getting to grips with

aircraft noise

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AIRBUS

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1. INTRODUCTION

1.1. BROCHURE ORGANIZATION

The operational context linked to noise restrictions calls for various and numerous notions related to sound theory. Obviously it is not the purpose of this book to drown the readers in an enumeration of “barbaric” and daunting equations.
Consequently, and for the sake of an easy reading, the main body of this document is dedicated to the operational context.
The second part of the brochure acts as a technically detailed inventory of notions and quantities linked to sound theory, where the sought information can quickly be located with the help of the index at the end of the booklet.

1.2. BACKGROUND

Among the various environmental concerns, the aircraft noise item has been constantly growing in importance over the past years.
Indeed, unlike a Mozart’s symphony, airplane noise is one of those sounds which are undesirable to most of the observers. Its various effects on man, especially on the people living in the vicinity of civilian and military airfields must be studied to be better accounted for.
This shall allow the determination and continuous refinement of indices reflecting noise impact, in order to develop an appropriate noise policy. The latter has the difficult mission to conciliate both the noise reduction around airfields while not penalizing too much the airlines operations, that is to say the air transport industry as a whole.

Consequently it is necessary to bear in mind this philosophy of continuously improving the ways of alleviating the noise exposure in a consensual way, namely the **“balanced approach”** concept :

- by adopting an appropriate land use and urban development
- by promoting ways to improve the aircraft design (noise reduction at the source)
- by establishing specific operating procedures
- by restricting operations (if needed)

The purpose of this document is to provide Airbus operators with a general background for a better understanding of what is behind the current regulations/recommendations.

1.3. ABOUT THE INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)

Air transport activity being a global industry both in terms of manufacturing and operations of the aircraft, it is very difficult to cope with various different local rules aiming at reducing the local noise burden. The air transport industry requires world-wide agreed business practices and to that purpose, it is necessary that any regulatory framework be set on an international basis.

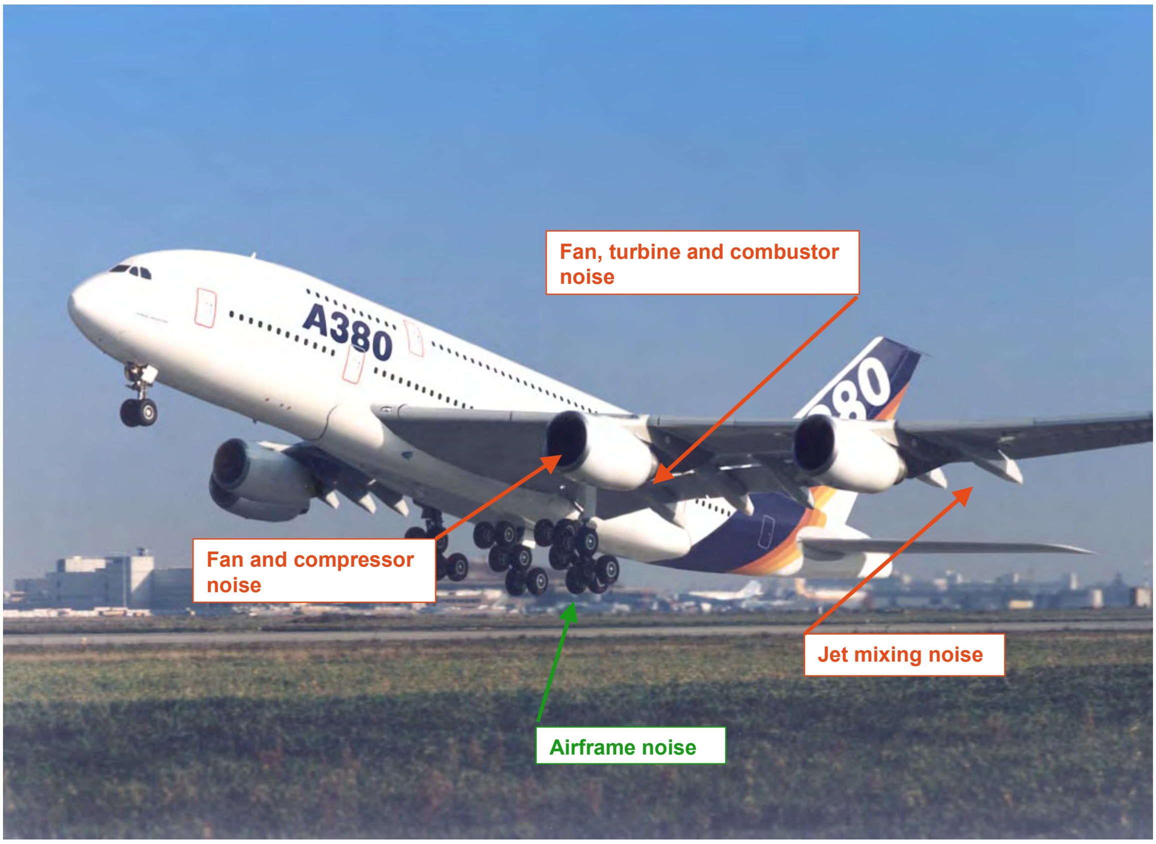
ICAO is the only recognized body that can establish such Standard and Recommended Practices through its Committee on Aviation Environmental Protection (CAEP).

Airbus promotes the ICAO leadership in the establishment of environmental recommendations that are then the base for national laws in the different ICAO Member States.

Thus the ICAO leadership for operational recommendations is highlighted as well as the means provided by Airbus to fully optimize airlines operations in a noise level constrained context, and with the highest level of safety.

2. AIRPLANE NOISE SOURCES

For the large majority of commercial jets, the primary noise source is the engines. The secondary one originates in the airflow around the aircraft (aerodynamic source). The purpose of this section is to give nice-to-knows regarding these sources.



2.1. ENGINE NOISE

2.1.1. JET NOISE

The jet noise is linked to the intense exhaustion of the burnt gases at high temperature. Downstream of the aeroplane wings, the jet generates strong turbulence as it enters a still area (relatively to the jet speed).
The main characteristics of this noise are the following:

- the generation area is located rear of the engines, at a distance equivalent to a few nozzle diameters
- the noise directivity is strong, heading for the back of the aircraft
- the noise generated does not contain remarkable tones, and its frequency band is quite wide.

2.1.2. FAN NOISE

The noise produced by the fan results of the superimposition of a wide-band noise (as for the jet) and noise with harmonics.

- The wide band noise is due to the boundary layer developing on the fan blades, and more generally to the airflow around them.
- The harmonics are originating in the intrinsic cycling character of the fan motion (spinning motion). The most remarkable frequency is the **fundamental**, the value of which is the number of blades times the fan rotation speed. The harmonics are multiples of this fundamental.
- When the engine rating is high (during takeoff for instance), the airflow around the fan blades transitions to supersonic and these multiple pure tones are at the origin of a the so-called **"buzz saw noise".**

2.1.3. COMPRESSOR NOISE

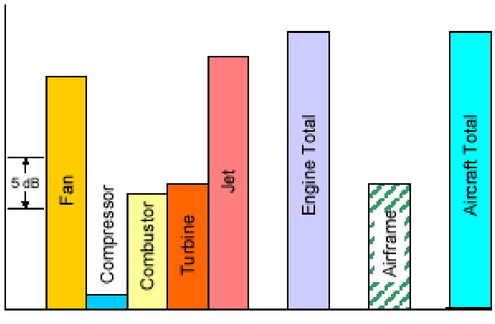
It is of the same kind than the fan noise, but the harmonics are less emergent due to interaction phenomena.

2.2. AIRFRAME NOISE

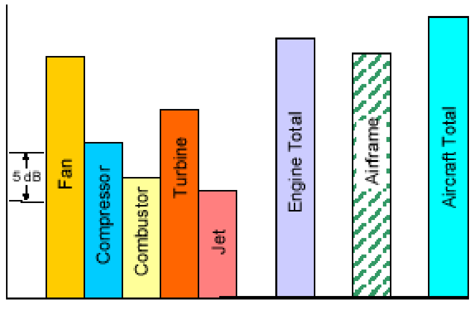
The airframe noise would be the noise produced by the aircraft, if all engines were made inoperative. It is generated by the airflow surrounding the moving plane. The main sources are the discontinuities of the aircraft structure, such as high-lift devices, landing gear wheels (when extended), trailing edges where there is a speed shearing (aircraft speed versus still air).
It was empirically determined that the noise emissions are dependent on the sixth power of the aircraft's true airspeed. This noise produced from aerodynamic phenomena is most sensitive during approach, when engine power is the lowest.

2.3. EXAMPLE OF SHARE BETWEEN ENGINE AND AERODYNAMIC NOISE

The following sketches illustrate the share between engine parts and airframe regarding noise emissions.



Take-off



Approach

3. JET-PLANES NOISE CERTIFICATION

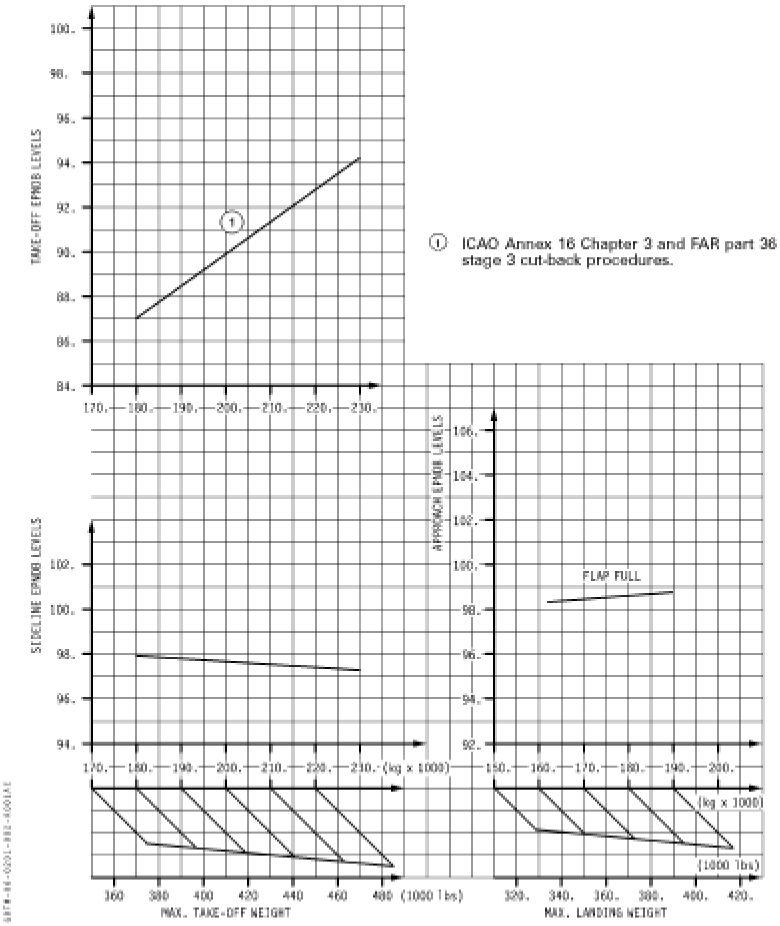
The purpose of this section is to remind the reader of some basic information which is nice-to-know regarding jet-planes noise certification and subsequent classification.
The aircraft noise certification aims at classifying various aircraft within a common background of procedures.
The following section exposes the **ICAO Annex 16 Volume 1**, which sets the background for aircraft noise certification. This context is introduced in the **JAR/FAR part 36**, and as such the noise levels identified are part of the approved documentation of the aircraft. They can be found within the Airbus **Airplane Flight Manual** on pages 6.02.01 p1 and 2, an example of which follows:

AIRBUS FLIGHT MANUAL	APPENDICES AND SUPPLEMENTS	6.02.01 P 02	
	EXTERNAL NOISE		

Engines :

Nacelle treatment : Basic configuration including inlet and fan duct treatments.

Noise levels are determined by entering the following graph at the maximum weights defined in the limitation chapter of this Flight Manual.



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3.1. ICAO ANNEX 16 VOLUME 1 CHAPTER 2

This ICAO Chapter 2 is applicable to aircraft for which the application for certificate of airworthiness for the prototype was accepted before 6 October 1977. As a consequence, all relevant aircraft are nicknamed “Chapter 2”.

3.1.1. NOISE EVALUATION MEASURE

ICAO Annex 16 Volume 1 Chapter 2 §2.2

The noise evaluation measure shall be the effective perceived noise level in ***EPNdB***

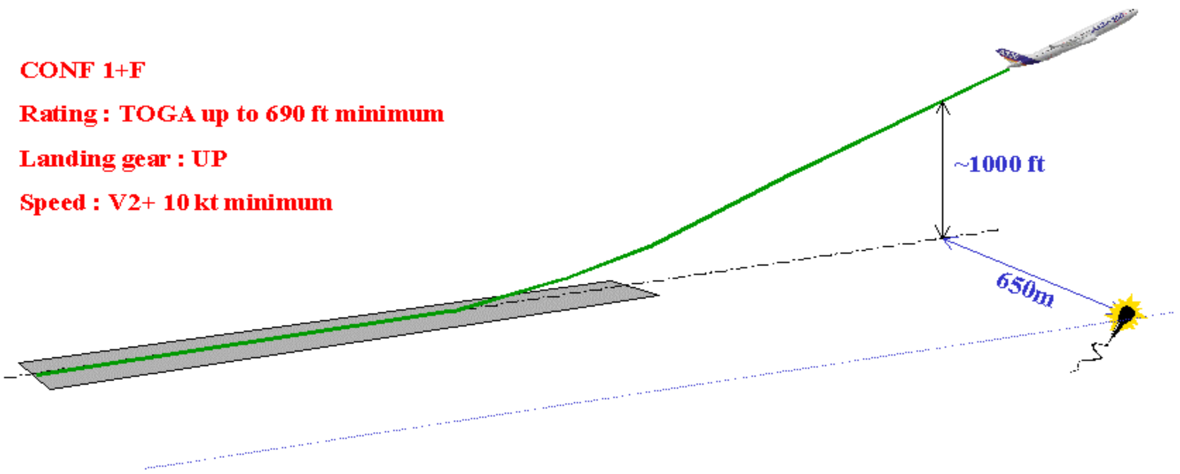
3.1.2. NOISE MEASUREMENT POINTS

ICAO Annex 16 Volume 1 Chapter 2 §2.3

An aeroplane, when tested in accordance with the flight test procedures of §2.6, shall not exceed the noise levels specified in §2.4 at the following points:

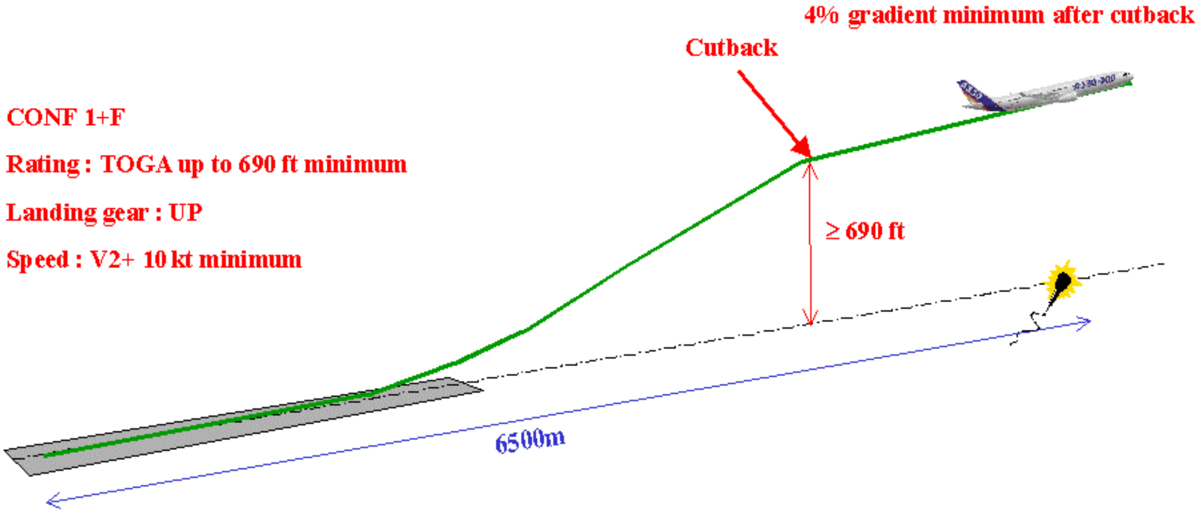
3.1.2.1. LATERAL NOISE MEASUREMENT POINT

The point on a line parallel to and 650 m from the runway center line, or extended runway centerline, where the noise level is a maximum during take-off.



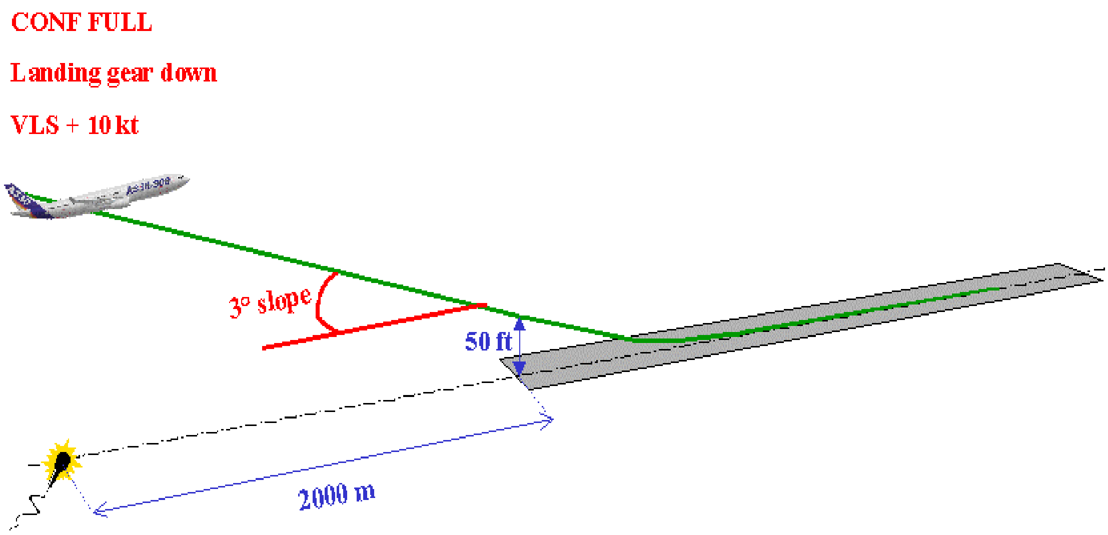
3.1.2.2. FLYOVER NOISE MEASUREMENT POINT

The point on the extended centerline of the runway and at a distance of 6.5 km from the start of roll.



3.1.2.3. APPROACH NOISE MEASUREMENT POINT

The point on the ground, on the extended center line of the runway, 120 m (395 ft) vertically below the 3° descent path originating from a point 300 m beyond the threshold. On level ground this corresponds to a position 2 000 m from the threshold.



3.1.3. MAXIMUM NOISE LEVELS

ICAO Annex 16 Volume 1 Chapter 2 §2.4

The maximum noise levels of those aeroplanes covered by Annex 16 Volume 1 Chapter 2 §2.1.1, when determined in accordance with the noise evaluation method of Appendix 1 of Annex 16, shall not exceed the following:

3.1.3.1. AT LATERAL AND APPROACH NOISE MEASUREMENT POINTS

106 EPNdB for aeroplanes with maximum certificated take-off mass of 272000 kg or over, decreasing linearly with the logarithm of the mass at the rate of 2 EPNdB per halving of the mass down to 102 EPNdB at 34 000 kg, after which the limit remains constant.

3.1.3.2. AT FLYOVER NOISE MEASUREMENT POINT

108 EPNdB for aeroplanes with maximum certificated take-off mass of 272 000 kg or over, decreasing linearly with the logarithm of the mass at the rate of 5 EPNdB per halving of the mass down to 93 EPNdB at 34 000 kg, after which the limit remains constant.

3.1.3.3. TRADE-OFFS

If the maximum noise levels are exceeded at one or two measurement points:

a) The sum of excesses shall not be greater than 4 EPNdB, except than in respect of four-engined aeroplanes powered by engines with by-pass ratio of 2 or more and for which the application for certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority before 1st December 1969, the sum of any excesses shall not be greater than 5 EPNdB.

b) Any excess at any single point shall not be greater than 3 EPNdB

c) Any excesses shall be offset by reductions at the other point or points

3.1.3.4. RECAPITULATIVE TABLE

M= Maximum Take-off mass in 1000 kg	***From 0 to 34***	***From 34 to 272***	***272 and above***
Maximum Lateral noise level (EPNdB) – All aeroplanes	**102**	**91.83+6.64 log M**	**108**
Maximum Approach noise level (EPNdB) – All aeroplanes	**102**	**91.83+6.64 log M**	**108**
Maximum Flyover noise level (EPNdB) – All aeroplanes	**93**	**67.56+16.61 log M**	**108**

3.2. ICAO ANNEX 16 VOLUME 1 CHAPTER 3

This ICAO Chapter 3 is applicable to aircraft for which the application for certificate of airworthiness for the prototype was accepted on or after 6 October 1977 and before 1 January 2006. As a consequence, all relevant aircraft are nicknamed “Chapter 3”. This is the case of most commercial airplanes, and **for all Airbus aircraft**.

3.2.1. NOISE EVALUATION MEASURE

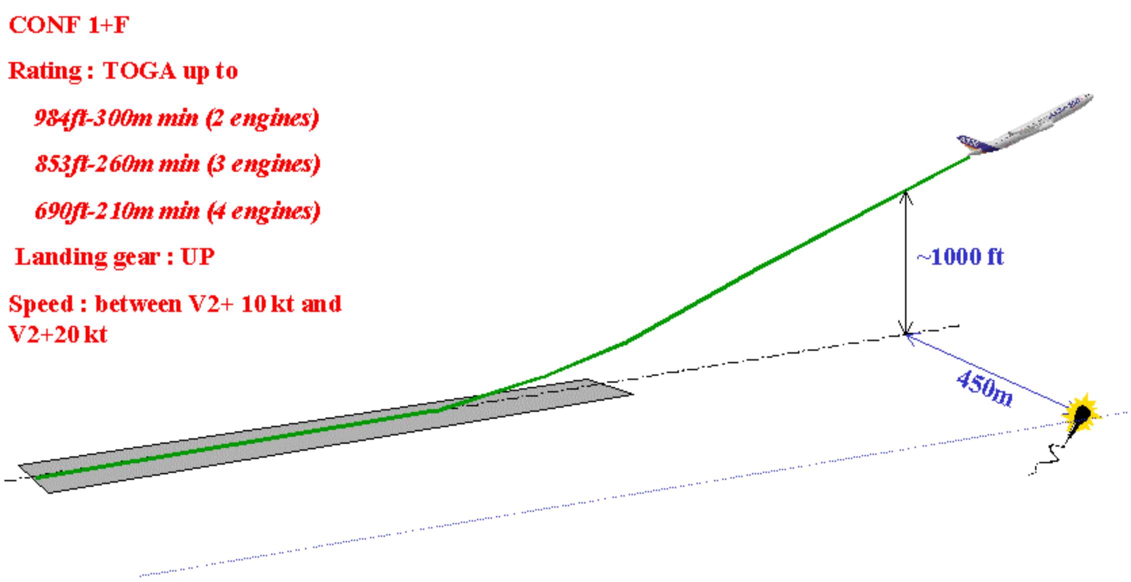
ICAO Annex 16 Volume 1 Chapter 3 §3.2
The noise evaluation measure shall be the effective perceived noise level in EPNdB.

