \qquad (7\text{-}4)$$

where

- EL_{seg} is the emission level of the pollutant produced on the segment (g);
- ΔT_{seg} is the duration (in seconds) of the flight segment. ΔT_{seg} is calculated using the distance between the two end-points of the segment, divided by the average speed of the aircraft on the segment;
- P_{seg} is the segment-specific power setting (%), obtained from (7-3);
- P_i and P_{i+1} are the two tabulated power setting values bounding P_{seg} (%);
- $EF_{seg}(P_i)$ and $EF_{seg}(P_{i+1})$ are the emission flow values (g/s) associated to P_i and P_{i+1}, obtained from (7-2).

7.5.3. CO_2 , SO_2 , H_2O

CO_2 , SO_2 and H_2O emission levels are directly proportional to the calculated fuel burn and are estimated using the following emission coefficients:

Component	Emission coefficient
CO_2	3.149 (kg/kg fuel)
SO_2	0.84 (g/kg fuel)
H_2O	1.23 (kg/kg fuel)

7.6. Limitations / Validity

The first limitation of TBEC is that it does not take into account the variation of the emission indices with altitude due to temperature and pressure changes. Indeed, the ICAO databank provides emission indices for ISA conditions; these are, however, assumed to be valid for altitudes below 3,000 ft. Implementing the Boeing Method 2 (*BM2*), described in [AEM], which TBEC does not do for the moment, would allow the modelling of the effects of non-ISA temperature and pressure conditions at the airport.

Another limitation is due to the assumption that emission indices vary linearly with the thrust level, which is obviously not the case in real life. Here again, implementing the *BM2* would enable the modelling of non-linear variations between the four thrust settings in the ICAO databank (Take-Off, Climb-Out, Approach and Idle).

The method used to calculate the power setting parameter required to perform the interpolations might be questionable. Using the N1 parameter instead could be more appropriate. Further investigation of this point is required.

TBEC should be, therefore, considered as a prototype, which can only be used to derive general trends between different procedural scenarios, rather than to assess the exact amount of gaseous emissions generated by a specific procedure.

Appendix A: Description of the selected SII procedures

A.7. Approach procedures

A.7.1. Baseline

The baseline procedure (Procedure I) includes a level deceleration segment at 3000ft, followed by a 3°glide slope.

Condition	Parameter values
7000 ft (Fixed height)	– Speed 250 KTS CAS – Level flight – Clean configuration – Landing Gear up
	– Idle thrust – Constant CAS descent
3000 ft (Fixed height)	– Level flight – Decelerate to intermediate flap speed (IFS) and change to intermediate configuration
	– Fixed descent angle of 3° – Landing gear down – Decelerate (+) and change to landing configuration (++) – Decelerate to final approach speed (FAS)
Landing configuration and speed reached (Resulting height, minimum 1000ft)	– Adapted Thrust for descent at 3° – Constant speed (FAS) descent to 50ft

Table A- 1: Procedure I (baseline) definition

(+) To maximum allowable speed to select landing configuration

(++) Minimum allowable flap deployment

A.7.2. *Procedure II*

Procedure II is a basic continuous descent approach (CDA) with a 2° initial Flight Path Angle (FPA).

Condition	Parameter values
7000 ft (Fixed height)	– Speed 250 KTS CAS – Level flight – Clean configuration – Landing Gear up
	– Idle thrust – Fixed 2° Flight Path Angle (FPA) – Decelerate to intermediate flap speed (IFS) and change to intermediate configuration
3000 ft (Fixed height)	– Fixed descent angle of 3°. – Landing gear down – Decelerate and change to landing configuration (++) – Decelerate to final approach speed (FAS)
Landing configuration and speed reached (Resulting height, minimum 1000ft)	– Adapted thrust for descent at 3° – Constant speed (FAS) descent to 50ft

Table A- 2: Procedure II definition

(+) To maximum allowable speed to select landing configuration

(++) Minimum allowable flap deployment

Here it can be noticed that the final approach takes place at the minimum allowable flap deployment whereas the baseline procedures defines maximum allowable flap deployment.