3.2.2. NOISE MEASUREMENT POINTS

ICAO Annex 16 Volume 1 Chapter 3 §3.3
An aeroplane, when tested in accordance with these Standards, shall not exceed the noise levels specified in Chapter 3 §3.4 at the following points:

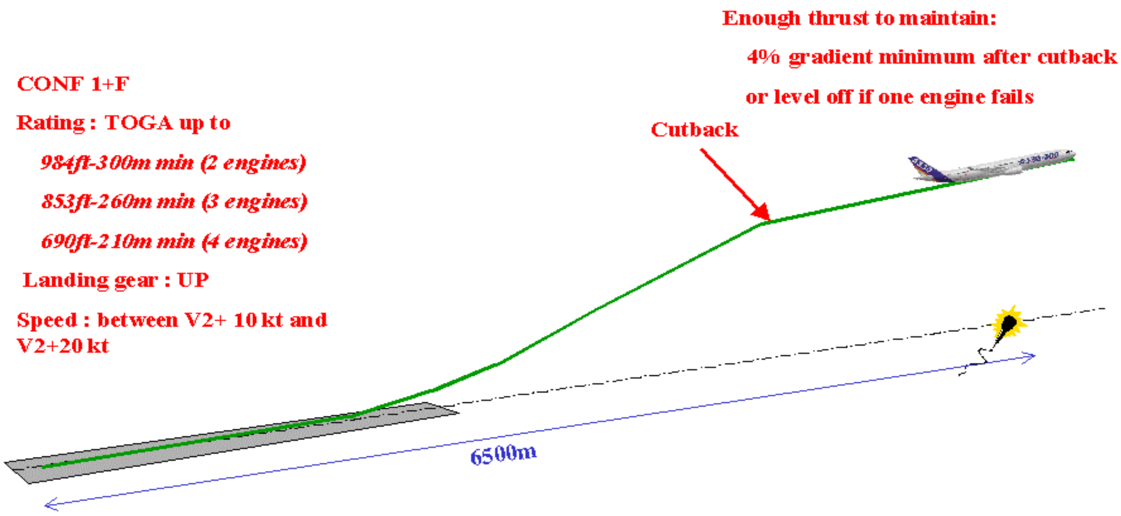
3.2.2.1. LATERAL FULL-POWER REFERENCE NOISE MEASUREMENT POINT

The point on a line parallel to and 450 m from the runway centerline, where the noise level is a maximum during take-off.



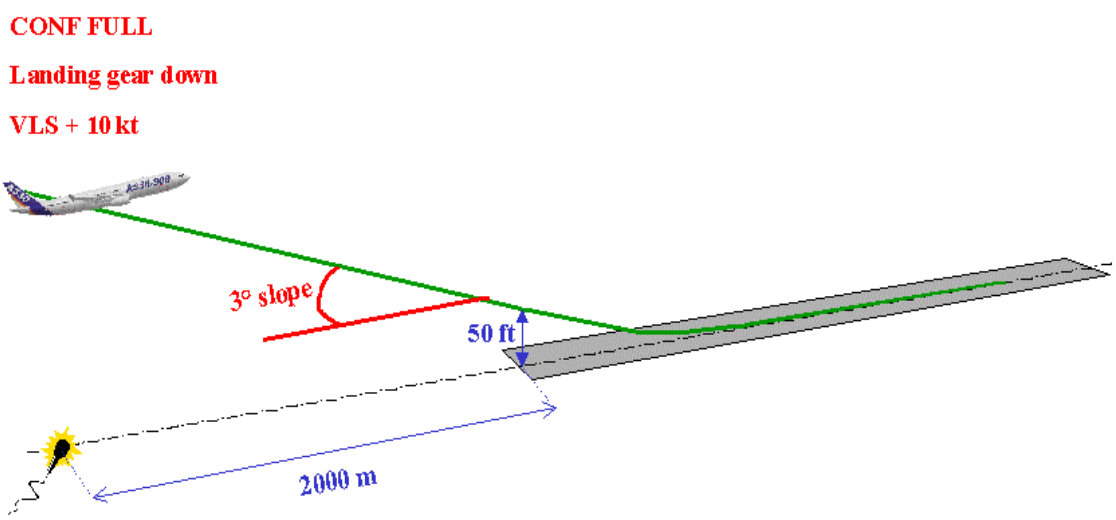
3.2.2.2. FLYOVER REFERENCE NOISE MEASUREMENT POINT

The point on the extended centerline of the runway and at a distance of 6.5 km from the start of roll.



3.2.2.3. APPROACH REFERENCE NOISE MEASUREMENT POINT:

The point on the ground, on the extended centerline of the runway 2 000 m from the threshold. On level ground this corresponds to a position 120 m (394 ft) vertically below the 3° descent path originating from a point 300 m beyond the threshold.



3.2.3. MAXIMUM NOISE LEVELS

ICAO Annex 16 Volume 1 Chapter 3 §3.4
The maximum noise levels, when determined in accordance with the noise evaluation method of Appendix 2 of Annex 16, shall not exceed the following:

3.2.3.1. AT THE LATERAL FULL-POWER REFERENCE NOISE MEASUREMENT POINT

103 EPNdB for aeroplanes with maximum certificated take-off mass, at which the noise certification is requested, of 400 000 kg and over and decreasing linearly with the logarithm of the mass down to 94 EPNdB at 35 000 kg, after which the limit remains constant.

3.2.3.2. AT FLYOVER REFERENCE NOISE MEASUREMENT POINT

a) Aeroplanes with two engines or less
101 EPNdB for aeroplanes with maximum certificated take-off mass, at which the noise certification is requested, of 385 000 kg and over and decreasing linearly with the logarithm of the aeroplane mass at the rate of 4 EPNdB per halving of mass down to 89 EPNdB, after which the limit is constant.

b) Aeroplanes with three engines
As a) but with 104 EPNdB for aeroplanes with maximum certificated take-off mass of 385 000 kg and over.

c) Aeroplanes with four engines or more
As a) but with 106 EPNdB for aeroplanes with maximum certificated take-off mass of 385 000 kg and over.

3.2.3.3. AT APPROACH REFERENCE NOISE MEASUREMENT POINT

105 EPNdB for aeroplanes with maximum certificated take-off mass, at which the noise certification is requested, of 280 000 kg or over, and decreasing linearly with the logarithm of the mass down to 98 EPNdB at 35 000 kg, after which the limit remains constant.

3.2.3.4. TRADE-OFFS

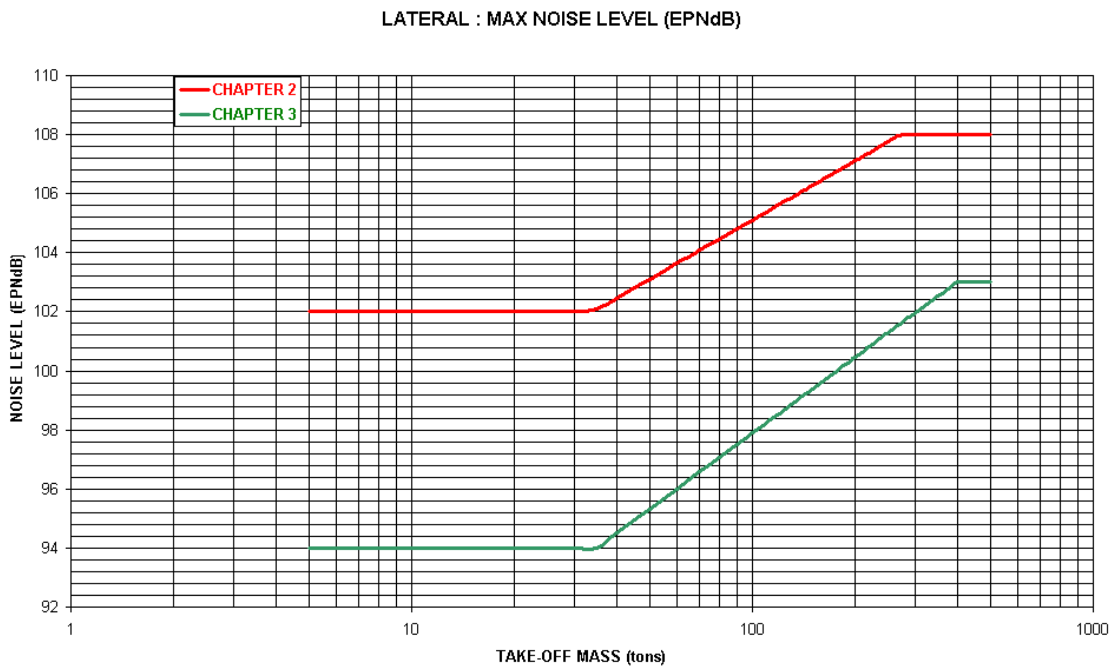
If the maximum noise levels are exceeded at one or two measurement points:

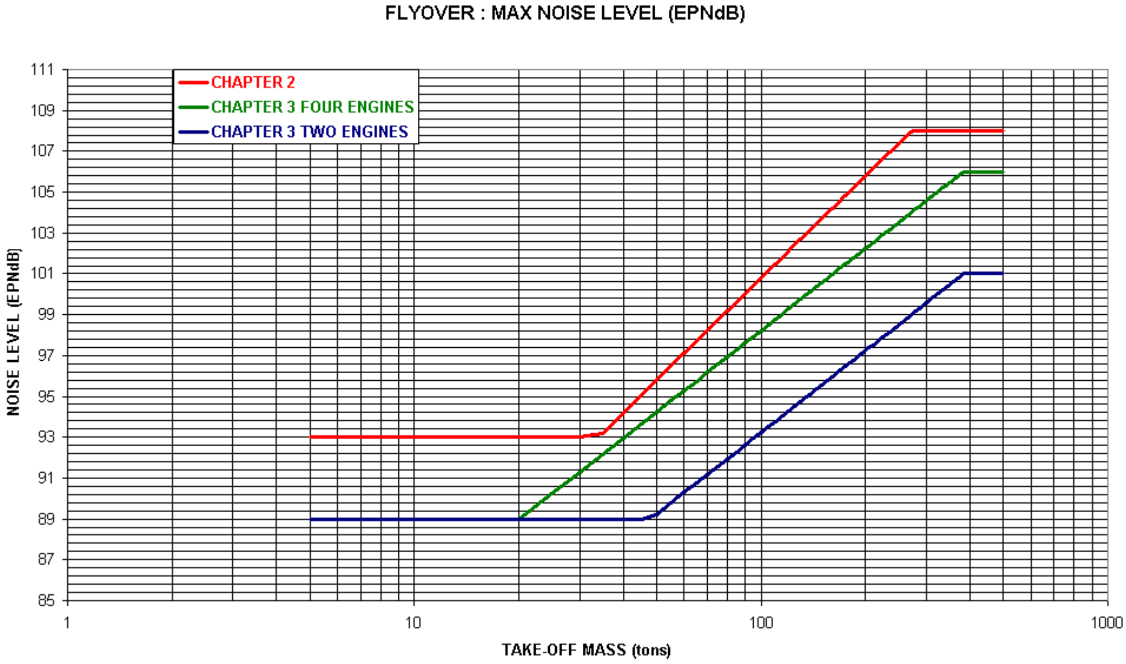
a) The sum of excesses shall not be greater than 3 EPNdB
b) Any excess at any single point shall not be greater than 2 EPNdB
c) Any excesses shall be offset by reductions at the other point or points

3.2.3.5. RECAPITULATIVE TABLE

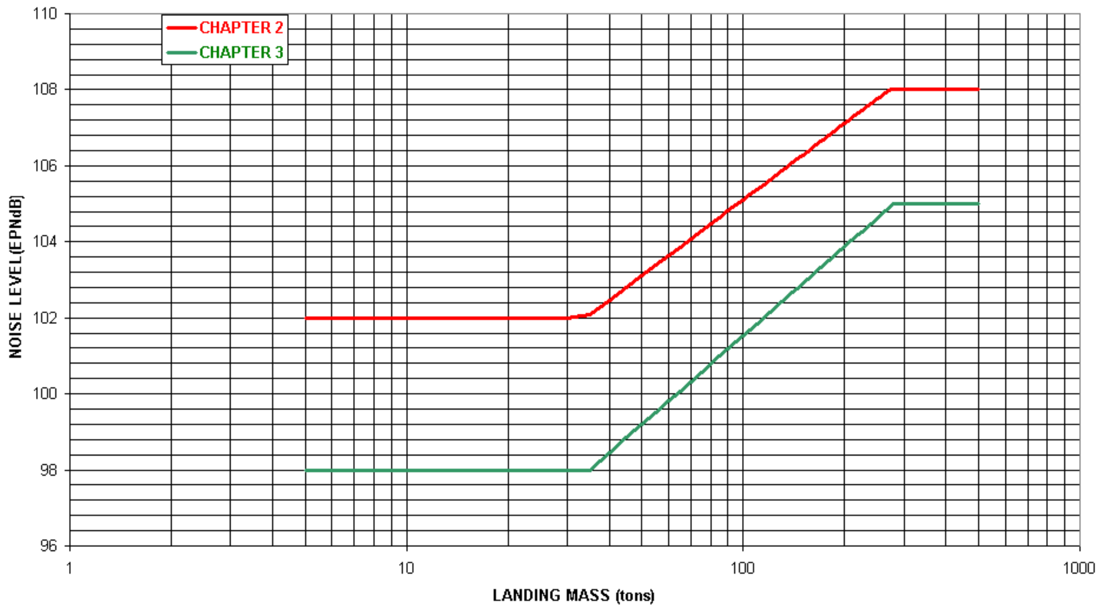
M= Maximum Take-off mass in 1000 kg	***From 0 to 35***	***From 35 to...***	***above***
Maximum Lateral noise level (EPNdB) – All aeroplanes	**94**	**...400** **80.87+8.51 log M**	**103**
Maximum Flyover noise level (EPNdB) 2 engines 3 engines 4 engines	 **89** **89** **89**	**...385** **66.65+13.29 log M** **69.65+13.29 log M** **71.65+13.29 log M**	 **101** **104** **106**
Maximum Approach noise level (EPNdB) – All aeroplanes	**98**	**...280** **86.03+7.75 log M**	**105**

3.2.3.6. CHAPTER 3 VERSUS CHAPTER 2 LIMITS





APPROACH : MAX NOISE LEVEL (EPNdB)



3.3. ICAO ANNEX 16 VOLUME 1 CHAPTER 4

This ICAO Chapter 4 is applicable to aircraft for which the application for certificate of airworthiness for the prototype was accepted on or after 1 January 2006. As a consequence, all relevant aircraft will be nicknamed “Chapter 4”. This will be the case of the A380 and most current Airbus aircraft are eligible to re-certification in this new category.

3.3.1. NOISE EVALUATION MEASURE

ICAO Annex 16 Volume 1 Chapter 4 §4.2

The noise evaluation measure shall be the effective perceived noise level in EPNdB as described in Appendix 2 of Annex 16.

3.3.2. NOISE MEASUREMENT POINTS

ICAO Annex 16 Volume 1 Chapter 4 §4.3

An aeroplane, when tested in accordance with these Standards, shall not exceed the maximum noise level specified in Chapter 4 §4.4 of the noise measured at the points specified in ICAO Annex 16 Volume1 Chapter 3, §3.3.1 a), b) and c).

3.3.3. MAXIMUM NOISE LEVELS

ICAO Annex 16 Volume 1 Chapter 4 §4.4

The maximum permitted noise levels are defined in ICAO Annex 16 Volume 1 Chapter 3, §3.4.1.1, §3.4.1.2 and §3.4.1.3, and shall not be exceeded at any of the measurement points.

- *The sum of the differences at all three measurement points between the maximum noise levels and the maximum permitted noise levels specified in Chapter 3, §3.4.1.1, §3.4.1.2 and §3.4.1.3 shall not be less than 10 EPNdB.*
- *The sum of the differences at any two measurement points between the maximum noise levels and the corresponding maximum permitted noise levels specified in Chapter 3, §3.4.1.1, §3.4.1.2 and §3.4.1.3 shall not be less than 2 EPNdB.*

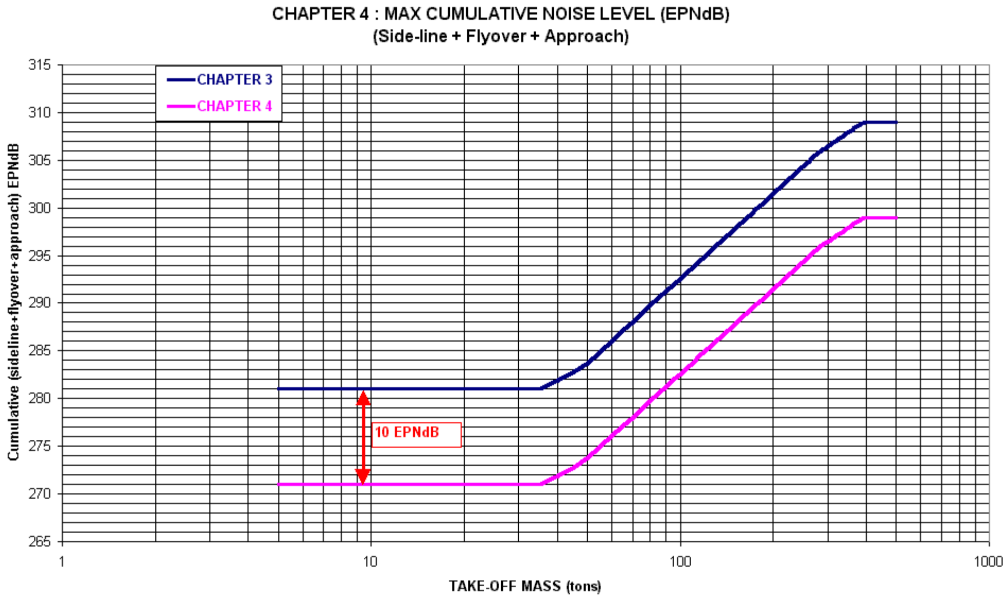
3.3.4. TRADE-OFFS

No trade-offs are allowed.

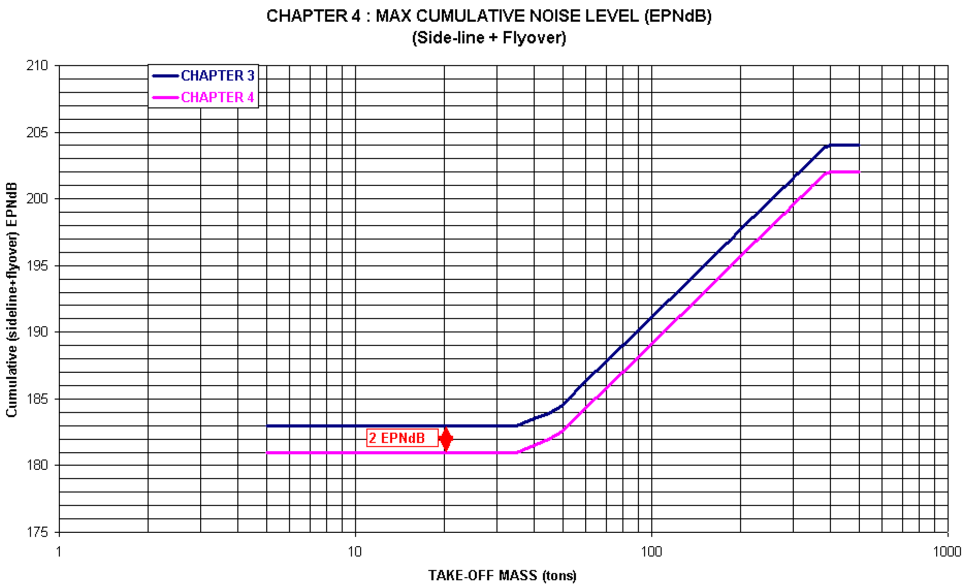
3.3.5. CHAPTER 4 VERSUS CHAPTER 3 LIMITS

For CHAPTER 4 :

- *The sum of the differences at all three measurement points between the maximum noise levels and the maximum permitted noise levels specified in Chapter 3, §3.4.1.1, §3.4.1.2 and §3.4.1.3 shall not be less than 10 EPNdB.*



- *The sum of the differences at any two measurement points between the maximum noise levels and the corresponding maximum permitted noise levels specified in Chapter 3, §3.4.1.1, §3.4.1.2 and §3.4.1.3 shall not be less than 2 EPNdB.*



4. AIRCRAFT NOISE MANAGEMENT AROUND AIRPORTS

The community noise does not only include the aircraft emissions but also other sources, such as road traffic. Actually the airport-side residents are also exposed to these other sources, the noise of which may be higher than the one produced by the aircraft, at least in terms of equivalent acoustic energy.
The noise produced by aeroplanes was not really a major issue before the early 60's, when the traffic of jet-planes started to grow. Nowadays, it can be considered as the most obvious kind of pollution due to aircraft operations. Nonetheless, we must acknowledge that the noise perception (and especially for aircraft) is very subjective and depends on the sensitivity to noise of each person. This is the reason why even though the global amount of aircraft noise energy has decreased, in the meanwhile the feeling of disturbance has increased.

To stay on the trend of noise reduction, different courses of action to decrease as much as reasonable (environmentally and economically speaking) the airport-side residents exposure have to be envisaged
This mission can be achieved by adopting the so-called "balanced approach" prescribed by the ICAO resolution A33-7, voted in October 2001.

4.1. THE BALANCED APPROACH

It encourages the ICAO member states in striking a smart balance between:

- the promotion and support of studies, research and technology programs aiming at reducing noise at the source or by other means,
- the application of land-use planning and management policies to limit the encroachment of incompatible development into noise-sensitive areas
- the application of noise abatement operational procedures, to the extent possible without affecting safety, and
- the non-application of operating restrictions as a first resort but only after consideration of the benefits to be gained from other elements of the balanced approach.

This philosophy is of great help for a realistic noise management. This brochure will only focus on possible actions in flight operations, as the land-use and urban development are not under the operator's control.

4.2. NOISE ZONING PLANS

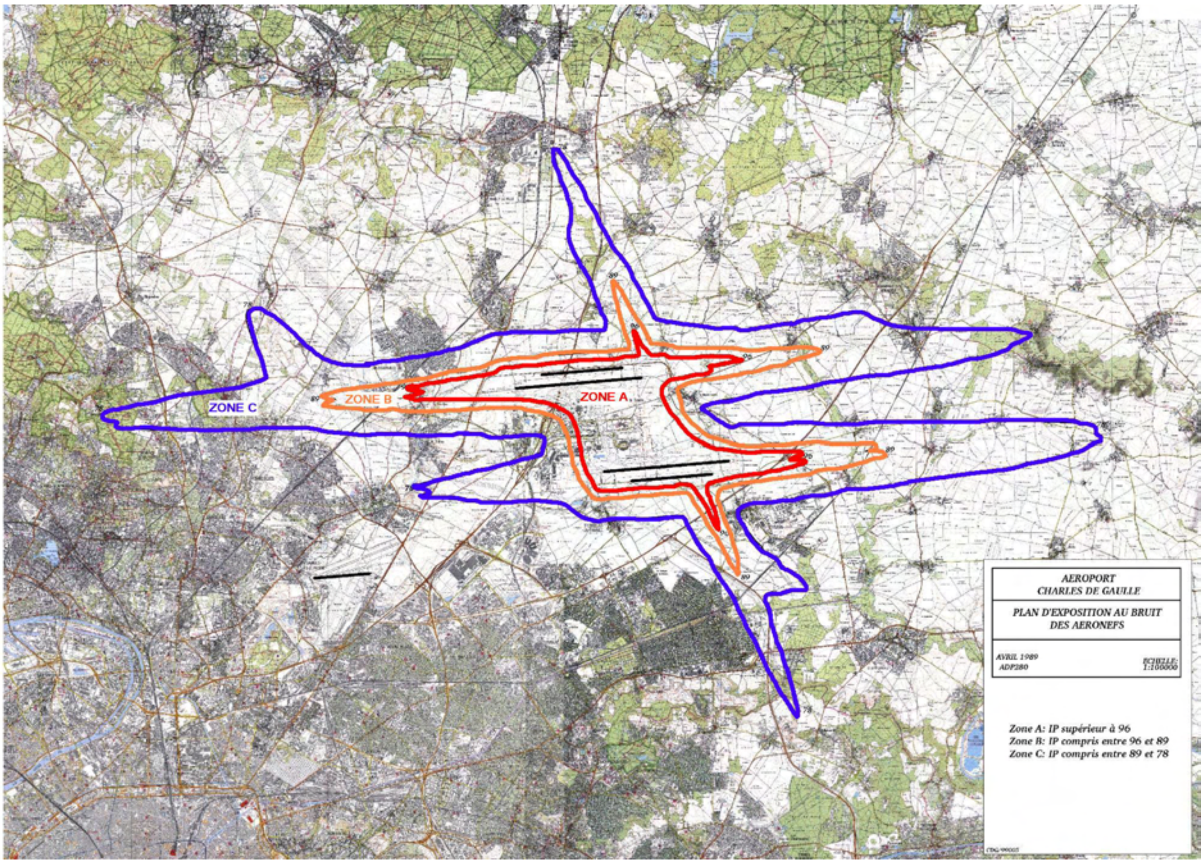
Once the choice of a **noise index** *(see section 9.5)* is made, several zones (at least two according to ICAO recommendations) can be defined for the purpose of land use planning. These are also used to enact specific policies in terms of admissible noise levels within sensitive areas, and/or to restrict operations (quotas, curfews...) for some aeroplanes:

1. The ZONE A, which is the high exposure zone at the very proximity of the runways, should not see noise-sensitive developments.
2. The ZONE B, where moderate noise exposure is experienced, may authorize land developments provided adequate measures are applied.

Additional zones (C, D...) may be defined, in order to refine the policy in terms of land use and admissible noise levels around the airport within the identified sensitive areas.
Each zone corresponds to an area within which the noise exposure exceeds a certain threshold (expressed with the relevant noise index).
Regarding the enactment of noise policy, the airport authorities also need to identify the already populated areas near the airfield. In a nutshell, these regions are then assigned a maximum “admissible” noise energy, averaged over a given period (typically a quarter), the value of which is expressed through a **noise exposure index**.
The knowledge of the forecasted traffic and associated procedures then allows to set a maximum permissible noise level per operation in order to comply with the maximum allowed **noise “budget”** defined for each area.

Example : Noise zoning plan at Paris-Charles de Gaulle airport

The zone C identifies the area within which sensitive areas are located (Noise Index between 78 IP and 89 IP). Within this zone (area between the blue and the amber contour on the chart), any flight operation must not generate a noise exceeding 80 dB(A).



4.3. POTENTIAL IMPACTS ON OPERATIONS

In the light of the previous considerations, noise constraints, depending on their level, may impact airline flight operations.
For existing airports, the noise zoning plan is helpful in order to specify the most efficient remedy to alleviate noise in an already populated (that is to say-sensitive) area.
Typically, such measures, which can be combined, are:

1. To enact a maximum permissible noise level, the value of which is relevant to target the intended noise index values in the considered region (also given the forecasted traffic and associated trajectories).
2. To classify the aircraft on a “quota count” scale, which means clearance for a limited number of operations per day depending on the noise level of the aeroplane.
3. Curfews
4. The preferential use of a runway
5. Noise abatement procedures

Such limitations may be coped with/attenuated in close co-operation between Airbus and the operator through the elaboration of appropriate operational procedures, namely the **Noise Abatement Procedures**. The goal of these is to reduce as much as possible the noise perceived on ground while maintaining the highest level of flight safety (*see also Section 5*):

- Pilots must not be overloaded, nor the ATC
- Minimum separation between aircraft must be respected

This is the reason why attention must be paid in the design process of **Noise Abatement Procedures** in order to avoid additional (and unnecessary) fees and restrictions (payload reduction, night-time curfews, quotas)

Consequently, because of this apparently difficult compromise, such procedures were late in being introduced in the **ICAO PANS OPS**, an overview of which is given hereafter.

5. NOISE ABATEMENT PROCEDURES

This section deals with the presentation of various kinds of Noise Abatement Procedures (for departure and approach). For takeoff, one type aims at reducing noise exposure in the airport vicinity, while the other is dedicated to noise alleviation remote to the airport. For approach, several ways of investigation are discussed.

Typical procedures are recommended by the **ICAO in PANS-OPS VOLUME 1 PART V CHAPTER 3**, in order to reduce the community noise.
While accounting for the published constraints (Standard Instrument Departures, airport published Noise Abatement Procedure), these ICAO noise abatement procedures shall be applied when noise benefits can be expected.

In no way must they prevail over safety aspects. In line with this philosophy, the pilot always retains full authority not to comply with such a procedure (even when published) if safety margins may be reduced by its application (i.e. in case of emergency).

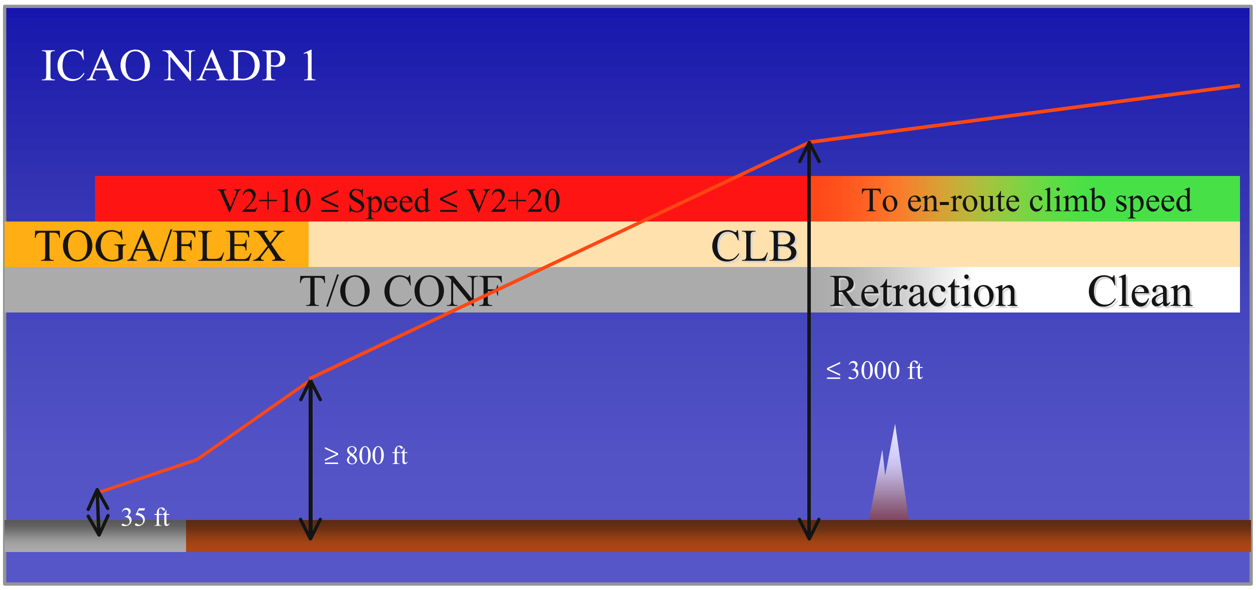
5.1. ICAO NADP CLOSE-IN AND NADP DISTANT PROCEDURES

These procedures are variations on the theme of reducing engine thrust (derate, cutback…) and managing speed at specific points along the takeoff flight path.

As a general recommendation, the minimum level of thrust for the current flap/slats configuration after cutback, is defined as the lesser of the climb power and that level necessary to maintain a specified engine inoperative minimum climb gradient (1.2% and 1.7% respectively for twins and quads) in the event of loss of the critical engine.

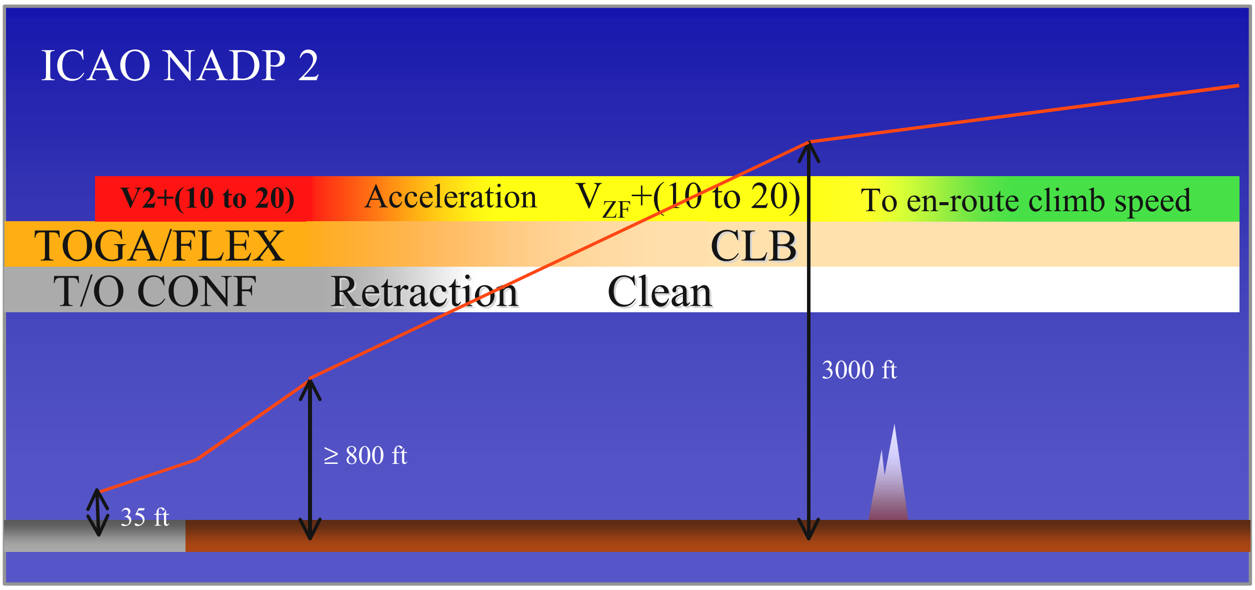
5.1.1. NOISE ABATEMENT DEPARTURE PROCEDURE "CLOSE-IN"

This procedure intends to reduce noise levels close to the airport. It involves a thrust cutback at or above a prescribed minimum altitude (800 ft) and delaying the flaps/slats retraction no later than the prescribed maximum altitude (3000 ft). At the prescribed maximum altitude, acceleration and flaps/slats retraction are performed according to standard schedule while maintaining a positive rate of climb and then completing the transition to normal en-route climb procedures.



5.1.2. NOISE ABATEMENT DEPARTURE PROCEDURE "DISTANT"

This procedure aims at reducing noise levels further away from the airport. It involves initiation of flap/slat retraction upon reaching the prescribed altitude (above 800 ft). The flaps/slats are to be retracted in accordance with standard schedule while maintaining a positive rate of climb. Acceleration targets the zero flaps safe maneuvering speed (**V_{ZF}**, or **S** in the Airbus world) plus 10 to 20 knots (typically **S+15**). The thrust cutback is to be performed simultaneously with the initiation of the first flap/slat retraction **or** when CONF 0 is achieved. At the prescribed altitude (3000 ft AAL), the transition to normal en-route climb procedures is completed.



5.2. POSSIBLE ACTIONS FOR AIRLINE AND AIRFRAMER

Considering the above, each operator may freely:

- Define the appropriate take-off rating (TOGA, DERATE or FLEX when possible)
- Determine the cutback height (above 800 ft)
- Adapt the climb rating (in respect to ICAO recommendations quoted above)
- Tune the V_{ZF} (for NADP 2)

This means nothing else but to design an optimized procedure, based on published airport constraints (as applicable).

5.3. APPROACH PROCEDURES

5.3.1. BACKGROUND

The engine power being close to its minimum during the approach phase, decreasing the noise levels means to minimize the airflow influence around the high-lift devices (flaps, slats) and landing gear, which are extended in this flight phase. Therefore, reducing the noise at the source is less easy than for take-off, where the engine rating can be tuned.
Thus, in approach, reducing noise means to decrease the drag and/or to increase the distance between the aircraft and the sensitive areas (when possible). This can be done by:

- Reducing the aircraft speed
- Performing the landing with the minimum certified aerodynamic configuration (eg CONF 3 instead of CONF FULL)
- Adapting the approach procedure profile (when possible, ex: steeper glide slope, continuous descent approach)

Clearly the first two items appear to be contradictory as decreasing the aerodynamic configuration means to increase the approach speed. Nonetheless, experience shows that for Airbus aircraft the noise decrease due to a lesser flaps deflection is higher than the one due to speed increase.

5.3.2. STEEP APPROACH

This kind of procedure allows a higher fly-over, as well as a faster direct approach. In Toulouse-Blagnac, an experiment with a 3.5° ILS axis was conducted, and proved to reduce the noise by 1 to 2 dB(A) close to the airport (around 6 km) and by 2 to 3 dB(A) remotely (around 11 km).

This steeper ILS approach was eventually given up since increasing the angle of descent might be detrimental to flight safety.

5.3.3. CONTINUOUS DESCENT APPROACH

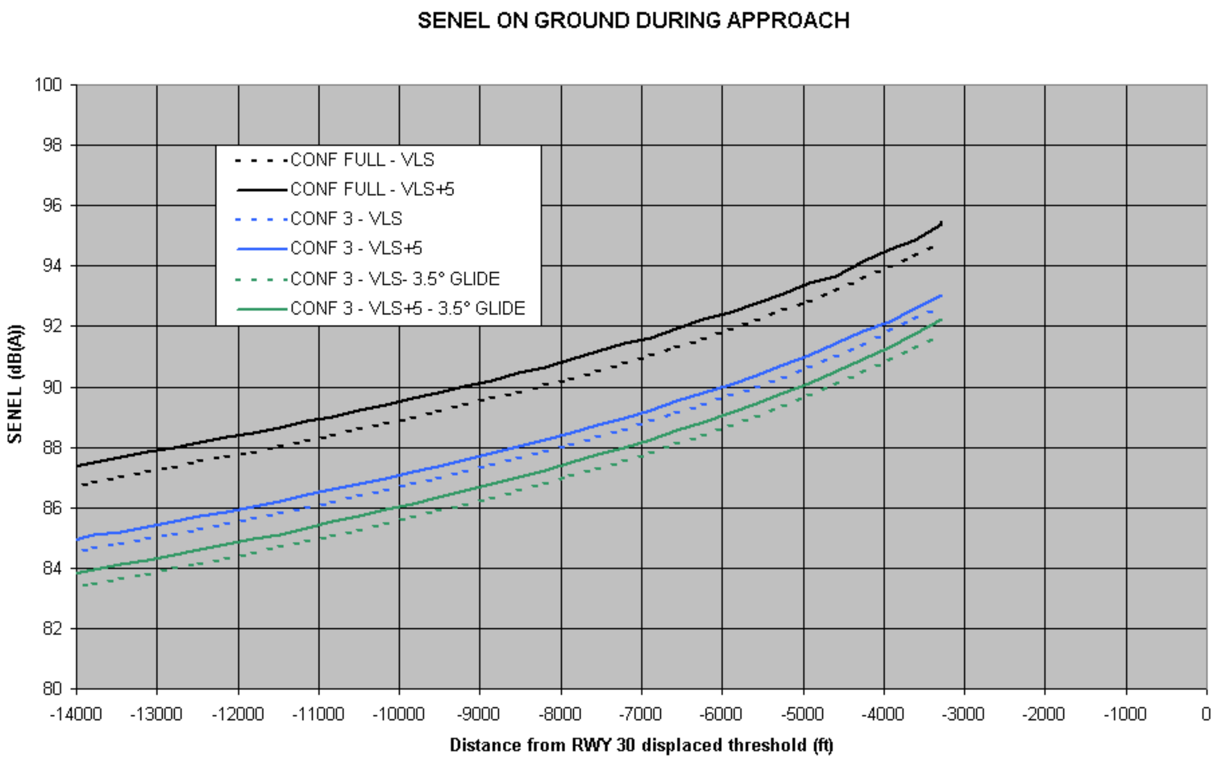
A continuous descent approach is an approach with minimum or no recourse to level segments below typically 7000ft AFE. It is not necessarily established on the ILS above 3000ft. It should be combined with appropriate flap/gear deployment schedule to avoid that additional airframe noise eliminates the noise reduction obtained by flying higher.
Experiments were conducted in London-Heathrow, where the glide was intercepted at around 7000 ft.
This kind of procedure is now applied by some airlines in London (33% during daytime), and up to 5 dB(A) can be gained at 8-12 NM from the airport.
The problem resides in the actual ILS interception at high altitude, due to the intrinsic reduced reliability. Also traffic stacking and displacement of the affected areas must be considered.
Nonetheless the potential is quite significant, as 2 dB(A) per 1000 ft increase of the minimum interception altitude can be expected over the previously mentioned area.

5.3.4. APPROACH AND LANDING WITH MINIMUM CERTIFIED FLAPS/SLATS SETTING

This kind of procedure is already applied by some airlines (when not limited by landing performance), and a gain up to 4 dB(A) can be expected close to the airport (distances less than 4 NM).

5.3.5. EXAMPLE OF NOISE ON APPROACH (FUNCTION OF APPROACH CONFIGURATION, SPEED AND GLIDE)

The following figure shows an example of the influence of approach speed, flaps/slats setting and glide angle on the approach noise.



5.4. COOPERATION BETWEEN AIRBUS AND AIRLINES

The optimization of a noise abatement procedure can be done with of Airbus software available within the **PEP for Windows** environment.
Airbus philosophy remains as always to provide airlines with all necessary support and associated tools for the optimization of flight operations. Although the process is now quite a routine for runway analysis (except where Engine Out Standard Instrument Departures have to be established), it is a little bit more complicated when noise limitations are added.
When only digitized Flight Manual and TLO software are used for standard take-off and landing optimization, additional software is required to optimize the operations when the regulatory performance limited take-off/landing weight and/or current operational procedures are likely to lead to an overshoot of noise limitations.
These are namely:

1. **OFP (Operational Flight Path)**: dedicated to the computation of operational (actual) trajectories. This program is part of the basic PEP package, and is available on request. ***Refer to Performance Programs Manual (PPM) Chapter 40.***
2. **NLC (Noise Level Computation)**: dedicated to the computation of single-event noise levels associated with an operational flight path computed by OFP. Not part of the basic PEP package, but working in the PEP environment (part of the noise package). ***Refer to PPM Chapter 45.***
3. **NEX (Noise EXposure)**: dedicated to the computation of noise indices, thus reflecting the noise exposure for a given operations scenario. Not part of the basic PEP package, but working in the PEP environment (also part of the noise package). ***Refer to PPM Chapter 46.***
4. In a close future (2004), a new component will be able to take over the above manual tasks. It is called **ADAS (Airbus Departure Analysis Software)**. ***Refer to Section 8 §8.6 – ADAS*** for more information.

The following chapter shows two examples:

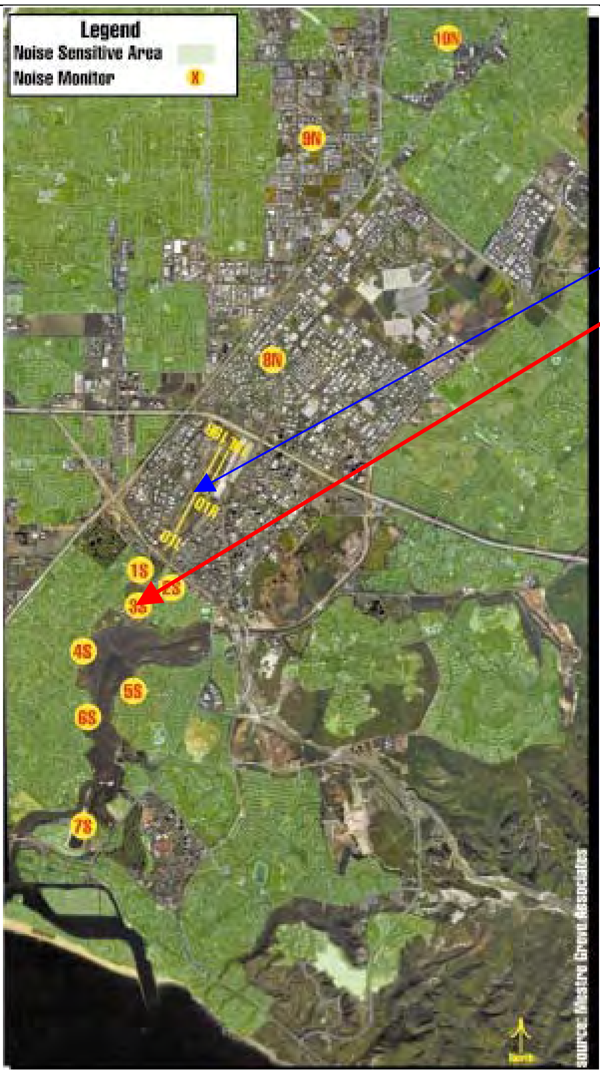
1. take-off noise abatement procedure optimization
2. airline fleet contribution to noise exposure for a given flight operations scenario

6. EXAMPLES

6.1. THE ORANGE COUNTY CASE

CAUTION: It must be underlined that the noise level optimization must be considered as particular to each airport. The primary goal of this example is to raise the reader's awareness regarding potential operational impact of noise limitations, and to highlight the Airbus philosophy of providing the operators with the most advanced tools for the highest operational efficiency and safety.

6.1.1. BACKGROUND



Airport authorities state that the noise level must not exceed 89 ***SENEL*** over **NMS 3S**, which is located 3300 m from the runway 19R threshold on the extended runway centerline.

For take-off :

Pilots are expected to comply with manufacturers recommended Noise Abatement Procedures.

IF NO MANUFACTURER GUIDANCE IS AVAILABLE:

RUNWAY 19R
Noise abatement procedure must be used due to proximity to noise sensitive areas.

1. *climb as quickly as appropriate*
2. *reduce power to maintain V2+10 and 1000 FPM prior to **Noise Monitoring Station 1S**.*

6.1.2. TAKE-OFF PROCEDURES EVALUATION

6.1.2.1. INTRODUCTION

The purpose is to compare different take-off procedures from runway 19R with an A319, assuming that the standard take-off optimization has been performed.
In this example, the following take-off parameters are retained, assuming no wind, ISA+15 (realistic temperature), no bleeds, initial climb at V2+10:

Take-off thrust	***: TOGA, no FLEX***
Take-off configuration	***: CONF 2***
Take-off weight	***: 62500 kg***
V1/Vr/V2	***: 125/125/130***

In addition, the sensitive areas being located close to the airport (NMS 3S is located around 3km from runway threshold), the **NADP "Close-in"** philosophy obviously prevails.
Let us then consider the 3 following procedures in order to rank them in terms of noise perceived at NMS 3S:

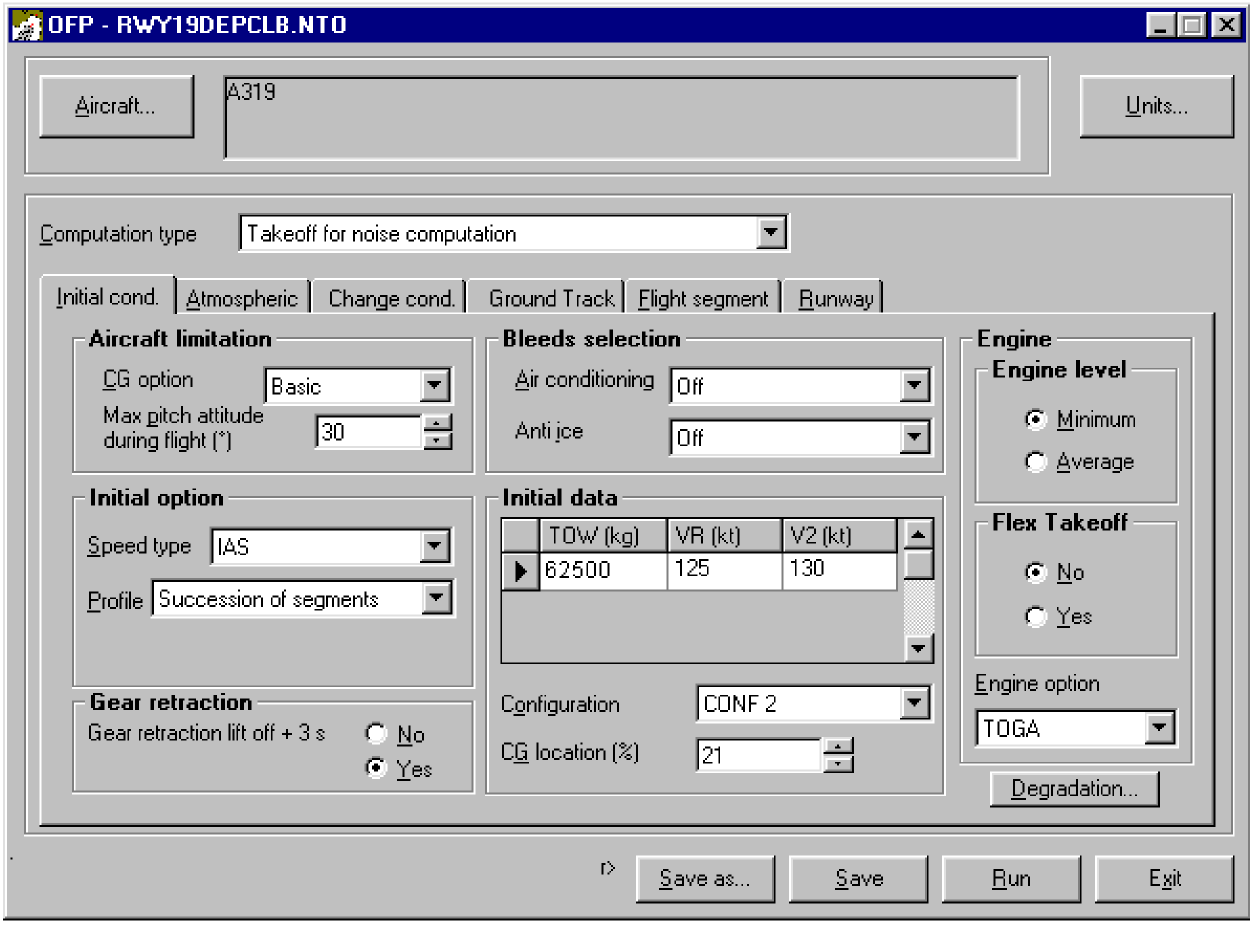
1. Take-off applying the Noise Abatement Procedure published by the Airport Authorities
    - cutback at 1500 ft AAL, reduction to MAX CLB
    - acceleration at 3000 ft AAL and high lift devices retraction

2. Take-off applying the Noise Abatement Procedure published by the Airport Authorities (tuning the cutback height).
    - cutback at 800 ft AAL (minimum prescribed by the ICAO), reduction to MAX CLB,
    - acceleration at 3000 ft AAL and high-lift devices retraction

3. Take-off applying an optimized **"Close-in"** procedure, the aim being to reduce noise close to the airport
    - cutback at 800 ft AAL, reduction to a thrust allowing 1.2% gradient in case of engine failure (minimum authorized in this case as per ***ICAO PANS-OPS***)
    - acceleration at 3000 ft AAL, high-lift devices retraction and normal CLB resumption.