A.7.3. *Procedure III*

Procedure III is a CDA with 2° initial FPA and increased final glide slope

Condition	Parameter values
7000 ft (Fixed height)	– Speed 250 KTS CAS – Level flight – Clean configuration – Landing Gear up
	– Idle thrust – Fixed 2° Flight Path Angle (FPA) – Delay flap deployment as late as possible – Decelerate and change to intermediate configuration – Decelerate to intermediate flap speed (IFS)
3000 ft (Fixed height)	– Fixed descent angle of 4°. – Landing gear down – Decelerate and change to landing configuration (++) – Decelerate to final approach speed (FAS)
Landing configuration and speed reached (Resulting height, minimum 1000ft)	– Adapted thrust for descent at 4° – Constant speed (FAS) descent to 50ft

Table A- 3: Procedure III definition

In this procedure the final approach again takes place at the minimum allowable flap deployment. The final flight path angle is 4º.

A.7.4. Procedure IV

Procedure IV is a CDA with constant speed, variable FPA segment at landing configuration.

Condition	Parameter values
7000 ft (Fixed height)	– Speed 250 KTS CAS – Level flight – Clean configuration – Landing Gear up
	– Idle thrust – Decelerate, landing gear down and change to landing configuration (+), – Decelerate to final approach speed (FAS)
Landing configuration reached (Resulting FPA)	– Descend at constant speed (FAS) to 2000ft – Idle thrust
2000 ft (Fixed height)	– Adapted thrust for descent at 3° – Constant speed (FAS) descent to 50 ft.

Table A- 4: Procedure IV definition

(+) To maximum allowable speed to select landing configuration

(++) Minimum allowable flap deployment

Here we have a variable initial glide slope, with ILS interception from above at 2000ft. Speed remains constant from the top of descent, 7000ft, as does the configuration (landing).

A.7.5. Procedure V

Procedure V has a constant speed, variable FPA segment at intermediate configuration

Condition	Parameter values
7000 ft (Fixed height)	– Speed 250 KTS CAS – Level flight – Clean configuration – Landing Gear up
	– Idle thrust – Decelerate and change to intermediate configuration – Decelerate to intermediate flap speed (IFS)
Intermediate configuration reached (Resulting FPA)	– Descend at constant speed (IFS) to 3000ft – Idle thrust
3000 ft (Fixed height)	– Fixed descent angle of 3°. – Landing gear down – Decelerate and change to landing configuration (++) – Decelerate to final approach speed (FAS)
Landing configuration and speed reached (Resulting height, minimum 1000ft)	– Adapted thrust for descent at 3° – Constant speed (FAS) descent to 50ft

Table A- 5: Procedure V definition

(+) To maximum allowable speed to select landing configuration

(++) Minimum allowable flap deployment

Despite the above diagram's showing a constant 3º glide slope from 7000ft, the initial part, down to 3000ft, of this is variable and depends on the type of aircraft for its actual profile.

A.8. Departure procedures

A.8.1. Baseline

This is the ICAO-A noise abatement procedure.

Altitude (ft)	
0 ft	- TOGA (Take-Off Go Around) Thrust - Conf 1+F - Climb out at V2 + 10 kt
1500 ft	- Reduce to Climb Thrust - Maintain V2 + 10 kt
3000 ft	- Acceleration to 250 kt, retracting flaps/slats on schedule - Climb to 15000 f

Table A- 6: Departure baseline definition

A.8.2. Close-in procedure

The Sourdine optimised close-in procedure as defined in the original Sourdine project.