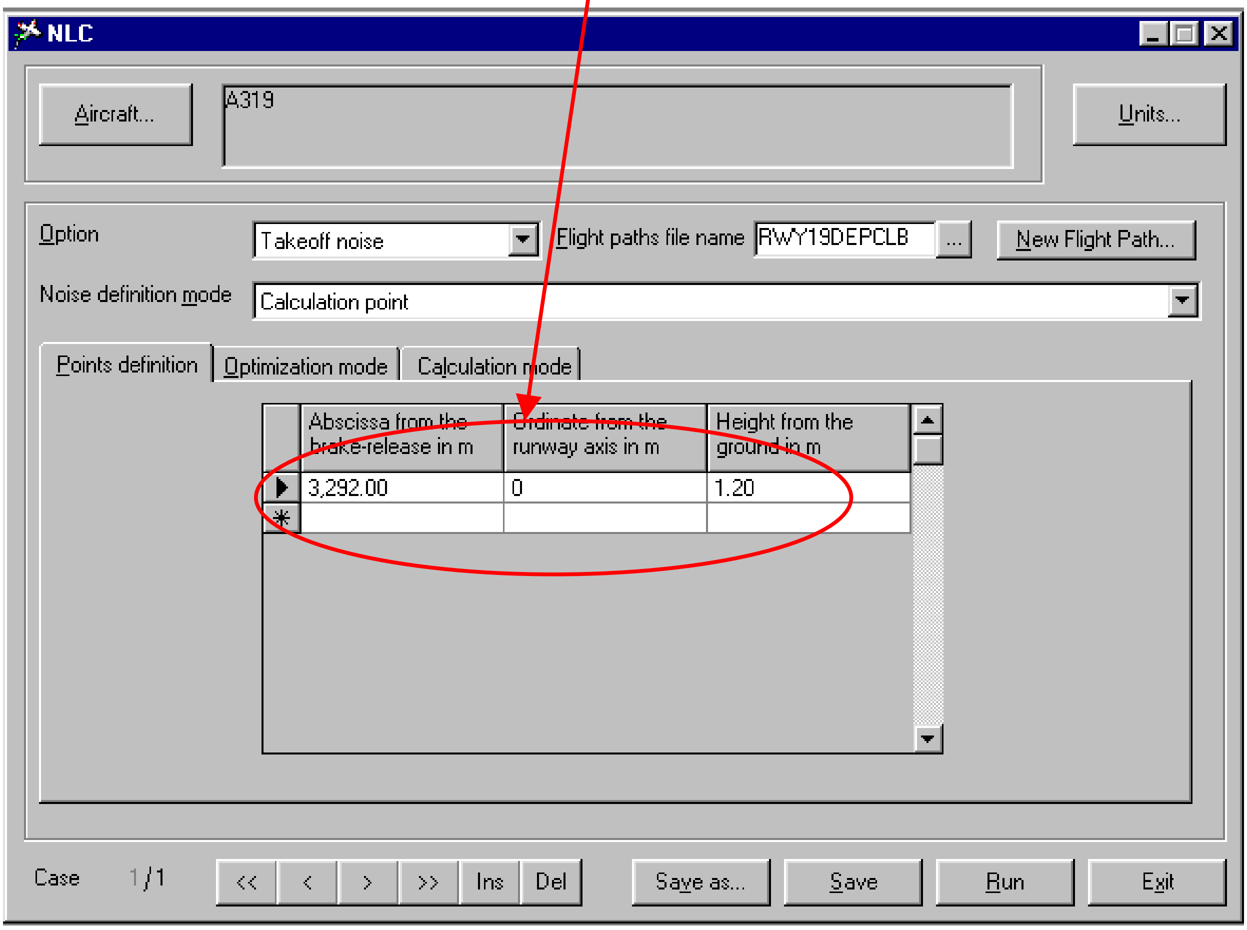
6.1.2.2. SIMULATION OF PROCEDURES

Each of the three procedure is programmed within the OFP software, using the “take-off for noise” computation mode (refer to PPM section 40.20.30). The latter produces a set of output parameters, which are needed by the NLC to assess the corresponding noise emissions.



6.1.2.3. NOISE LEVEL COMPUTATION

The NLC program is used to compute the noise levels for a single-event (refer to PPM section 45.30.20). Regarding our specific case, it will be used to assess the noise measurements at NMS 3S, the **location of which** is an input of the program.



Graphics can be customized by importing NLC outputs into Microsoft Excel.

EXAMPLE OF NLC OUTPUT (Point computation)

```
-----------------------------------------------------------------------------------------------------------------------------------
: A319                                                                                                                              :
:                                                    TAKEOFF PATH                                                                   :
:                                                                                                                                   :
:    NOISE DATA BASE         A319XXX                                        AIRPORT TEMPERATURE (DISA C)            15.00          :
:    FLIGHT PATH DATA FILE   RWY19DEPCL                                      AIRPORT HUMIDITY (PERCENT)              80.00          :
:    ENGINE LEVEL THRUST     MINIMUM ENGINE                                  QNH (HPA)                             1013.25          :
:    AXIS ORIGINE            BRAKE RELEASE                                                                                          :
:    LATERAL ATTENUATION     ESDU 75020                                      ATMOSPHERIC ABSORPTION       LC Sutherland ISO 9613-1 :
-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------
:                                 TAKEOFF WEIGHT       62100 KG                                                                     :
:    FLIGHT PATH NUMBER   1       VR                 125.00 KT IAS          INITIAL TAKEOFF RATING         NO DERATE                :
:                                 A/C CONFIGURATION    22/15                 AIR CONDITIONNING  OFF        ANTI-ICING  OFF          :
:----------------------------------------------------------------------------------------------------------------------------------:
:EMISSION:   DISTANCE  :   DISTANCE  :             :   PRESSURE   :       :        :       :  TOTAL NET :      :      :      :      :
:  TIME  :      X      :      Y      :    HEIGHT   :   ALTITUDE   : MACH  :   N1   :  N1K  :   THRUST   : ALPHA: TETA : HEAD : ROLL :
:   (S)  :     (M)     :     (M)     :     (FT)    :     (FT)     :       :  (%)   :  (%)  :   (DAN)    : (DG) : (DG) : (DG) : (DG) :
:--------:-------------:-------------:-------------:--------------:-------:--------:-------:------------:------:------:------:------:
:   0.00 :       0.00  :       0.00  :       0.00  :       42.00  : 0.000: 29.837: 29.10:      3468.  :  0.10:  0.24:194.00:  0.00:
:  10.00 :      86.52  :       0.00  :       0.71  :       42.69  : 0.062: 87.435: 85.30:     17796.  :  0.10:  0.24:194.00:  0.00:
:  20.00 :     434.65  :       0.00  :       3.57  :       45.41  : 0.136: 88.215: 85.94:     16767.  :  0.10:  0.24:194.00:  0.00:
:  28.52 :     923.57  :       0.00  :       7.58  :       49.23  : 0.191: 88.419: 85.99:     16060.  :  0.10:  0.24:194.00:  0.00:
:  30.37 :    1050.64  :       0.00  :       8.62  :       50.19  : 0.202: 88.465: 86.00:     15940.  :  8.90:  9.05:194.00:  0.00:
:  33.18 :    1252.37  :       0.00  :      45.27  :       85.06  : 0.209: 88.508: 86.03:     16233.  : 11.96: 18.00:194.00:  0.00:
:  33.96 :    1310.22  :       0.00  :      57.02  :       96.21  : 0.212: 88.526: 86.04:     16205.  :  8.47: 11.54:194.00:  0.00:
:  43.96 :    2042.64  :       0.00  :     429.04  :      449.78  : 0.213: 88.681: 86.27:     16131.  :  8.34: 18.18:194.00:  0.00:
:  52.84 :    2693.87  :       0.00  :     810.27  :      812.09  : 0.215: 88.850: 86.53:     16060.  :  8.21: 18.60:194.00:  0.00:
:  62.84 :    3434.77  :       0.00  :    1180.89  :     1164.25  : 0.216: 84.961: 82.81:     13907.  :  8.38: 16.72:194.00:  0.00:
:  69.89 :    3960.00  :       0.00  :    1432.43  :     1403.24  : 0.217: 85.024: 82.94:     13838.  :  8.39: 16.67:194.00:  0.00:
:  79.84 :    4691.52  :     116.18  :    1777.53  :     1731.07  : 0.218: 85.110: 83.11:     13742.  :  8.94: 16.86:175.00:  0.00:
:  89.84 :    5402.54  :     361.00  :    2128.57  :     2064.54  : 0.220: 85.195: 83.27:     13643.  :  8.41: 16.50:175.00:  0.00:
:  99.84 :    6117.17  :     607.07  :    2478.97  :     2397.34  : 0.221: 85.277: 83.44:     13543.  :  8.42: 16.42:175.00:  0.00:
: 109.84 :    6835.49  :     854.41  :    2827.01  :     2727.86  : 0.222: 85.355: 83.60:     13443.  :  8.43: 16.33:175.00:  0.00:
: 115.13 :    7217.23  :     985.85  :    3010.27  :     2901.88  : 0.223: 85.396: 83.69:     13390.  :  8.43: 16.29:175.00:  0.00:
: 117.63 :    7402.06  :    1049.49  :    3040.18  :     2930.27  : 0.230: 85.399: 83.68:     13280.  :  8.65: 11.06:175.00:  0.00:
: 120.13 :    7592.65  :    1115.12  :    3068.25  :     2956.95  : 0.237: 85.392: 83.66:     13168.  :  8.30: 10.74:175.00:  0.00:
: 122.63 :    7789.00  :    1182.73  :    3097.34  :     2984.55  : 0.244: 85.386: 83.63:     13056.  :  7.58: 10.03:175.00:  0.00:
: 125.13 :    7991.12  :    1252.32  :    3127.32  :     3013.05  : 0.251: 85.381: 83.60:     12945.  :  6.91:  9.36:175.00:  0.00:
: 127.63 :    8199.00  :    1323.90  :    3158.12  :     3042.27  : 0.258: 85.376: 83.58:     12846.  :  6.30:  8.74:175.00:  0.00:
: 130.13 :    8412.65  :    1397.47  :    3189.71  :     3072.28  : 0.265: 85.373: 83.55:     12747.  :  5.73:  8.17:175.00:  0.00:
: 132.63 :    8632.03  :    1473.01  :    3222.04  :     3102.98  : 0.272: 85.370: 83.53:     12649.  :  5.20:  7.63:175.00:  0.00:
: 135.13 :    8857.14  :    1550.52  :    3255.04  :     3134.30  : 0.279: 85.369: 83.51:     12552.  :  4.72:  7.13:175.00:  0.00:
: 137.63 :    9087.93  :    1629.98  :    3288.66  :     3166.24  : 0.286: 85.369: 83.48:     12456.  :  4.27:  6.66:175.00:  0.00:
: 140.13 :    9324.37  :    1711.40  :    3322.82  :     3198.66  : 0.293: 85.369: 83.46:     12361.  :  3.84:  6.21:175.00:  0.00:
: 142.63 :    9566.39  :    1794.73  :    3357.35  :     3231.44  : 0.300: 85.371: 83.44:     12268.  :  3.46:  5.80:175.00:  0.00:
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: 146.24 :    9925.30  :    1918.31  :    3408.54  :     3280.06  : 0.310: 85.849: 83.87:     12359.  :  3.67:  6.05:175.00:  0.00:
: 148.74 :   10180.93  :    2006.33  :    3445.91  :     3315.52  : 0.317: 86.210: 84.20:     12433.  :  4.00:  6.44:175.00:  0.00:
: 151.24 :   10442.30  :    2096.33  :    3485.03  :     3352.68  : 0.324: 86.580: 84.54:     12508.  :  4.35:  6.85:175.00:  0.00:
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: 156.24 :   10982.87  :    2282.46  :    3569.11  :     3432.49  : 0.339: 87.354: 85.24:     12664.  :  5.09:  7.73:175.00:  0.00:
: 158.74 :   11262.38  :    2378.70  :    3614.14  :     3475.24  : 0.347: 87.757: 85.60:     12751.  :  4.76:  7.43:175.00:  0.00:
: 160.96 :   11516.90  :    2466.34  :    3655.53  :     3514.54  : 0.354: 87.964: 85.78:     12768.  :  4.47:  7.16:175.00:  0.00:
-----------------------------------------------------------------------------------------------------------------------------------
```
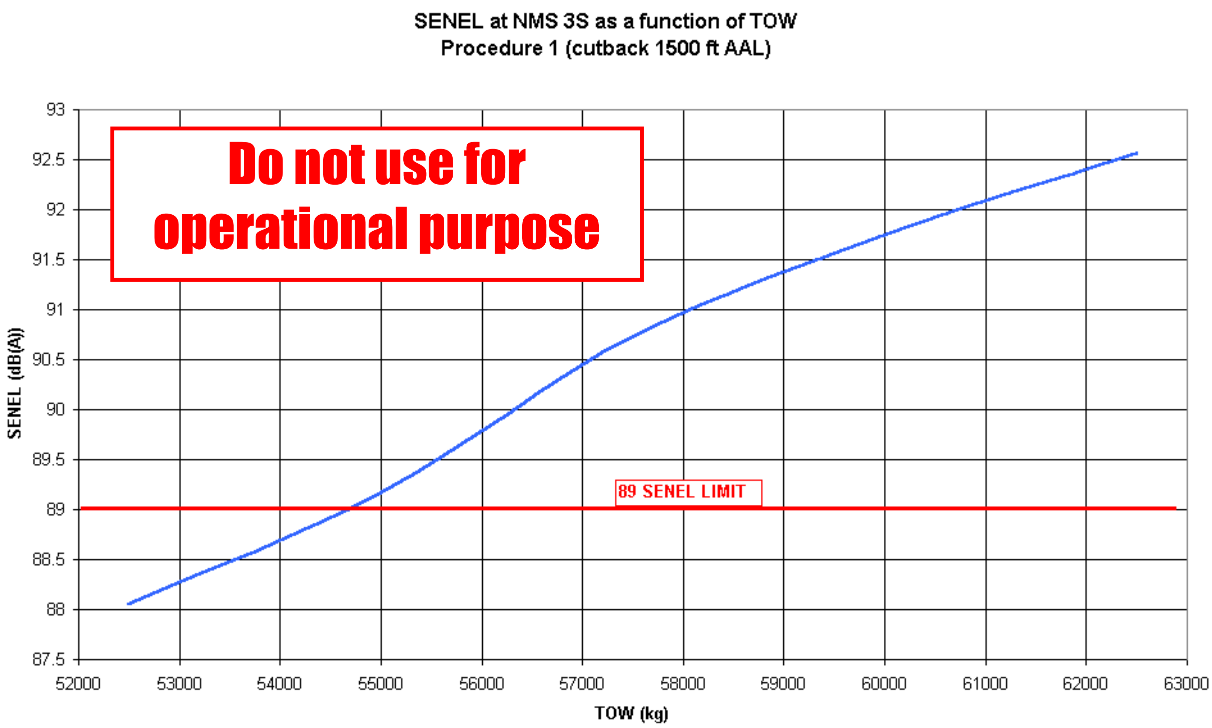

```
------------------------------------------------------------------------------------------------------------------------------
: A319-                                                                                                   :
:                                              TAKEOFF NOISE CALCULATION                                                     :
:                                                                                                                            :
:    NOISE DATA BASE       A319XXX                                     AIRPORT TEMPERATURE (DISA C)          15.00           :
:    FLIGHT PATH DATA FILE RWY19DEPCL                                  AIRPORT HUMIDITY (PERCENT)            80.00           :
:    ENGINE LEVEL THRUST   MINIMUM ENGINE                              QNH (HPA)                           1013.25           :
:    AXIS ORIGINE          BRAKE RELEASE                                                                                     :
:    LATERAL ATTENUATION   ESDU 75020                                  ATMOSPHERIC ABSORPTION      LC Sutherland ISO 9613-1  :
------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------------
:                                TAKEOFF WEIGHT       62100 KG                                                               :
:    FLIGHT PATH NUMBER   1      VR                   125.00 KT IAS          INITIAL TAKEOFF RATING        NO DERATE         :
:                                A/C CONFIGURATION    22/15                  AIR CONDITIONNING  OFF       ANTI-ICING  OFF    :
------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------------
:                                      :        ABSCISSA (M)       3292.00        :    LATERAL DISTANCE (M)          52.00   :
:     CALCULATION POINT NUMBER     3   :        ORDINATE (M)         52.00        :    MINIMAL DISTANCE (M)         341.41   :
:                                      :        HEIGHT   (M)          1.20        :    ELEVATION ANGLE (DG)          81.24   :
:----------------------------------------------------------------------------------------------------------------------------:
:EMISSION: RECEPT : AIRCRAFT : AIRCRAFT : AIRCRAFT : STRAIGHT : INDIRECT : EMISSION :  DOPPLER :          :          :          :
:  TIME  :  TIME  : ABSCISSA : ORDINATE :  HEIGHT  : DISTANCE : DISTANCE :  ANGLE   :  ANGLE   :   PNL    :   PNLT   :   DBA    :
:  (S)   :  (S)   :   (M)    :   (M)    :   (FT)   :   (M)    :   (M)    :   (DG)   :   (DG)   :   (DB)   :   (DB)   :   (DB)   :
:--------:--------:----------:----------:----------:----------:----------:----------:----------:----------:----------:----------:
:   31.85:   37.97:   1156.43:      0.00:     18.60:   2136.21:   2136.23:     20.00:      3.96:     60.01:     60.68:     50.90:
:   33.19:   39.03:   1253.25:      0.00:     45.50:   2039.48:   2039.50:     20.00:      6.51:     60.78:     61.72:     51.60:
:   34.59:   40.14:   1356.26:      0.00:     69.31:   1936.58:   1936.62:     20.00:      5.94:     61.60:     62.62:     52.35:
:   42.61:   46.49:   1943.21:      0.00:    372.49:   1354.74:   1355.00:     25.00:     14.89:     66.78:     68.72:     55.60:
:   47.18:   50.14:   2278.69:      0.00:    563.33:   1029.42:   1029.93:     30.00:     19.82:     72.26:     73.57:     61.43:
:   49.85:   52.27:   2474.31:      0.00:    678.44:    845.54:    846.28:     35.00:     24.90:     78.46:     79.59:     66.51:
:   51.85:   53.90:   2621.52:      0.00:    766.78:    712.63:    713.61:     40.00:     30.02:     82.08:     84.48:     70.53:
:   53.96:   55.63:   2776.41:      0.00:    857.12:    581.27:    582.58:     45.00:     36.71:     84.11:     86.10:     72.82:
:   54.91:   56.42:   2846.98:      0.00:    894.25:    525.52:    527.02:     50.00:     40.87:     86.82:     87.97:     74.96:
:   55.73:   57.11:   2907.11:      0.00:    924.62:    481.08:    482.75:     55.00:     45.40:     87.91:     88.95:     75.86:
:   56.42:   57.70:   2958.63:      0.00:    950.17:    446.00:    447.82:     60.00:     50.07:     88.83:     89.37:     76.71:
:   57.05:   58.25:   3005.35:      0.00:    973.16:    417.24:    419.20:     65.00:     54.98:     89.94:     90.38:     77.45:
:   57.61:   58.74:   3046.60:      0.00:    993.31:    394.77:    396.85:     70.00:     59.91:     90.75:     91.67:     78.35:
:   58.11:   59.20:   3083.98:      0.00:   1011.51:    377.24:    379.42:     75.00:     64.85:     91.88:     92.85:     78.99:
:   58.58:   59.62:   3118.65:      0.00:   1028.35:    363.73:    365.98:     80.00:     69.84:     92.00:     92.81:     79.08:
:   59.44:   60.43:   3182.33:      0.00:   1059.19:    346.84:    349.17:     90.00:     79.85:     92.55:     93.04:     79.65:
:   59.85:   60.84:   3213.05:      0.00:   1074.05:    342.73:    345.08:     95.00:     84.96:     92.58:     94.03:     79.73:
:   60.25:   61.23:   3242.66:      0.00:   1088.34:    341.40:    343.75:    100.00:     89.96:     92.44:     93.53:     79.92:
:   60.65:   61.63:   3272.28:      0.00:   1102.64:    342.69:    345.02:    105.00:     94.97:     93.41:     95.04:     80.27:
:   61.06:   62.06:   3302.77:      0.00:   1117.34:    346.72:    349.01:    110.00:    100.04:     93.62:     94.81:     80.86:
:   61.48:   62.50:   3334.04:      0.00:   1132.41:    353.60:    355.84:    115.00:    105.09:     94.75:     96.87:     81.49:
:   61.91:   62.96:   3366.00:      0.00:   1147.80:    363.35:    365.52:    120.00:    110.01:     93.62:     94.92:     81.06:
:   62.39:   63.48:   3401.73:      0.00:   1164.99:    377.23:    379.32:    125.00:    115.16:     93.97:     95.45:     81.16:
:   62.88:   64.01:   3438.01:      0.00:   1182.45:    394.22:    396.22:    130.00:    119.99:     94.38:     96.54:     81.35:
:   64.09:   65.37:   3527.65:      0.00:   1225.52:    446.45:    448.22:    140.00:    130.10:     91.88:     92.68:     79.30:
:   65.68:   67.21:   3646.59:      0.00:   1282.58:    531.87:    533.39:    150.00:    140.04:     88.44:     89.17:     75.85:
:   68.15:   70.11:   3830.15:      0.00:   1370.42:    684.48:    685.72:    160.00:    150.04:     82.60:     84.10:     70.63:
:----------------------------------------------------------------------------------------------------------------------------:
:     MAXIMUN PERCEIVED NOISE LEVEL (PNLMAX)                          94.75     EMISSION ANGLE (DG)       115.00             :
:     MAXIMUN TONE CORRECTED PERCEIVED NOISE LEVEL (PNLTMAX)          96.87     EMISSION ANGLE (DG)       115.00             :
:     EFFECTIVE PERCEIVED NOISE LEVEL (EPNL)                          93.93                                                  :
:     MAXIMUM TOTAL PRESSURE LEVEL ON DBA (DBAMAX)                    81.49     EMISSION ANGLE (DG)       115.00             :
:     SOUND EXPOSURE LEVEL (SEL)                                      90.09                                                  :
:     SENEL                                                           90.31                                                  :
------------------------------------------------------------------------------------------------------------------------------
```

6.1.2.4. SINGLE EVENT NOISE EXPOSURE LEVEL (SENEL) AT NMS 3S AS A FUNCTION OF THE AIRCRAFT TOW

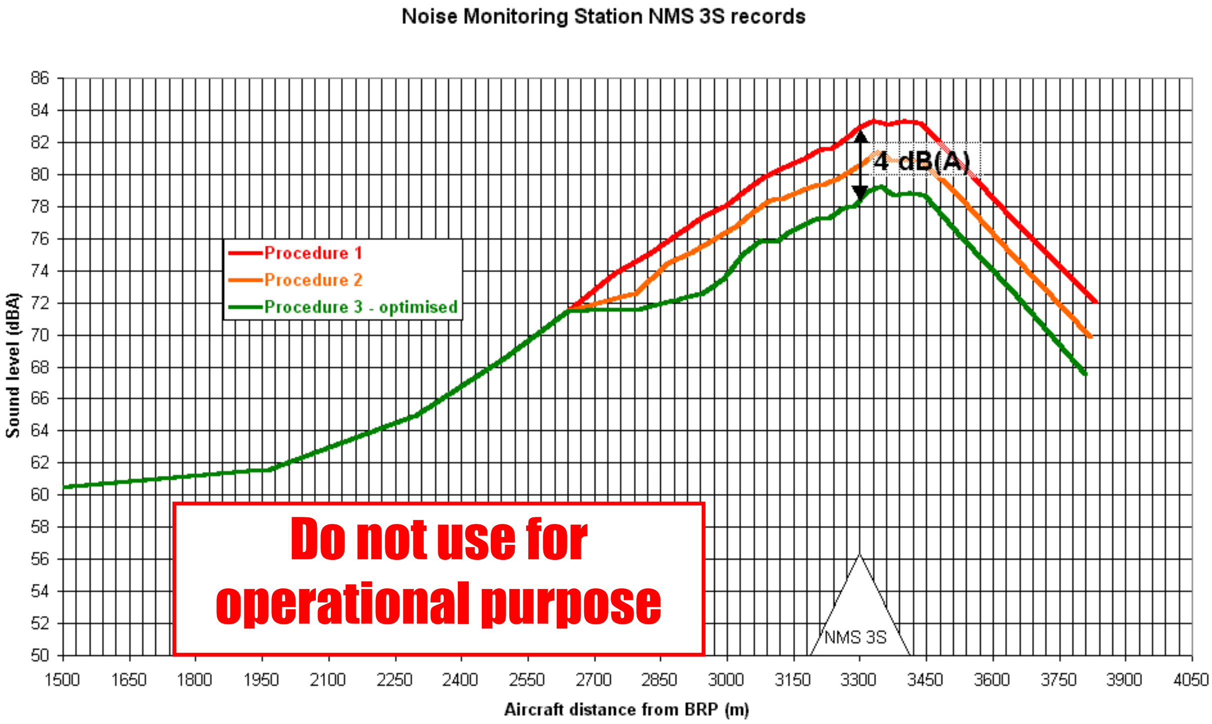
Let us have a look at the SENEL value measured at NMS 3S when a standard procedure is applied as per airport recommendations (when no manufacturer guidance is given).



Applying ***procedure 1*** with regulatory take-off weight does not permit to comply with the enforced rule. This would mean for the airline to reduce the TOW until the constraint is met, generating a high payload penalty. Before failing back on this radical solution, it is worth investigating possibilities of tuning the other influence parameters (cutback height, take-off configuration, engine ratings…) in order to avoid payload reduction.

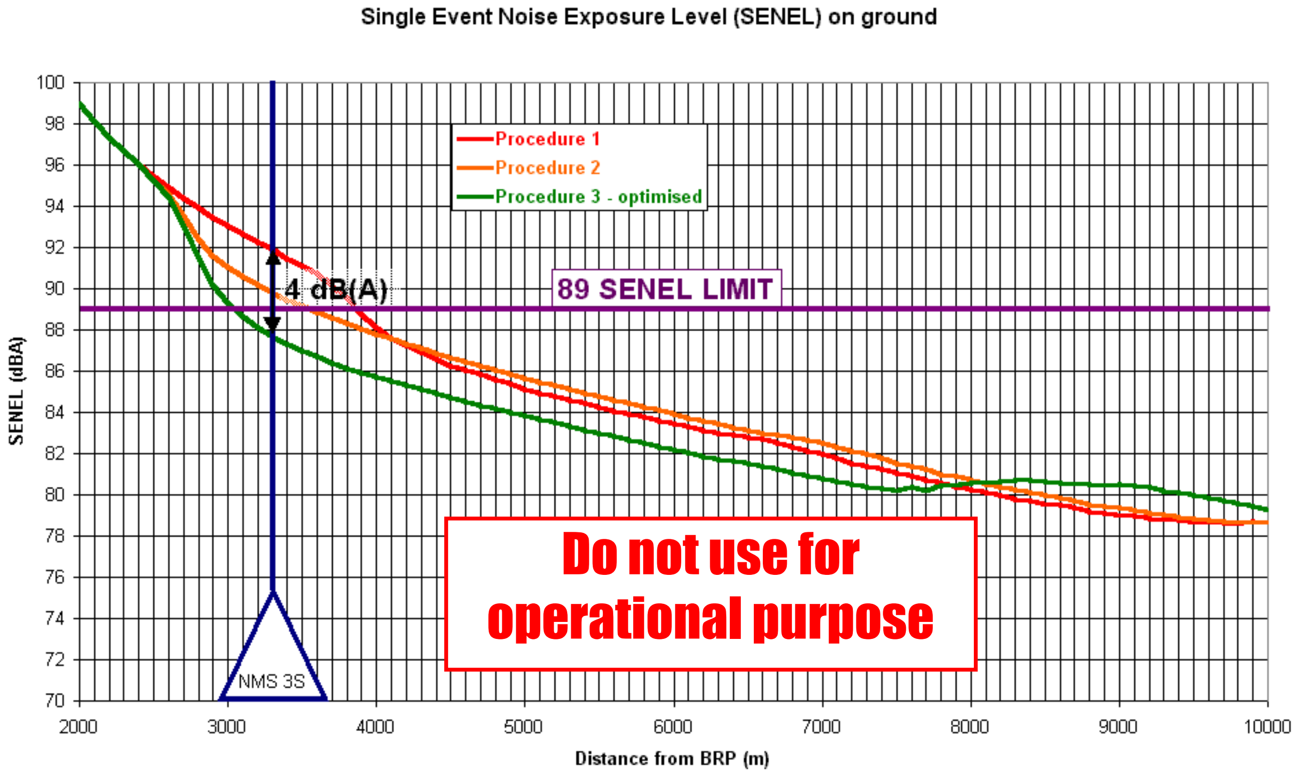
There is no general rule on how to optimize a noise abatement departure procedure. Nonetheless, applying ***procedure 1*** with a 62500 kg TOW shows (thanks to OFP outputs) that the noise monitoring station is flown over while the engine rating is still TOGA (1500 ft AAL not reached yet). It also shows that the actual altitude over the NMS 3S is above 800 ft, which means that if a cutback is performed at this altitude, we could expect some noise alleviation. This is the purpose of ***procedure 2***.
The following charts then illustrate the benefits implied by ***procedure 2 and 3***.

6.1.2.5. NMS 3 SOUND LEVEL RECORDS IN FUNCTION OF THE AIRCRAFT DISTANCE FROM BRP



The above clearly shows that a least-noise procedure does exist. Comparing ***procedure 1*** and ***procedure 2*** proves that tuning the reduction height allows reducing the measured sound level at the above-mentioned microphone, the cutback occurring before reaching the latter.
Furthermore, adapting the climb thrust as per ICAO recommendations (***procedure 3***) allows another step in noise alleviation. In this particular case, the difference between the first procedure and an "optimized" one reaches 4 dB(A), which is quite significant.
It is now interesting to focus on the noise constraints, and to track the SENEL value on ground (function of the ground distance from brake release), in order to check whether a payload penalty is still to be expected or not.

6.1.2.6. SINGLE EVENT NOISE EXPOSURE LEVEL (SENEL) ON GROUND



The noise limit at NMS 3S is 89 dB(A) calculated in SENEL.
As previously said, adopting ***procedure 1*** does not allow to meet this requirement with the regulatory MTOW.
Procedure 2, which implies to decrease the reduction height to the minimum prescribed by the ICAO (800 ft) allows to reduce the SENEL at NMS 3 down to 90 dB(A), as the mike location is further along the track from the point where the cutback occurs.
Nonetheless, this is not enough to meet the constraint, and the operator has to adjust the CLB thrust to the minimum recommended one in order to comply with the SNA noise policy (***procedure 3***)
With this procedure, there is no need for a reduction of the aircraft regulatory performance limited take-off weight.

6.2. FLEET CONTRIBUTION TO NOISE EXPOSURE

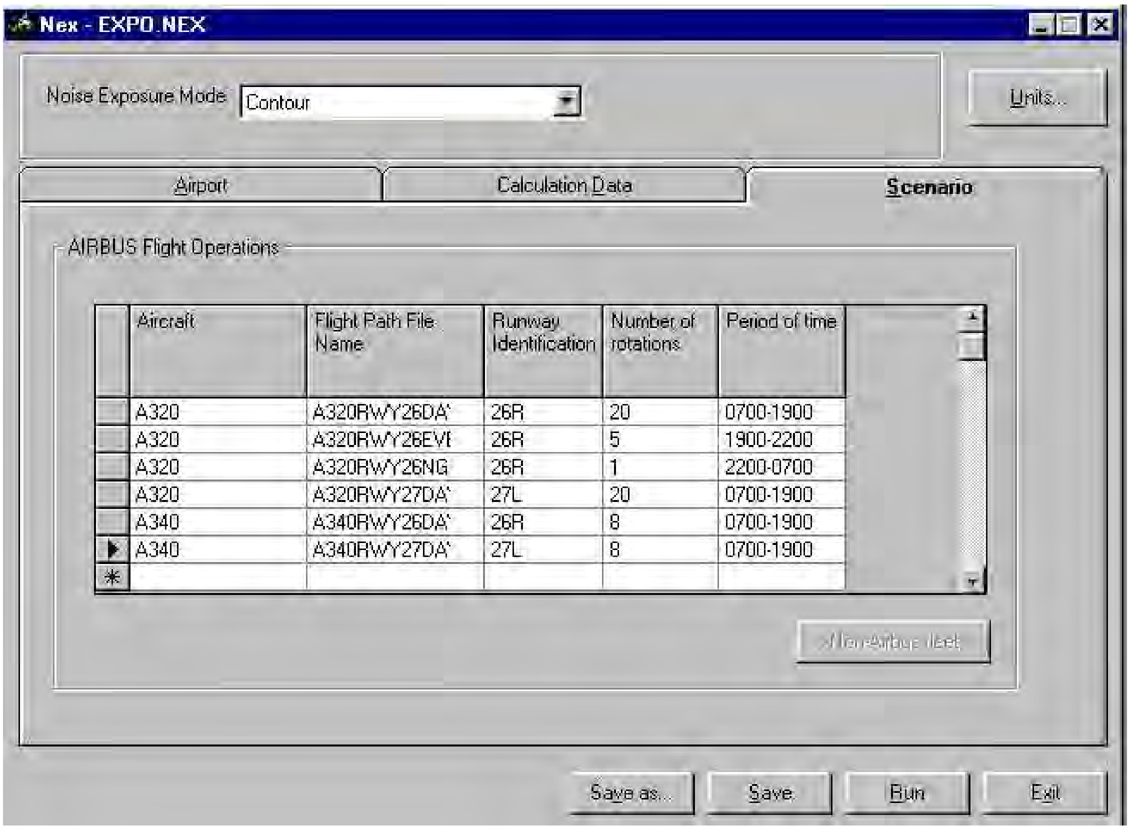
In this example, we will work with a virtual airline operating from/to Charles-De-Gaulle airport with A340s and A320s. For a given daily flight operations scenario (to simplify, we will assume the same flights schedule whatever the day), we will compute values for different noise exposure indices.

6.2.1. DAILY OPERATIONS SCENARIO

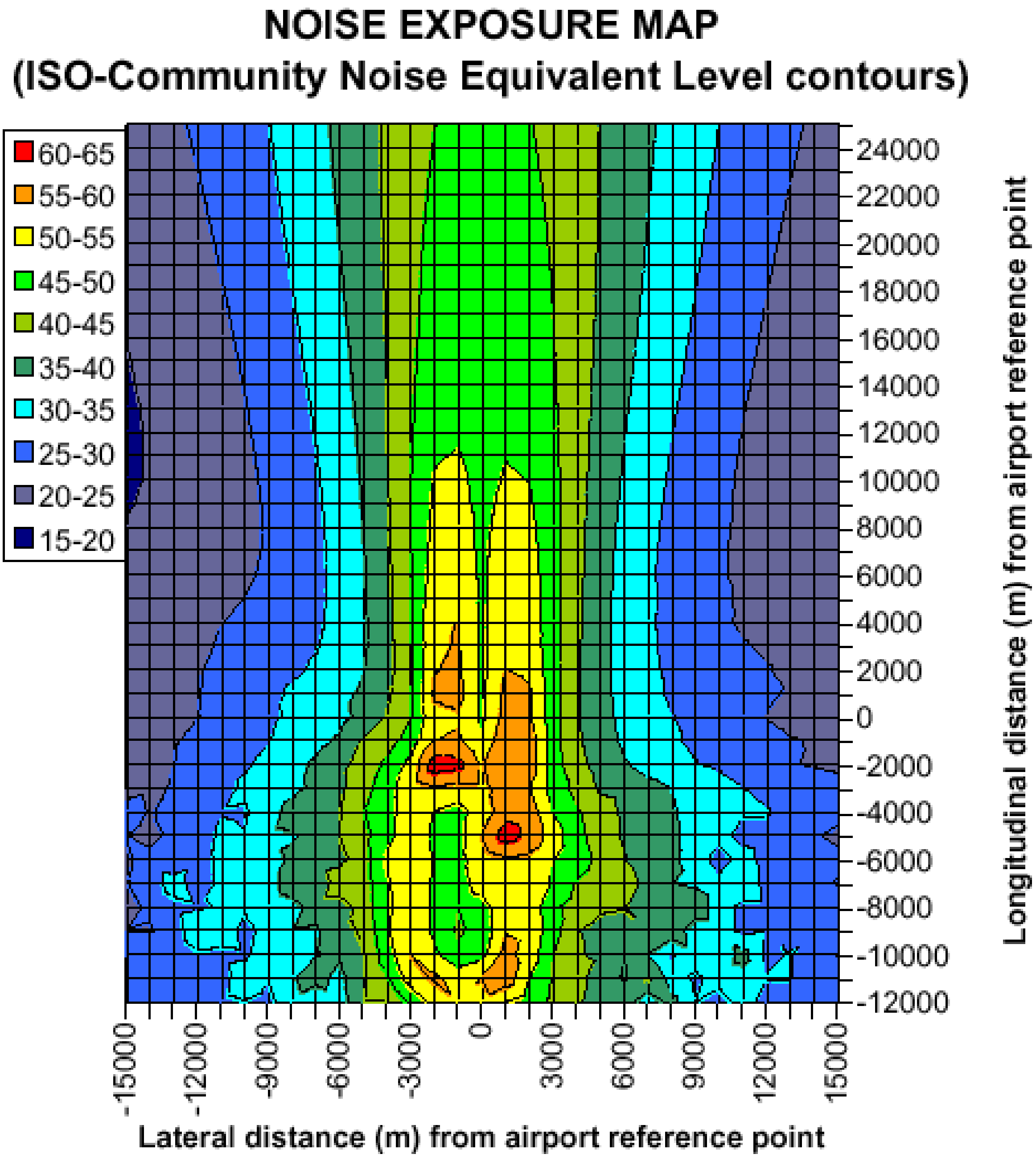
AIRCRAFT	TIME	ARRIVALS	DEPARTURES	
		Number	Number	QFU
A320	0700-1900	15	20	26R
A340		2	8	26R
A320	1900-2200	0	8/20	26R/27L
A340		0	8	27L
A320	2200-0700	5	1	26R

6.2.2. COMPUTING NOISE EXPOSURE INDICES WITH NEX

1. Standard SIDs and approach procedures shall be assumed. The OFP software is used to simulate each flight operation and its associated parameters.
2. The NEX software is then used to program the flight operations scenario. The calculations are in this case performed in the background with NLC, the outputs of which are integrated over the applicable time frame for the retained index.



3. It is then possible to draw iso-noise exposure index contours, or get the noise exposure index value at a precise location in the airport vicinity (for instance at a given noise monitoring station).



7. INFLUENCE FACTORS

CAUTION: all the charts presented hereafter only illustrate examples of the possible sources of scatter evocated below for a specific case, and as such must not be used for the evaluation of corrections in particular situations.

7.1. BACKGROUND

The noise levels computed by the NLC or the NEX are based on the best knowledge we have of the aircraft (flight tests). This knowledge is translated into an engine acoustic model.
In addition, both software use models to account for the atmospheric absorption and the lateral attenuation of the sound.
The noise levels computed for a procedure assume certain atmospheric conditions, which are likely to differ from the actual conditions (humidity, temperature).

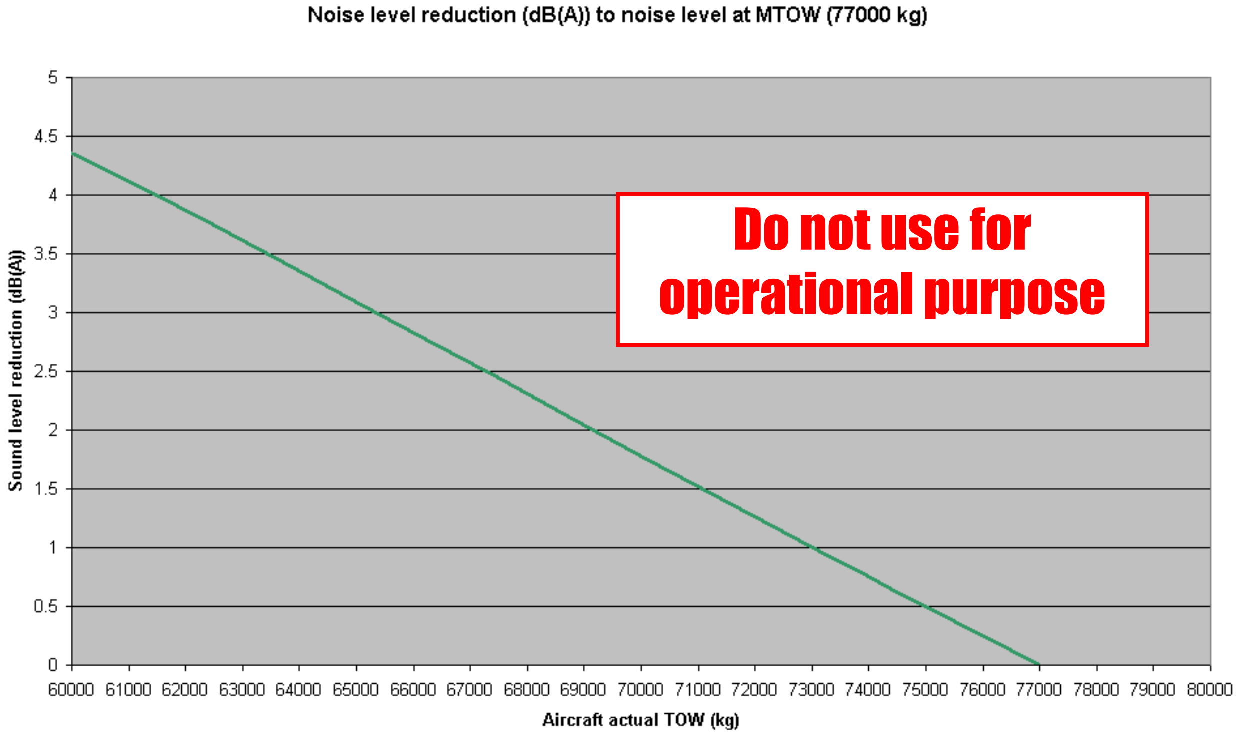
- In that context, it is worth noticing that atmospheric conditions influences on the noise atmospheric absorption are shown in **ICAO Annex 16 Volume 1 Appendix 1 paragraph 8 – Sound attenuation in air*.***
- The assumed weight of the aircraft is based on the load and trim sheet, and is likely to differ from the actual one.
- Neither NLC nor NEX account for the actual topography around the airport when computing the effect of sound waves reflections on the ground.

For all these reasons, a certain difference may exist between NLC computations and actual levels as monitored during flight operations, though the deviations are small.
Consequently, it is worth mentioning that the confidence to put in these computations stands in the value of the calculated gain between different procedures, rather than into the absolute noise level value itself, which must not be considered as guaranteed.

The following charts displays the influence of different parameters on the measured noise levels 6.5 km from brake release point, considering an A320 straight takeoff from sea level.

7.2. ACTUAL TOW INFLUENCE

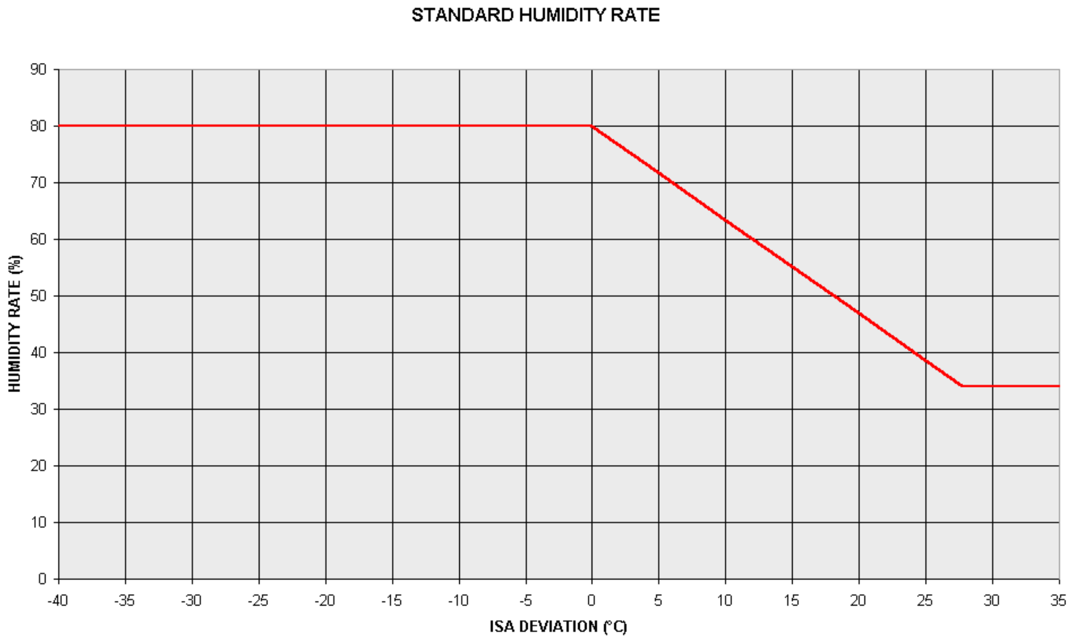
All other parameters being fixed, the actual TOW has got an influence on the noise perceived on ground, through the impact it has on the actual aircraft trajectory. This influence can be considered linear and quite small (around –0.2dB(A) per ton in that case).