Condition (altitude ft)	Parameter values
0 ft	– TOGA (Take-off Go Around) thrust – Brake release and acceleration to rotation speed (*) – Rotation and lift-off
	– Retraction of undercarriage – Climb out at a speed of V2 + 10-20 KTS IAS (**)
At 800ft	– Reduce thrust to *CUTBACK* or Max Climb, whichever is lowest – Maintain V2 + 10-20 KTS IAS
3000 ft	– If *CUTBACK* thrust was selected: perform *GRADUAL THRUST INCREASE* to Max Climb thrust – Maintain V2 + 10-20 KTS IAS
Upon achieving Max Climb	– Accelerate and retract flaps/slats on schedule to clean configuration – Continue acceleration to 250KTS – Climb to 15000ft

Table A- 7: Close-in procedure definition

(*) cleanest possible takeoff configuration

(**) V2+10 where possible

A.8.3. *Distant procedure*

The Sourdine optimised distant procedure

Condition (altitude ft)	Parameter values
0 ft	– TOGA (Take-off Go Around) thrust – Brake release and acceleration to rotation speed (*) – Rotation and lift-off
	– Retraction of undercarriage – Climb out at a speed of V2 + 10-20 KTS IAS (**)
At 800ft	– Accelerate to zero-flap speed (Vzf) – Retract flaps/slats on schedule to intermediate configuration
Upon reaching Vzf	– Complete flaps/slats retraction to clean configuration – Reduce thrust to *CUTBACK* thrust or Max Climb, whichever is lowest – Maintain speed
5000 ft	– If *CUTBACK* thrust was selected: perform *GRADUAL THRUST INCREASE* to Max Climb thrust, maintaining constant speed
Upon achieving Max Climb	– Accelerate to 250 KTS IAS – Maintain speed – Climb to 15000 ft

Table A- 8: Distant procedure definition

(*) cleanest possible takeoff configuration

(**) V2+10 where possible

Appendix B: Substitution table for the SII airport noise studies

Table B- 1 below provides a list of aircraft substitutions, to be used in the airport noise assessments of the SII procedures. The “Aircraft” column gives the list of the main aircraft types likely to operate at the four studied airports in 2015. The “INM Subsitution” column provides an “equivalent” aircraft type for each of them, within the list of the twelve Sourdine aircraft (or “none” in the case of small jet and turbo-prop aircraft).

MTOW Class [1000kg]	**Aircraft**	***MTOW [1000kg]***	**SL Max EPNdB**	**INM Substitution**
15 ≤MTOW< 40	CRJ-100/200	21.5	86	*none*
	EMB145	22-24	84.6	*none*
	ATR42	16	80.7	*none*
	Dornier 328	16	83.8	*none*
40 ≤MTOW< 60	Fokker70/100	45.18	91.7	B737-300
60 ≤MTOW <100	B737-300	62.8	90.4	B737-300
	A319-111	64-75.5	92	A319-111
	B737-400	62.9-68.1	93.2	B737-300
	B737-700	60-70	94.7	B737-800
	MD-88	72.5	97.2	A321-232
	MD-87	63.5	97.1	A321-232
	MD 81(S80)	63.5	97.3	A321-232
	MD82	67	96.3	A321-232
	A320-211	73.5-77	94.4	A320-211
	A320-214	73.5-77	94.4	A320-214
	A320-232	73.5-77	94.4	A320-232
	B737-800	78-79	93.1	B737-800
	B737-900	78-79	94.3	B737-800
	A321-211	83-93.5	94.3	A321-211
	A321-232	83-93.5	95.6	A321-232
100 ≤MTOW <160	B757-200	98.8-115.6	94.2-94.4	B757-200
	B757-300	123.6	94.5	B757-200

MTOW Class [1000kg]	Aircraft	MTOW [1000kg]	SL Max EPNdb	INM Substitution
$160 \le MTOW < 230$	B767-300	184.8-186.8	97	A330-301
$230 \le MTOW < 300$	A330-301	230-233	97.2	A330-301
	A340-313	271-275	95.8	A340-313
	MD11	275	96.1- 96.5	B777-200
	B777-200	253-305.97	96.1	B777-200
$300 \le MTOW < 400$	747-400	363-396.6	103.8	A340-313
	A340-600	368-380	98	A340-313

Table B- 1: Aircraft substitution table