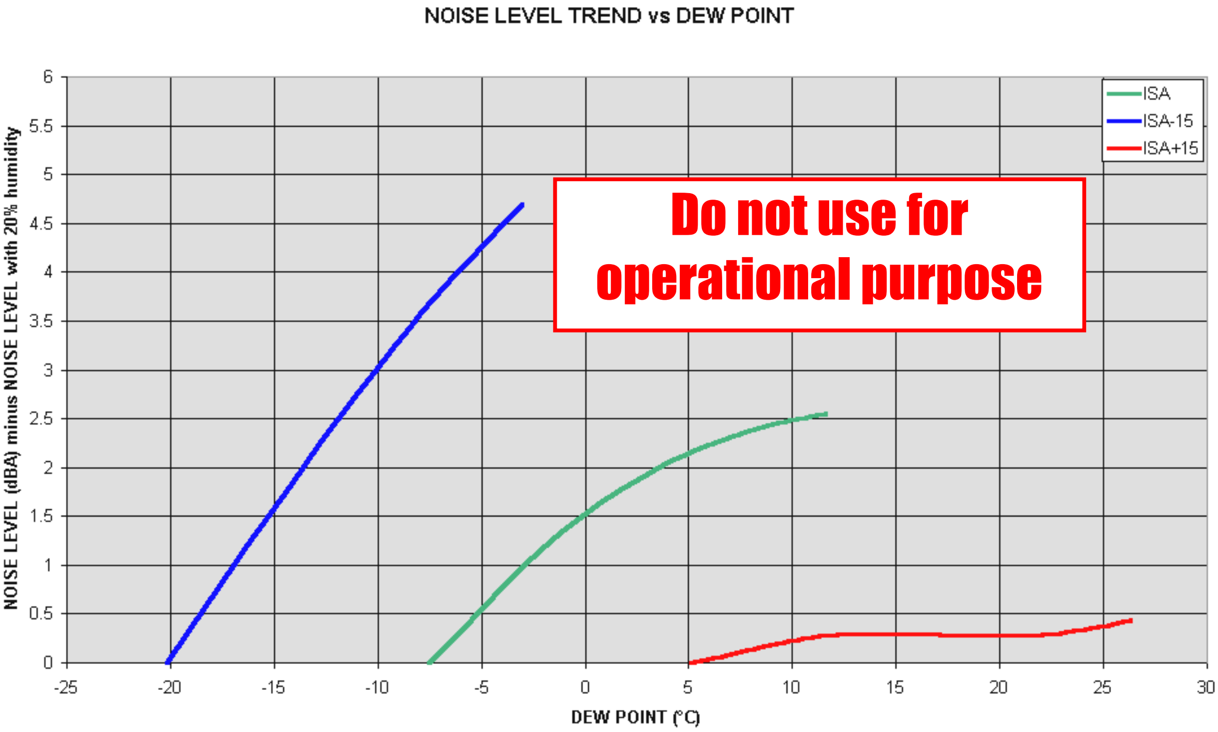
7.3. DEW POINT INFLUENCE

For the purpose of illustrating this influence, we first have to remind that the regulatory performance (for dispatch purposes) is computed according to the standard humidity law published in **JAR 25.101 (b)**.

"*The performance, as affected by engine power or thrust, must be based on the following relative humidity:*
80% at and below standard temperatures; and
34% at and above standard temperatures plus 50°F (or 27.8°C)
Between these two temperatures, the relative humidity must vary linearly."



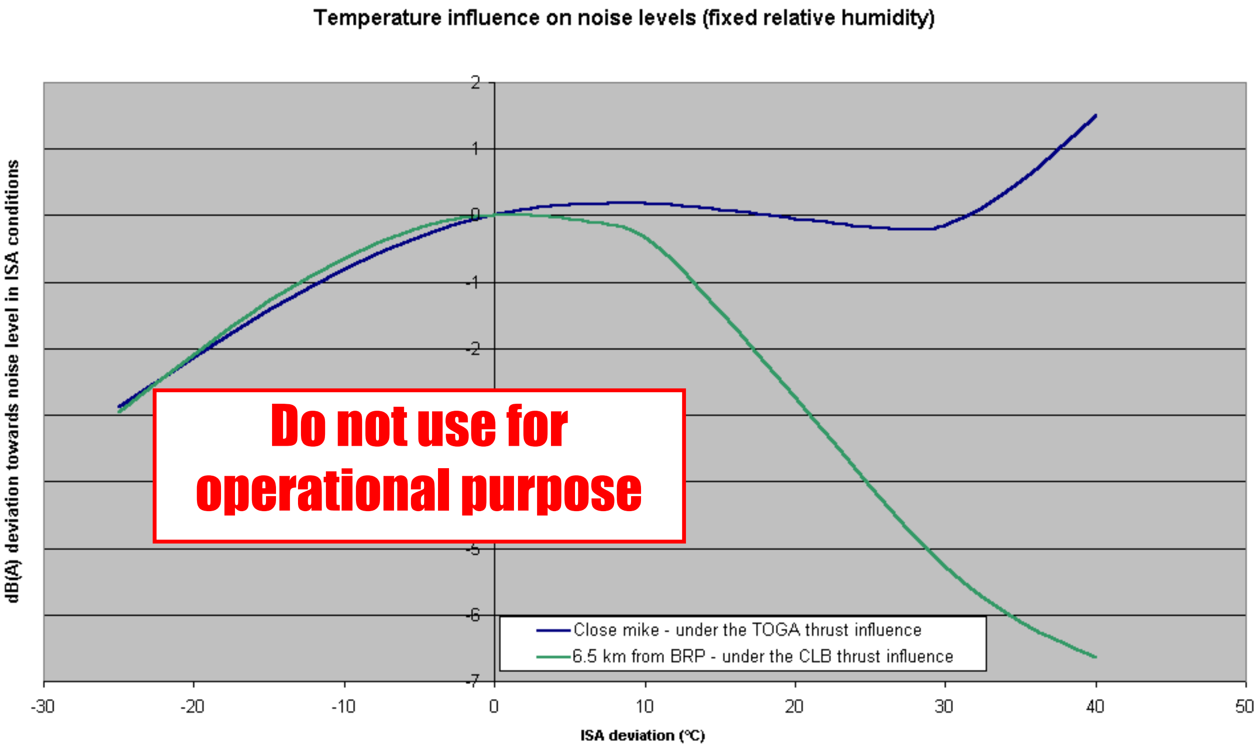
In the reality, the humidity rate is likely to differ from the one retained for the determination of regulatory performance. The following chart displays the dew point influence for three different outside air temperatures:



The dew point variation corresponds to a relative humidity variation from 20% to 80%.
It is thus obvious that the dew point influence becomes greater when the temperature decreases. This is due to the absorption properties of the air, which are function of the noise frequency, the outside air temperature and the relative humidity (see also charts in **ICAO Annex 16 Volume I Appendix 1**).

7.4. TEMPERATURE INFLUENCE

There is no simple rule regarding temperature influence. Indeed, the temperature impacts the aircraft thrust, and when it is greater than the corner point (i.e. the temperature at which the engine thrust becomes limited by the EGT constraint), this significantly lowers the aircraft trajectory. It also affects the noise absorption (as mentioned above). That means that depending on the mike location, the temperature may impact the perceived noise differently.
In the following graph, the noise level evolutions versus outside air temperature both include the thrust variations and the trajectory changes due to them, as well as the sound absorption variations.



This chart shows that the temperature influence on noise levels depends on the location at which they are perceived.
For the close microphone, which is under the TOGA thrust influence, the levels increase again from ISA+30, which corresponds here to the TREF (corner point). Beyond that temperature, the thrust is EGT limited, which means a sharper decrease versus temperature, thus a flyover much closer to the ground, resulting in higher noise levels.

8. FLYING A NOISE ABATEMENT DEPARTURE PROCEDURE

8.1. BACKGROUND

When a specific noise abatement procedure has to be applied during normal take-off (namely NADP), it is worth accurately storing the information describing it in the FMS. This is done to reduce pilot workload in the cockpit, thereby getting the utmost level of flight safety. This section provides some guidance on how to fly a Noise Abatement Departure Procedure when established, for current FMS standards and the future FMS 2 release 1A.

8.2. FLIGHT MANAGEMENT GUIDANCE COMPUTER (FMGC) REMINDERS

8.2.1. FLIGHT MANAGEMENT AND GUIDANCE SYSTEM (FMGS) STANDARD 1 (SO-CALLED "LEGACY")

Each FMGC has its own database, one field of which contains customized and standard navigation data such as navaids, waypoints, airways, en-route information, holding patterns, airports, runways, procedures (SIDs/EOSIDs, STARs, etc.), company routes, fuel policy, alternates.

The airline updates this part every 28 days in sync with the ARINC cycles, and is responsible for defining, acquiring, updating, loading, and using this data.
The other field contains pilot-stored elements that enable the pilot to create 20 waypoints, 10 runways, 20 navaids, and 3 routes.

8.2.2. FLIGHT MANAGEMENT AND GUIDANCE SYSTEM (FMGS) STANDARD 2 (SO-CALLED "PEGASUS"): FLY-BY- WIRE ONLY

Each FMGC contains these main databases:

1. The Navigation database contains standard navigation data: navaids, waypoints, airways, en-route information, holding patterns, airports, runways, procedures (SIDs/EOSIDs, STARs, etc.), company routes, alternates. The airline updates this part every 28 days, and is responsible for defining, acquiring, updating, loading, and using this data.
2. **The Airline Modifiable Information (AMI, also referred to as the FM Airline Configuration file) contains, amongst others the airline policy values such as the THR RED altitude, ACC altitude, EO ACC altitude.**
3. The Aircraft Performance database, which comprises the Engine model, the aero dynamical model, and the Performance model. The airline cannot modify this database.
4. The Magnetic Variation database.

In addition, each FMGC contains pilot-stored elements that enable the pilot to create 20 waypoints, 10 runways, 20 navaids, and 5 routes.

8.3. FLIGHT PLANNING UPDATE

8.3.1. BACKGROUND

For flight planning purposes, the pilot inserts the following information into the FMS via the MCDU (Multi-Control Display Unit):

1. **The intended lateral trajectory (lateral flight plan)**

For departure, it includes the takeoff runway, the SID, the en-route transition

2. **The intended vertical trajectory, which is a speed and altitude profile**

The system requires this kind of information in order to compute the corresponding performance and the guidance commands.

The FMGS can contain two different flight plans:

1. **the ACTIVE flight plan**, which is the basis for :
   - lateral and vertical guidance
   - MCDU and ND display
   - radio navigation auto tuning
   - performance predictions
   - fuel planning
2. **the SECONDARY flight plan**, which the pilot may use :
   - to prepare and store a second departure procedure before takeoff
   - to plan a diversion
   - to prepare the next flight leg

Each flight plan is composed of the same elements:
- the primary flight plan, from origin to destination and missed approach
- the alternate flight plan, from destination to alternate destination

8.3.2. MCDU PAGES

8.3.2.1. INIT PAGE

The pilot enters the flight plan in either of two ways:

- Automatically by selecting a company route. Such a selection will call up all the elements of the route from the database.

- Manually by selecting an ORIGIN/DEST pair, and then selecting all successive waypoints, procedures, and vertical constraints on the MCDU.

8.3.2.2. DEPARTURE PAGES

Once departure airport is selected, the corresponding runway must be chosen within the departure pages: here the takeoff will be performed from runway 33L following the BISB4B SID.

Figure 8.3.2.2-1: SID selected, but not inserted

Figure 8.3.2.2-2: SID inserted

The pilot may then modify the flight plan on the ground or in flight, by making lateral and vertical revisions. A lateral revision to the F-PLN automatically generates a **TEMPORARY F-PLN.**

8.3.2.3. PERF TAKEOFF PAGE

A takeoff update requires that the takeoff runway be part of the flight plan (as it would be after pilot's review of the departure pages and insertion of relevant runway and SID). It must be kept in mind that an accurate takeoff update ensures a precise aircraft position during departure.
The information relevant to a specific procedure (i.e. ***Noise Abatement Departure Procedure***) must be entered in the FMS PERF TAKEOFF PAGE. This page is currently identical for both FMS standards.

The **THR RED** must be set to the value at which the pilot should reduce the thrust from TOGA/FLEX/DTO (as applicable) to MAX CLIMB/DCLB (as applicable) with all engines operating.

1. CLB or LVR CLB appears on the FMA flashing amber
2. The default thrust reduction is 1500 ft AAL
3. The pilot can modify this value, knowing that the minimum is 400 ft AAL (800 ft as per ICAO recommendation)

The **ACC** must be set to a value at which the climb phase is initiated.

1. The target speed jumps to the initial climb speed
2. The default value is 1500 ft AAL
3. The flight crew can modify the value. Minimum is 400 ft AAL, though it is always higher than or equal to THR RED.
4. When a lower altitude is set on the FCU, ACC is brought down to the latter
5. If ACC is less than THR RED, the THR RED is brought down to this altitude (400 ft AAL mini still apply)

The **ENG OUT ACC** value is the one defined in the database, or manually entered by the pilot, or updated via ACARS if available. It cannot be cleared.

All these altitudes are defaulted to the same value (from FMS1 database or FMS 2 AMI, whichever is relevant) whatever the runway. The operator and the crew must pay attention when specific procedures are to be followed, such as a noise abatement procedure. In this case, the above-mentioned fields can be automatically updated via ACARS or manually by the crew through the MCDU.

8.4. NADP INSERTION (FMS LEGACY AND PEGASUS BEFORE 2005)

8.4.1. NADP "CLOSE-IN"

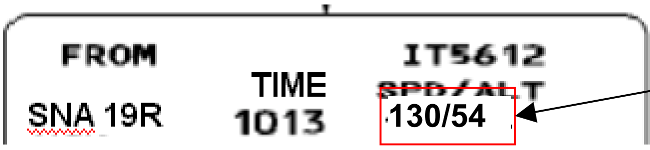
To illustrate the update of the PERF TO PAGE associated to such a procedure, let us take the example of Orange County airport we treated in Section 6.

Reminder of the aircraft performance and procedure to apply

Take-off configuration : CONF 2
Take-off weight : 62500 kg
V1/Vr/V2 : 125/25/30
Cutback at 800 ft AAL, reduction to a thrust allowing 1.2% gradient in case of engine failure
Acceleration at 3000 ft AAL, high-lift devices retraction and normal CLB resume.

Assuming the runway 19R has been entered in the flight plan, which means the SID associated to the noise abatement procedure has been inserted, the PERF TO PAGE must be filled-in with the relevant data, amongst them the following altitudes :

THR RED = 800
ACC = 3000
EO ACC = As applicable (1500 ft by default)



The field dedicated to SPEED or MACH is blank at the FROM waypoint except at airport of departure. (V2 is displayed associated with runway elevation, once the PERF TAKEOFF and INIT pages have been updated).

Reaching 800 ft, the **<CLB>** message will start flashing on the Flight Mode Annunciator. The pilot will have to move the thrust lever on the **CLB detent**.

8.4.2. NADP "DISTANT"

8.4.2.1. BACKGROUND

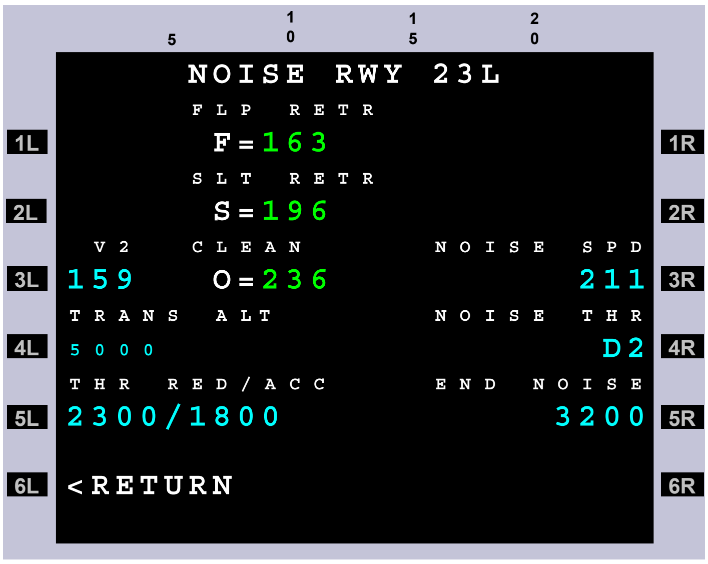
The **NADP Distant** procedure means the possibility of a reduction altitude (THR RED) greater than the acceleration one (ACC). No such insertion is currently possible.
Also a noise speed may be programmed before resuming en-route climb (this "noise" speed must be at least S+10, at the most S+20).
Thus, to perform a procedure of this kind, the pilot will have to disregard the flashing CLB (or LVR CLB) on the PFD passing THR RED, and reduce thrust to MAX CLB at the relevant altitude (within the regulatory 5 minutes). The noise speed will have to be set on the FCU (typically S+15)
The operational implementation of such a procedure **requires that relevant information is passed on to the pilots and highlights the flexibility of current systems which at the time did not consider that type of procedure.**

8.5. NADP INSERTION – NADP FUNCTION OF THE FMS 2 (2005 ONWARDS)

The intended future situation is forecasted to be available in year 2005 in release 1A, for Fly-by-wire aircraft only).
The new features are listed here below:

1. **Possibility of programming a NADP DISTANT procedure**, which allows the initiation of the slats/flaps retraction before reducing the thrust,
2. Add some functions to the current FMS NADP 1, which will be also applicable to the NADP 2.
    - Two or three altitudes selected on MCDU:
        - *Thrust Reduction Altitude*
        - *Acceleration Altitude*
        - ***End Noise Altitude*** *(new, with regards to the current FMS inputs, allowing another thrust level modification).*
    - **Selection on MCDU of a rating** (Derated Climb (if available) or Max Climb, or a constant N1 value (for A380 only)) **after thrust reduction up to "End Noise Altitude"**.
    - At acceleration altitude, **a "noise" speed is targeted** (selection on the MCDU of a noise speed: confirm value proposed by the FMS (**S+15** for instance) or enter a value)
    - **At "End Noise Altitude"**, the climb speed and the climb rating that have been set in the FMS by the pilot are targeted.

The **"Noise" panel** in the MCDU will be accessed through the PERF TAKEOFF PAGE and will be filled up according to operations engineering optimization.



8.6. THE AIRBUS DEPARTURE ANALYSIS SOFTWARE (ADAS)

This tool will be integrated in the PEP environment in 2004, as an "on-ground" preparation tool in order to compute the optimized inputs to set in the FMS2-NADP panel. This will fasten the optimization process, which is currently manual and takes several hours.

8.6.1. ADAS INPUTS

8.6.1.1. TAKEOFF OPTIMIZATION INPUTS

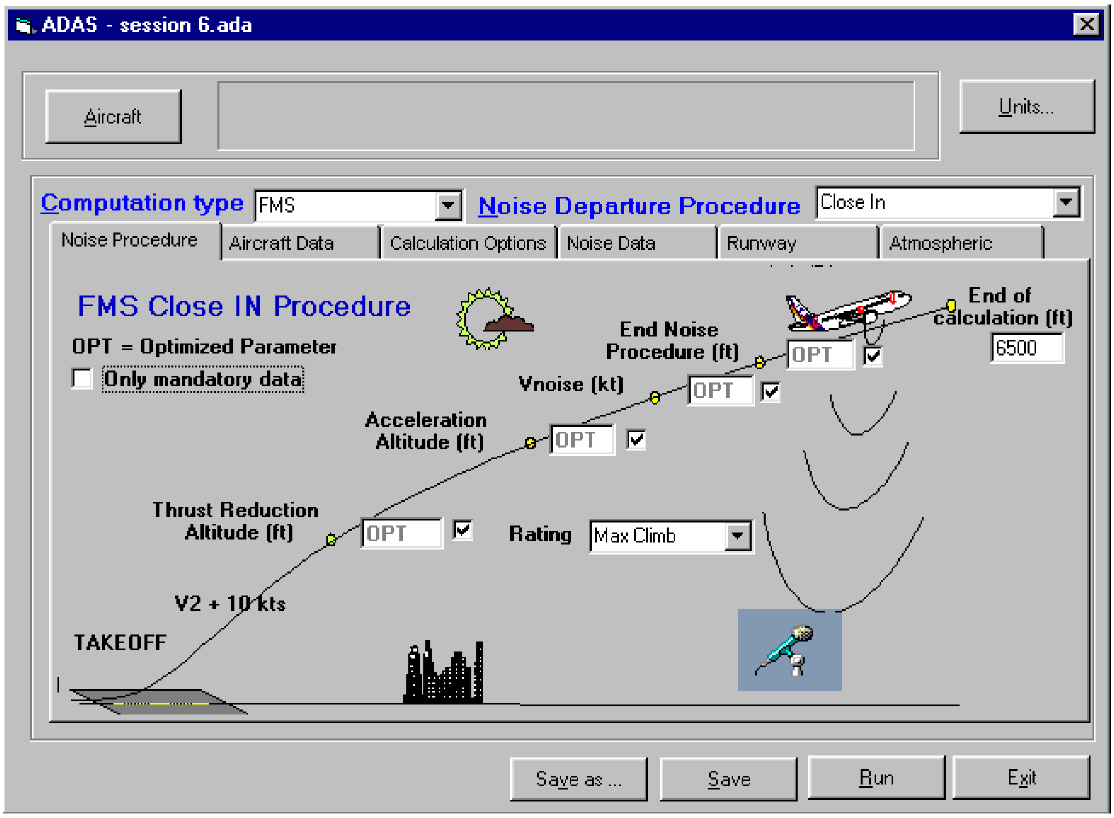
Temperature, wind, pressure altitude, takeoff configuration (fixed or to be optimized), runway characteristics (Slope, TORA, TODA, ASDA, obstacles to be considered, runway state...). If the TOW is fixed, the tool will maximize the TFLEX value for that actual weight.

8.6.1.2. NOISE INPUTS

Acoustic constraints, microphone positions...

8.6.1.3. OPERATIONAL FLIGHT PATH INPUTS

Type of Noise Abatement Departure Procedure: Close-in, Distant.
Some of the input parameters (acceleration altitude, thrust reduction altitude, rating after reduction…) may be fixed by the user. If not, the tool will optimize them.



8.6.2. ADAS OUTPUTS

TOW or Flex temperature (depending if TOW is fixed or not) and associated takeoff speeds (V1,VR, V2),
Takeoff configuration, if not fixed. The One engine out flight path parameters versus time will also be available (engine failure at VEF).
Optimum characteristics of the operational flight path: FMS2-NADP inputs (thrust reduction altitude, optimum rating after reduction…), and flight path parameters evolution versus time.
Status of the constraints: Noise levels, obstacle margins.

9. A BIT OF THEORY

9.1. PHENOMENOLOGICAL APPROACH

This section is dedicated to the familiarization with the different notions linked to acoustics and their application to aircraft noise.

9.1.1. INTRODUCTION

Sound is a physiological sensation generated by the air static pressure variations. It consists of vibrations of the air (which is a compressible environment) and moves in it as an acoustic wave. Its motion is deeply related to the environment characteristics and the source frequency. It propagates as a longitudinal wave, that is to say the air molecules motion is of the same direction as the motion of the wave.
More practically, sound is an expression of air properties that allows us to have a conversation or to listen to a nice music.

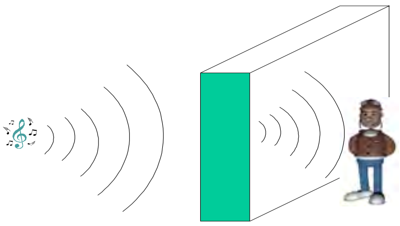
When sound is not appreciated because it is perceived as disturbing, it becomes a ***noise*** in that way it is an unwanted sound.

9.1.2. ATMOSPHERIC ABSORPTION

The sound waves travel in the air, one of the characteristics of which is the viscosity. Consequently, the movement that is transmitted by an air particle to an adjacent one loses part of its energy due to the shearing forces acting between these particles. The farther from the source, the less powerful is the sound, characterizing the atmospheric absorption. The factor of absorption is dependent on the temperature, humidity and frequency (the latter characterizing the speed of the particles around their equilibrium). For instance, at high frequencies, the air particles movement will be faster, then generating higher shearing forces, thus a greater absorption.

9.1.3. DIFFRACTION

It is easy to experience the fact that sounds can be heard behind corners. This proves that obstacles do not prevent sound from propagating, thus illustrating the diffraction property.



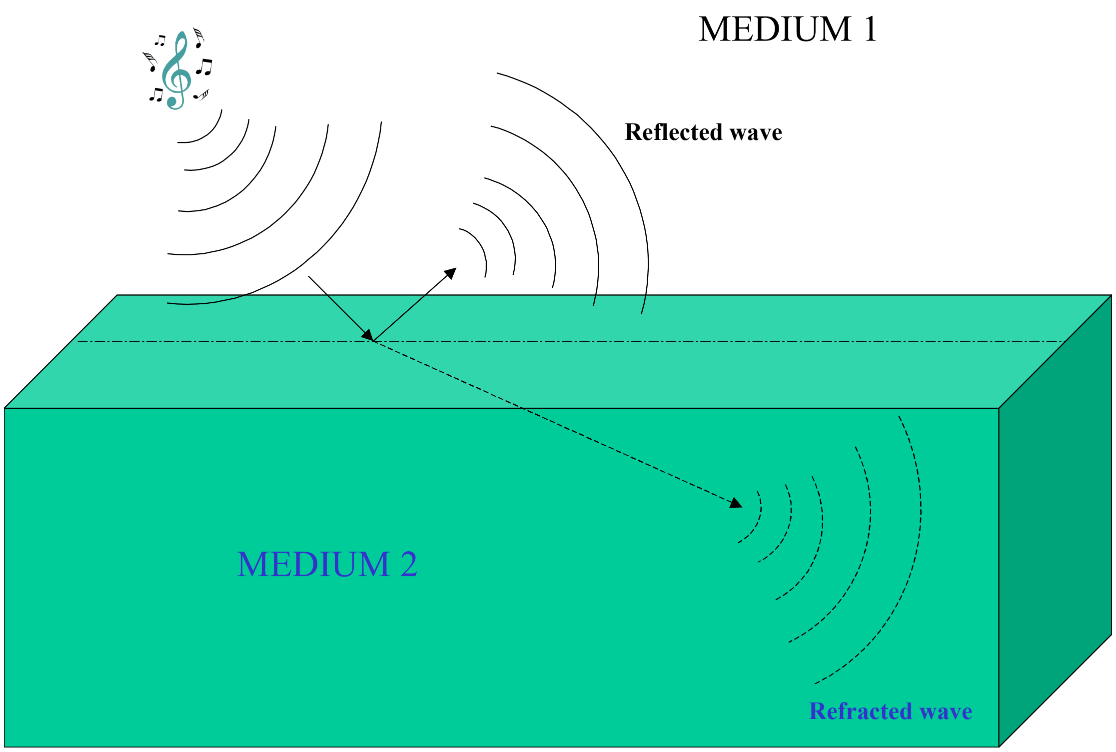
9.1.4. REFLECTION - REFRACTION

When undergoing an obstacle, part of the sound goes into the new medium and another part is reflected, following the equivalent of the **Descartes' law** for light waves.

When the characteristics of the medium of propagation of sound change, the acoustic wave direction and speed will be modified. It depends mainly on the temperature and humidity. For instance the sound celerity depends on the temperature and is given by the equation:

$$c = \sqrt{\gamma r T} \qquad (9.1.4\text{-}1)$$

Where ***γ*** is the specific heats ratio (equal to 1.4 for the air),
r is the specific gas constant (287.26 J/kg/K for the air),
T is the temperature in Kelvin.



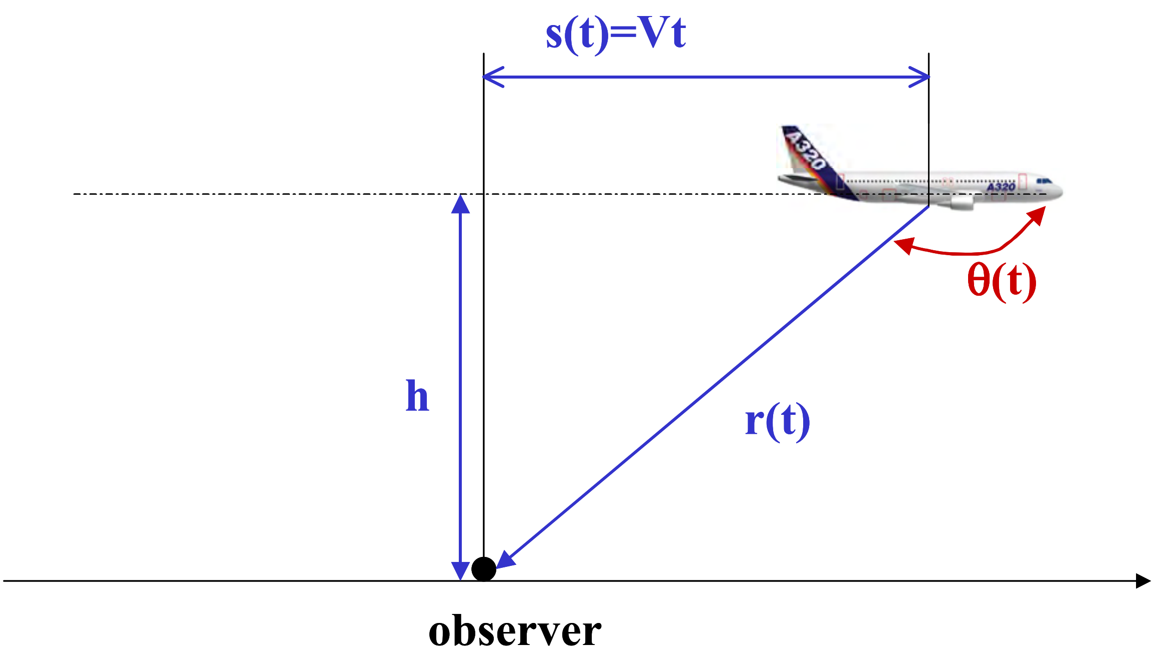
Sound waves emitted by an airplane will reflect on the ground, and also be partially absorbed by it. In terms of energy, only a given percentage will be reflected.

9.1.5. DOPPLER EFFECT

The Doppler effect is the change in the perceived frequency of a moving sound source. If both the observer and the source are motionless, the sound waves perceived by the observer are traveling at the speed of sound in the air c. The basic relationship between the wavelength and the frequency is then:

$$\lambda = \frac{c}{f} = cT \qquad (9.1.5\text{-}1)$$

Where: λ is the wavelength in meters
c is the speed of sound in m/s
f is the source frequency in Hz
T is the period of the phenomenon in seconds



If the aircraft is moving away from the observer at the speed **V** in level flight (altitude **h**), then the speed of the aircraft relatively to the observer is **dr/dt**.
Let us consider the aircraft is emitting **f** sound waves during **T** seconds (in its time reference). During this T time, the aircraft increases its distance from the observer by **dr/dt x T**. This quantity is nothing but the increase of the wavelength of the phenomenon from the observer point of view:

$$\lambda' = cT + \frac{dr}{dt}T = T\left(c + \frac{dr}{dt}\right) = \frac{\left(c + \frac{dr}{dt}\right)}{f} \qquad (9.1.5\text{-}2)$$

The ration between the frequency from the source and the frequency perceived by the observer is then:

$$\frac{f'}{f} = \frac{1}{1 + \frac{dr/dt}{c}} \qquad (9.1.5\text{-}3)$$

In our case, $\frac{dr}{dt} = \frac{d}{dt}\left(\sqrt{h^2 + V^2 t^2}\right) = \frac{V^2 t}{r}$ (9.1.5-4)

As $r = -\frac{Vt}{\cos(\theta)}$

And the Mach number $M = V / c$

We get:

$$\frac{f'}{f} = \frac{1}{1 - M\cos(\theta)} \qquad (9.1.5\text{-}5)$$

Consequently, the sound perceived on ground is more high-pitched when the aircraft is approaching (θ below 90°) and louder when moving away from the observer (θ above 90°).

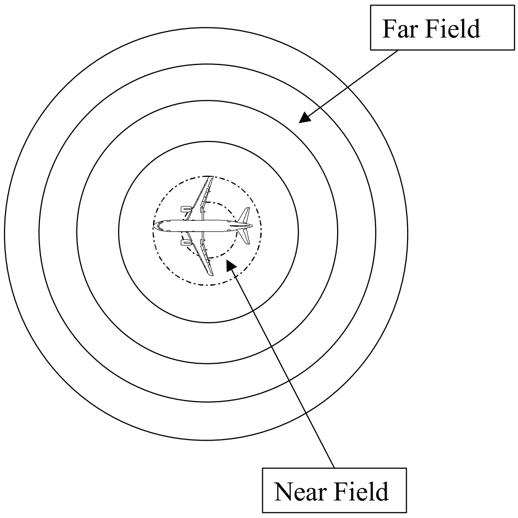
9.1.6. DIRECTIONALITY - DIRECTIVITY

Generally speaking, a sound source the characteristic dimensions of which are large compared to the wavelength prove to be directional. This is the case for airplanes. Consequently, the sound field around an aircraft depends both on distance and angular direction.
The descriptor used to assess the directivity of a source is called the directivity index and corresponds to the difference between the ***Sound Pressure Level*** (*see §9.3.2*) in a specified angular direction θ to the average Sound Pressure Level at the same distance r:

$$DI = SPL(\theta) - SPL_{average}$$

9.2. MATHEMATICAL APPROACH

We will assume a punctual acoustic source and a homogeneous and obstacle free medium. These assumptions are close to the conditions encountered when the source is an airplane, provided that the observation point is far enough from the aircraft (typically at least the wave length of the lowest frequency emitted or several times the greatest dimension of the aeroplane).



(9.2-1)

The far-field area sees the aircraft as a punctual source, while it is not the case within the near-field area, where the sound pressure is much more complex to be expressed mathematically.

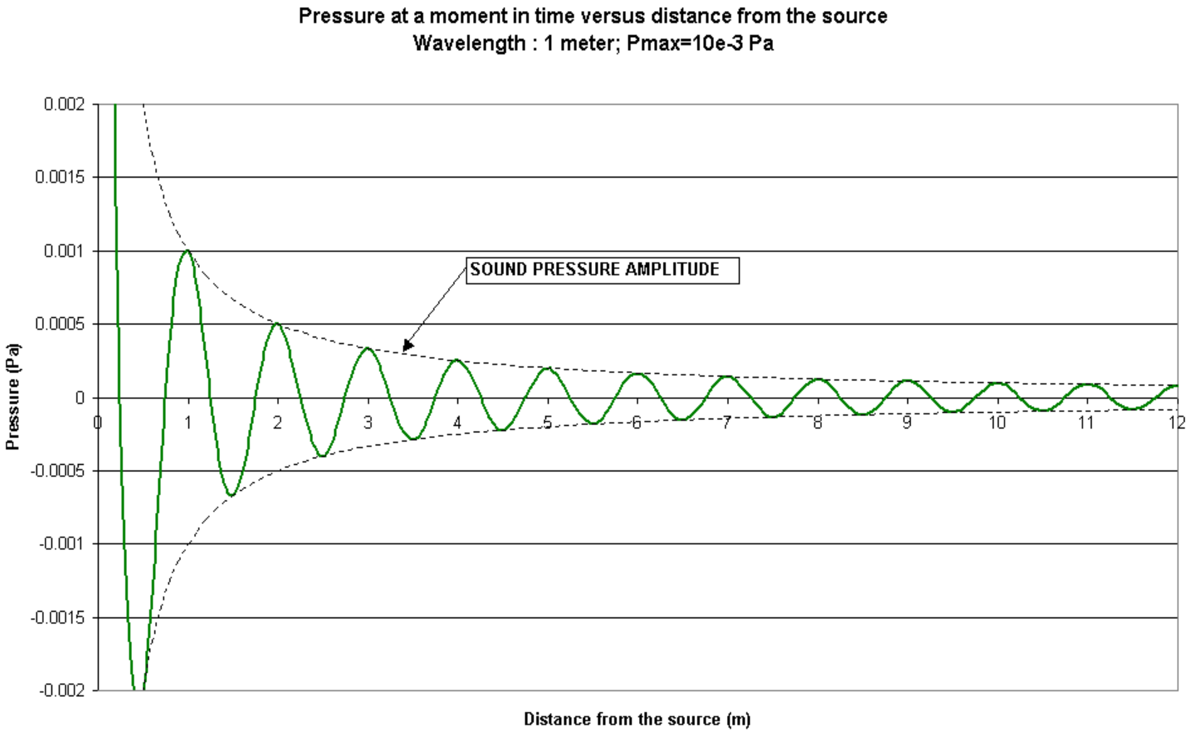
9.2.1. AMPLITUDE MEASURE

Note : For the sake of simplicity, we will base our reasoning upon one of the simplest form of sound wave emitted by a single source. All the conclusions demonstrated hereafter are applicable to the general case.

In the far-field, the simplest form of the local sound pressure variation is a sine, which means a pure tone (a mono-frequency sound).
The local pressure variation of a pure tone can be expressed as follows:

$$p = \frac{P_{\max}}{r}.\cos(\omega t - \frac{2\pi}{\lambda} r) \qquad (9.2.1\text{-}1)$$

Where: P_{max}/r is the amplitude of the wave
r is the distance from the source (in meters)
ω is the wave pulsation (in rad/s)
λ is the wave length (in meters)



The sound pressure amplitude varies inversely with the distance from the source. Nonetheless, the practical way to measure the wave amplitude is to use the effective acoustic pressure p_e, which is the root-mean-square of the instantaneous sound pressure variations over one period. This leads to the following relationship:

$$p_e = \frac{P_{\max}}{r\sqrt{2}} \qquad (9.2.1\text{-}2)$$

9.2.2. SOUND INTENSITY

It is the energy per unit of time per unit of area transmitted by a sound wave. The instantaneous sound intensity at a distance r from the source is equal to :

$$I(r) = \frac{p.dA}{dA} \cdot \frac{dr}{dt} \qquad (9.2.2\text{-}1)$$

Where: ***p.dA*** is the pressure force on the element of surface dA
dr/dt* = *v_r is the speed of the molecule in the **r** direction

Thus:

$$I(r) = pv_r \qquad (9.2.2\text{-}2)$$

Consequently, the average intensity of the sound wave over a period of time is given by:

$$\overline{I(r)} = \frac{1}{T}\int_0^T pv_r(t).dt \qquad (9.2.2\text{-}3)$$

The linearized equation of the dynamics first principle (the particle acceleration is mainly due to pressure forces) gives:

$$\rho_\infty \frac{\partial v_r}{\partial t} = -\frac{\partial p}{\partial r} \qquad (9.2.2\text{-}4)$$

Where: ρ_∞ is the density of the medium (in kg/m^3)
for the air at sea level, ρ_∞=1.29 kg/m^3

Consequently:

$$v_r(t) = \frac{-1}{\rho_\infty}\int \frac{\partial p}{\partial r} dt = p_{\max}\left(\frac{2\pi}{\lambda r \omega}\cos\left(\omega t - \frac{2\pi}{\lambda} r\right) - \frac{1}{\omega r^2}\sin\left(\omega t - \frac{2\pi}{\lambda} r\right)\right)$$

$$pv_r = \frac{p_{\max}{}^2}{\rho_\infty r}\cos\left(\omega t - \frac{2\pi}{\lambda} r\right)\left(\frac{2\pi}{\lambda r \omega}\cos\left(\omega t - \frac{2\pi}{\lambda} r\right) - \frac{1}{\omega r^2}\sin\left(\omega t - \frac{2\pi}{\lambda} r\right)\right)$$

Averaging the above equation over one period, leads to (as the product of a sine by a cosine has got a nil average over one period and the average of the squared cosine is equal to 0.5):

$$\overline{I(r)} = \frac{2\pi p_{\max}{}^2}{2\rho_\infty \omega r^2 \lambda}$$

As λ ***=cT*** and ω=***2π /T***, then

$$\overline{I(r)} = \frac{1}{\rho_\infty c}\left(\frac{p_{\max}}{r\sqrt{2}}\right)^2 = \frac{p_e{}^2}{\rho_\infty c} \qquad (9.2.2\text{-}5)$$

This equation is the equivalent of the Ohm's law in electricity (Intensity=potential difference divided by the resistance).
By analogy, the quantity $\rho_\infty c$ is called the acoustic resistance of the medium.

9.3. PSYCHO-ACOUSTICS

9.3.1. NOTION OF SOUND INTENSITY LEVEL (SIL)

The human eardrum is sensitive to sound intensity. Practically, the human ear perceives sounds, the intensity of which varies from 1.10^{-12} W/m^2 (threshold of perception) to 100 W/m^2, (threshold of pain).
In order to cope with this wide range, a logarithmic scaling has been defined. It is called the ***Sound Intensity Level*** (***SIL***) and its unit is the ***decibel (dB)***:

$$SIL = 10\log\left(\frac{\bar{I}}{I_0}\right)$$, in **decibel (dB)** (9.3.1-1)

Where: ***I*** is the actual average sound intensity
I_0 is the average intensity at the threshold of perception for a pure sound

The following chart gives some typical noise levels in our everyday life

Sound Intensity Level (dB)	Item
140	**Threshold of pain**
110	**Pneumatic drill**
100	**Concorde (at takeoff)**
90	**Truck**
60	**Conversation**
35/40	**Library**
25	**Bedroom**

9.3.2. NOTION OF SOUND PRESSURE LEVEL (SPL)

The effective pressure (as defined in **equation 9.2.1-2**) is linked to the sound intensity by the following equation:

$$I = \frac{p_e^{\,2}}{\rho_\infty c}$$

It is worth noticing that the effective pressure is the easiest quantity to measure, as most of the microphones are sensitive to air pressure variations. Consequently, it is very practical to define a quantity in the same philosophy as for the SIL, called the **Sound Pressure Level (SPL)**:

$$SPL = 10.\log\left(\frac{p_e^{\,2}}{p_0^{\,2}}\right)$$ in **decibel (dB)** (9.3.2-1)

Where: p_0 is the reference pressure of 2.10^{-5} N/m^2.

The value of the pressure is squared in order to get the homogeneity with intensity, since this what the human ear is sensitive to.

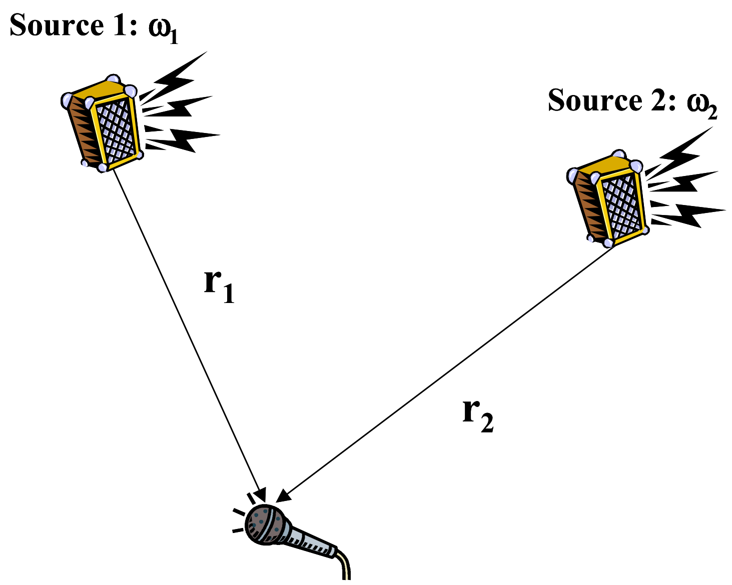
The relationship between SIL and SPL can then be expressed:

$$SPL = SIL + 10.\log\left(\frac{I_0}{p_0^{\,2}}\rho_\infty c\right) \qquad (9.3.2\text{-}2)$$

At sea level in ISA conditions, **SPL=SIL+0.2.**

9.3.3. ADDING SOUND PRESSURE LEVELS – NOTION OF MASKING EFFECT

In the case of several independent sound sources, it is not possible to add arithmetically the decibel values, as they are logarithmically defined.
Let us consider two sound sources, each of them emitting a pure tone at different frequencies ω_1 and ω_2 (corresponding characteristic periods are $\mathbf{T_1}$ and $\mathbf{T_2}$)



The resulting sound pressure at a given point is then:

$$p(t) = p_1(t) + p_2(t) \qquad (9.3.3\text{-}1)$$

$$p(t) = \frac{p_{1\max}}{r_1}\cos(\omega_1(t - r_1/c)) + \frac{p_{2\max}}{r_2}\cos(\omega_2(t - r_2/c)) \qquad (9.3.3\text{-}2)$$

The corresponding effective sound pressure is (considering a period **T** that is the lowest common multiple of $\mathbf{T_1}$ and $\mathbf{T_2}$:

$$p_e^{\,2} = \frac{1}{T}\int_0^T \left[\frac{p_{1\max}}{r_1}\cos(\omega_1(t - r_1/c)) + \frac{p_{2\max}}{r_2}\cos(\omega_2(t - r_2/c))\right]^2 dt$$

(9.3.3-3)

Using trigonometric relationship for the product of two cosines leads to:

$$\cos(\omega_1(t - r_1/c)).\cos(\omega_2(t - r_2/c)) = \frac{1}{2}\left[\cos((\omega_1+\omega_2)t - (r_1+r_2)/c) + \cos((\omega_1-\omega_2)t + (r_2-r_1)/c)\right]$$

,

Then the integration over **T** seconds of the product of these two cosines is null.

The average value of each squared cosine being equal to ½, we finally have:

$$p_e^{\ 2} = \left[\frac{p_{1\max}}{r_1\sqrt{2}}\right]^2 + \left[\frac{p_{2\max}}{r_2\sqrt{2}}\right]^2 \qquad (9.3.3\text{-}4)$$

The SPL corresponding to the combination of the two sound sources at the chosen point is then:

$$SPL = 10\log\left[\frac{p_{e1}^{\ 2} + p_{e2}^{\ 2}}{p_{e0}^{\ 2}}\right] \qquad (9.3.3\text{-}5)$$

- It can then be deduced from the above that if the two sources have got the same effective pressure, the SPL is increased by only 3 dB compared to a single source emission.

- If the source number 2 has got an effective pressure that is half the one of the source number 1, then:

$$SPL = 10\log\left[\frac{5p_{e1}^{\ 2}}{4p_{e0}^{\ 2}}\right] = 10\log\left[\frac{p_{e1}^{\ 2}}{p_{e0}^{\ 2}}\right] + 10\log\left(\frac{5}{4}\right) = 10\log\left[\frac{p_{e1}^{\ 2}}{p_{e0}^{\ 2}}\right] + 0.97 \qquad (9.3.3\text{-}6)$$

It shows that if one source is less powerful than the other, the increase in terms of SPL is rather small. The most powerful source ***masks*** the other one, highlighting the ***masking effect***.

9.3.4. COMPLEX SOUND SIGNALS

- We already mentioned that the simplest form of an acoustic wave is the pure tone.

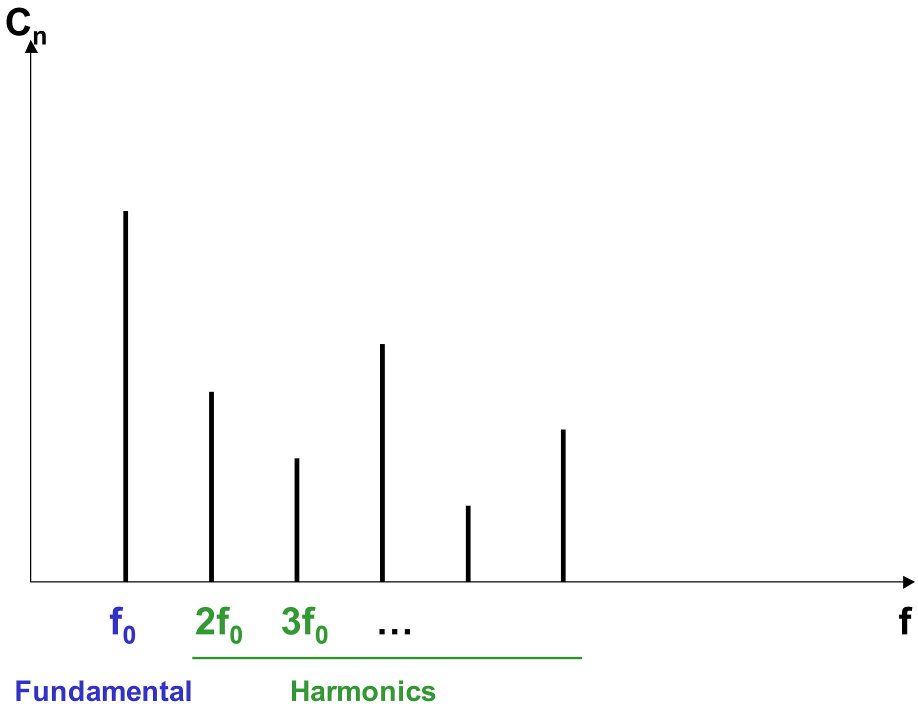
$$p(t) = A\cos(\omega t + \varphi) \qquad (9.3.4\text{-}1)$$

Where: **A** is the amplitude of the wave (in Pa)
φ is the phase of the wave (in rad)

- More generally, any periodic sound signal can be split up into **FOURIER** series (decomposition as the infinite sum of elementary pure sounds)

$$p(t) = \sum_{0}^{\infty} C_n \sin(n\omega t + \varphi)$$

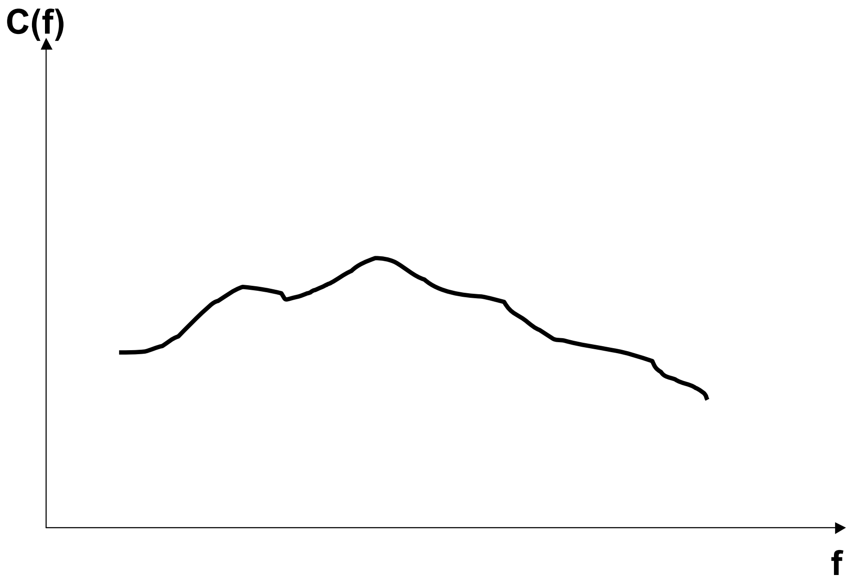
where : ω corresponds to the **fundamental** pulsation
$n\omega$ are the **harmonics**.
C_n are the Fourier coefficients (amplitude of each elementary pure tone)



- Practically, a sound is not periodic and thus cannot be split up into a Fourier series. In that case, the frequency spectrum is continuous and the previously mentioned Fourier series become an integral called the Fourier transform. Then, any sound can be expressed thanks to the **inverse Fourier transform** (***C(f)*** being the direct Fourier transform of ***p(t)***), which makes the pair with the **Fourier** series when the signal period becomes infinite.

$$p(t) = \int_{-\infty}^{+\infty} C(f) e^{j\omega t} \, df$$

Where: ***C(f)*** is called **spectrum** of the acoustic pressure ***p(t)***.



Sounds produced by aircraft cannot be considered periodical nor stationary. Moreover, the knowledge of the frequency distribution of a sound produced by an aircraft operation is necessary to evaluate the sensation perceived, thus to quantify the “disturbance” caused (see **section 9.3.5**).

9.3.5. AIRCRAFT NOISE DESCRIPTION

9.3.5.1. INTRODUCTION

Describing aircraft noise implies “designing” pertinent indices that would reflect as realistically as possible the disturbance on human beings, and not to focus only on gross physical quantities.
Indeed the disturbance felt by the observer first depends on the observer himself and cannot be easily extrapolated. For instance, some aircraft fanatic would rather listen to a aircraft take-off than nice music, which would not be the case of an average person. The disturbance will also depend on the time of the event occurrence, the noise being likely to be more acceptable at 10 A.M. than at midnight. Also a sound the harmonics of which are “arranged” in a musical way will prove to be less disturbing than another one with a random harmonics distribution.
Notwithstanding the previous remarks, it is necessary to focus on the average human being response to acoustic events.
The above context implies that the descriptors for the aircraft noise impact on human beings shall account for the physiological characteristics of the noise perception. This led the experts to make experiments and surveys on a significant number of people, the compiled results and averaging of which aimed at addressing (at least partially) this complex issue.
The conclusion is that the human ear is not equally sensitive to all frequencies, particularly in the low and high frequency ranges

9.3.5.2. OCTAVE, THIRD OF OCTAVE

The sound analysis within the “aircraft noise” context consists of quantifying the spectral energy in a given frequency band.
When two frequencies f_1 and f_2 are in a ratio 2:1, we say that they are distant from one octave.
In the purpose of **jet-planes noise assessment**, the frequency range for spectrum analysis is divided in bands, the width of which is **one third of octave**. Thus, two consecutive frequencies f_1 and f_2 are linked as follows:

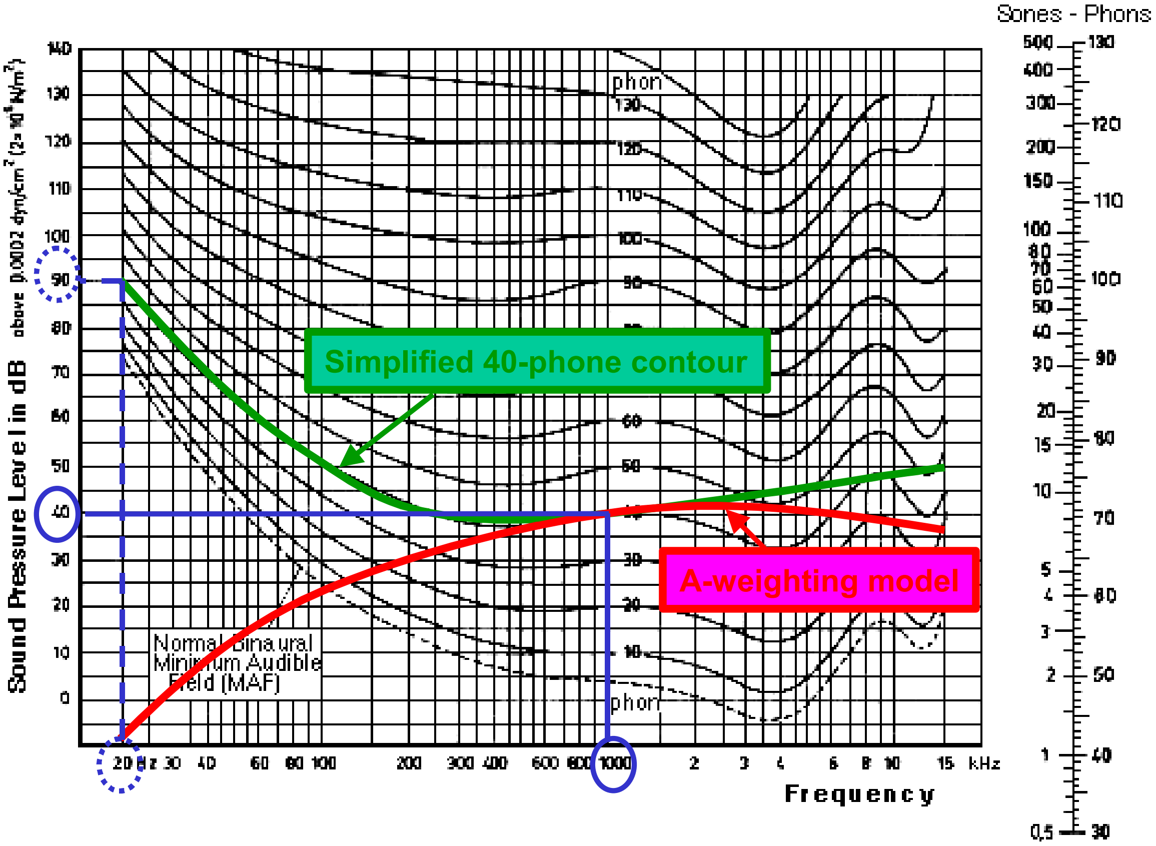
$$f_2 = 2^{\frac{1}{3}} f_1 \qquad (9.3.5.2\text{-}1)$$

Whereas the audible range is between 20 and 15000 Hz, the considered frequency range for aircraft noise assessment is 50-10000 Hz. Indeed the aircraft is mainly noisy in the 50-4000 Hz band. Moreover, the ear sensitivity over 10000 Hz is very low (see chart 9.3.4.2-1). The corresponding central frequencies of the 1/3 octave bands considered for airplane noise analysis are recapitulated in the chart hereafter:

50 Hz	**63 Hz**	**80 Hz**
100 Hz	**125 Hz**	**160 Hz**
200 Hz	**250 Hz**	**315 Hz**
400 Hz	**500 Hz**	**630 Hz**
800 Hz	**1000 Hz**	**1250 Hz**
1600 Hz	**2000 Hz**	**2500 Hz**
3150 Hz	**4000 Hz**	**5000 Hz**
6300 Hz	**8000 Hz**	**10000 Hz**

9.3.5.3. EQUAL LOUDNESS CONTOURS – NOTION OF DB(A)

Fletcher and Munson have originally charted the equal loudness contours over the audible frequency range in 1933. Their charts are graduated in **phons**.



(9.3.5.3-1)

The **phon** is a unit used to describe the **loudness level** of a given noise. The **loudness** is the subjective impression of the intensity or magnitude of a sound. It is dependent on the frequency, the waveform and the duration.
The system is based on the equal sound level contours where 0 **phon** at 1,000 Hz corresponds to 0 decibel, the threshold of hearing at that frequency (see graph). The hearing threshold of 0 **phon** then lies along the lowest equal loudness contour.

The **phon** is a descriptor for sounds that are equally loud. It cannot be used to compare sounds of different level. For instance, 40 **phons** is not twice as loud as 20 **phons**. An increase of 10 **phons** is sufficient to produce the impression that a pure tone is twice as loud.

In the frame of measuring sounds of different loudness, the **sone** scale for subjective loudness was invented. One **sone** is arbitrarily taken to be 40 **phons** *at any frequency,* i.e. at any point along the **40-phon** curve on the graph. Two **sones** are twice as loud, i.e. 40 + 10 **phons** = 50 **phons**. Four **sones** are twice as loud again, i.e. 50 + 10 **phons** = 60 **phons**. The relationship between **phons** and **sones** is shown in the following graph, and can be expressed as follows:

$$PHON = 40 + \log_2(SONE) \qquad (9.3.5.3\text{-}2)$$

It must be underlined that the previous chart illustrates an "average" response of the human ear to sound events. Thus from a person to another, there are of course deviations to the model. According to this graph, sensitivity is highest in the range from 1 to 6 kHz, with a dip at 4 kHz. This means that the intensity level of higher or lower tones must be raised substantially in order to create the same impression of loudness.
For instance, a 1000 Hz sound, the Sound Pressure Level of which is 40 dB will create the same impression of loudness than a 20 Hz sound, the Sound Pressure Level of which is 90 dB.

Interpreting the chart leads to consider the human ear as a filter, which acts differently depending on the sound frequency. Then any sound event history measured in dB has to be corrected. This calls up the notion of weighted sound levels.
In the purpose of aircraft noise loudness, the so-called **A-weighted model** (or filter) was retained. It can be approximately defined as the inverted function of the 40-phone equal loudness contour, the sound pressure levels of which vary between 40 and 90 dB. Applying this "correction" to the "standard" Sound Pressure Level in dB gives birth to the **A-weighted Sound Pressure Level in dB(A)**.
Reading the chart, a 1000 Hz sound, the Sound Pressure Level of which is 40 dB has got a A-weighted Sound Pressure Level of 40 dB(A). A 20Hz sound, the Sound Pressure Level of which is 90 dB has got a A-weighted Sound Pressure Level of 40 dB(A).
The correction value to bring to dB to get dB(A) is given as a function of the frequency:

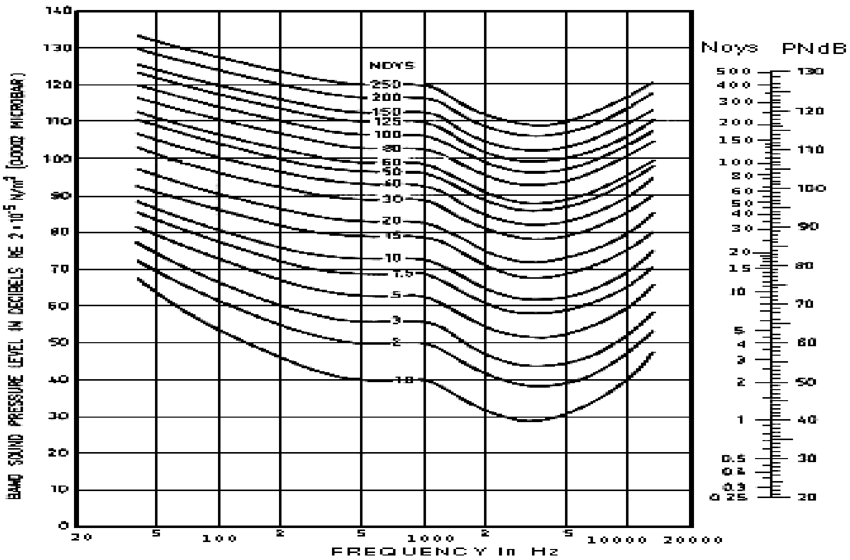
:

$$A(f) = \frac{12200^2 f^4}{(f^2 + 20.6^2)(f^2 + 12200^2)\sqrt{(f^2 + 107.7^2)(f^2 + 737.9^2)}}$$

(9.3.5.3-3)

9.3.5.4. EQUAL ANNOYANCE CONTOURS – NOTION OF PERCEIVED NOISE LEVEL (PNL)

In the same philosophy of the one of equivalent **loudness** curves in **phons**, K.D. Kryter invented equivalent **annoyance** or **noisiness** curves graduated in **noys**. For each one-third-of-octave band, the acoustic pressure level measured corresponds to a certain level of noisiness **n**.
This notion was developed in order to assess the impact of noise from jet airplane flyovers, accounting this time for the results of an investigation of the reactions of a large number of people. The purpose is to define the so-called **Perceived Noise Level (PNL).**
The following chart illustrates the **noy** scale:



(9.3.5.4-1)

In order to get a value that would represent the subjective response of the human ear, the following empirical equation has been developed. It consists in adding the different noy values of the individual one-third-of-octave bands, resulting in what is called the **overall noy value N.**

$$N = n_{MAX} + 0.15\left[\sum n - n_{MAX}\right] \quad (9.3.5.4\text{-}2)$$

Where: ***n_{max}** is the number of noys in the 1/3-octave band having the greatest noy value and **Σn** is the sum of the noy values in all bands.*

Then, the **Perceived Noise Level (PNL)** is calculated from the overall noy value in the same way the phon and the sone are linked:

$$L_{PN} = 40 + \log_2 N \text{, in PNdB} \quad (9.3.5.4\text{-}3)$$

The **PNL** is equal to the pressure level that results into the same amount of noisiness for the 1/3 octave band centered on 1000 Hz.

9.4. NOISE SINGLE EVENT DESCRIPTION

9.4.1. FOREWORD

Most of the indices that are used in the assessment of aircraft noise are based upon the A-weighting model.
Nonetheless, we must acknowledge that the noise perception (and especially for aircraft) is very subjective and depends on the sensitivity to noise of each person.
This is the reason of the existence of many descriptors, the need-to-knows being quoted hereafter.
In this section, we will focus only on descriptors for a given event. Further in this book, indices relative to successive events (notion of ***noise exposure***) will be discussed.

9.4.2. A- SOUND PRESSURE LEVEL – (ASPL TERMED L_A)

This unit is derived from the "standard" **SPL** (see Section 9 §9.3.5.3) using a filter corresponding to the A-weighting law, in order to consider the human ear perception. It is expressed in **dB(A)**.

9.4.3. EQUIVALENT A-SOUND PRESSURE LEVEL (EASPL TERMED $L_{AEQ,T}$)

In order to take into account the event duration, it is interesting to compute the acoustical A-weighted energy received during the measurement time period T. Dividing the total energy by the time give a single value, that describes a time-varying noise. It is expressed in **dB(A)**.

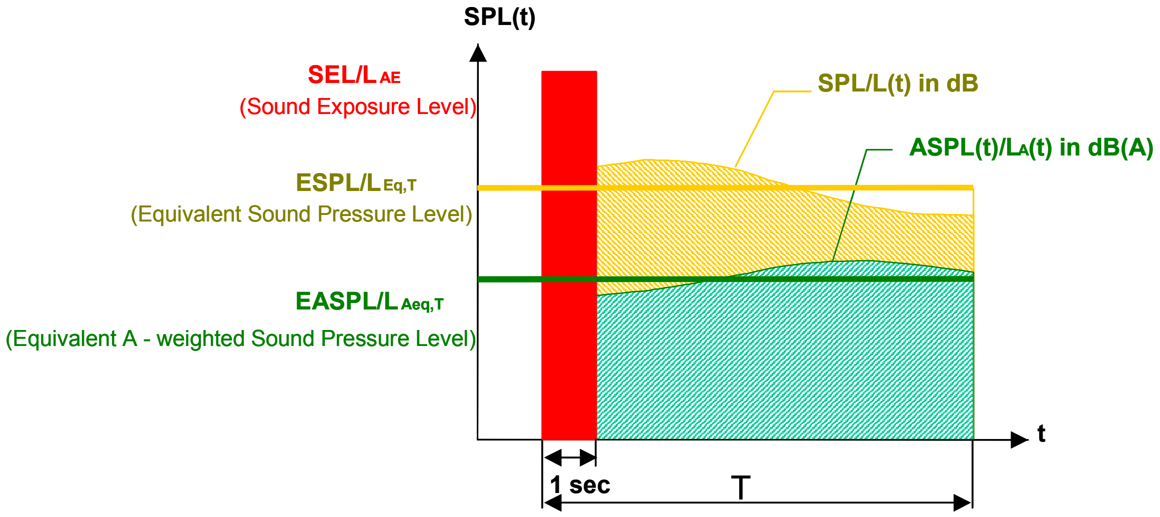
9.4.4. SOUND EXPOSURE LEVEL (SEL TERMED L_{AE})

In the same way, the **SEL** is a normalized value of the **EASPL**, the time period considered being one second. This **SEL** value represents the "A-weighted" sound level, which, produced during one second, would result in the same **EASPL**. This allows to get rid of the influence of the measurement period and allows comparison of events of different durations. It is also expressed in **dB(A)**.

9.4.5. SINGLE EVENT NOISE EXPOSURE LEVEL (SENEL)

SENEL stands for **Single Event Noise Exposure Level**. It is derived from SEL in the way that **only transient sounds exceeding a certain level** are accounted for (**typically 65 dB(A)**)

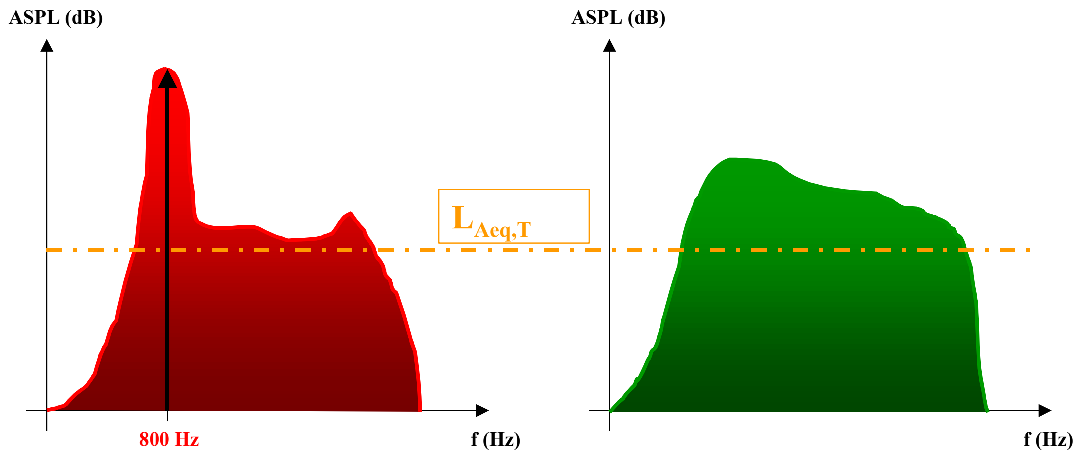
9.4.6. SPL, ASPL, EASPL, AND SEL REPRESENTATION



(9.4.5-1)

9.4.7. TONE PERCEIVED NOISE LEVEL (TPNL TERMED L_{TPN})

When some pure sounds are located in the frequency spectrum, the disturbance appears to be higher.



(9.4.7-1)

For instance, even if the two above spectra result in the same **PNL**, the first one will prove to be more disturbing, as it presents a pure tone at 800 Hz. This cannot be identified by the **PNL** and a correction must be brought to the latter, thus defining the **TPNL**.

$$TPNL = PNL + C \qquad (9.4.7\text{-}2)$$

Where: ***C*** corresponds to the correcting factor for the pure tone of the spectrum, the level of which is the highest (C can reach up 1.5 to 3 PNdB).

9.4.8. EFFECTIVE PERCEIVED NOISE LEVEL (EPNL TERMED L_{EPN})

This descriptor is derived from **PNL** and accounts for pure tones **and duration** effect. It is expressed in **EPNdB**. Its principle is the following: for two events the disturbance intensity of which is the same, the longest one will be identified as the most disturbing.

$$L_{EPN} = 10\log\left[\frac{1}{T_{10}}\int_0^T 10^{\frac{L_{TPN}(t)}{10}}.dt\right], \text{ in } \mathbf{EPNdB} \qquad (9.4.8\text{-}1)$$

Where: ***L_{TPN}*** *is the instantaneous Tone Corrected Perceived Noise Level*
T_{10} *is the reference time of 10 s*

It is important to underline that this descriptor is **used for the noise certification** of all the commercial subsonic jet aircraft (and also propeller-driven airplanes).

9.5. NOISE EXPOSURE DESCRIPTION

9.5.1. INTRODUCTION

One of the need-to-dos when elaborating a noise policy is to choose an indicator that will describe as accurately as possible the **noise exposure** in the airport vicinity. These indicators, namely **noise indices** are based upon investigations and surveys on human beings, and are strongly dependent on the countries. They aim at taking into account not only the noise events themselves, but also the frequency of their occurrence and time of the day.
Indeed repeated noise events prove to affect the human physiology as well as the time at which they take place. For instance a night event will prove to be more disturbing and weighting factors are thus implemented in the computation of these noise indices.

The definition of a “universal” index is a wishful thinking, as the various experts proposed different ones, the use of which remained in the relevant authorities’ hands. A large amount of indices has been developed around the world and thus they are very dependent on countries, in which they have been used to raise regulations around the sensitive aerodromes.

For most of these indices, they are based upon the **A-weighting** model or upon the **Perceived Noise Level**, and they aim at being a good evaluation of the amount of the perceived acoustic energy, with a given flight operations scenario.

9.5.2. EQUIVALENT CONTINUOUS SOUND LEVEL (QL TERMED L_{EQ})

This quantity corresponds to the sound level received on a given location around the airport, averaged over a given period of time, or over a given number of cycles. It is based on the $L_{eq,\,T}$ descriptor. For instance:

> ***$L_{eq(24h)}$*** corresponds to the L_{eq} over a whole day (day+evening+night)
> ***$L_{eq(daytime)}$*** corresponds to the L_{eq} over a 07.00h - 22.00h period of time.
> ***$L_{eq(nighttime)}$*** corresponds to the L_{eq} over a 22.00h - 07.00h period of time.
>
> ***n*** is the number of events during the considered period.

$$L_{eq(24h)} = 10.\log\left[\frac{1}{24\times 3600}\left[\sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}}\right]\right]$$

$$L_{eq(daytime)} = 10.\log\left[\frac{1}{(22-7)\times 3600}\left[\sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}}\right]\right]$$

$$L_{eq(nighttime)} = 10.\log\left[\frac{1}{(24-22+7)\times 3600}\left[\sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}}\right]\right]$$

Where: ***$L_{AE(i)}$*** *is the A-weighted sound level for the trajectory #i*

These indices are used world-wide.

9.5.3. TIME ABOVE THRESHOLD (TA)

TA is a unit of time that assesses the total time during which the received noise level is greater than a given threshold (in dB(A)).

$$TA = Time\ (L_A >= L_{AT}),\ \text{in } \mathbf{min}$$

Where: L_A *is the A-weighted sound level for the trajectory.*
L_{AT} *is the threshold of reference (in dB(A))*

9.5.4. DAY-NIGHT AVERAGE SOUND LEVEL (DNL TERMED L_{DN})

This index corresponds to the average sound level in dB(A) of all the events of a day, and weighted depending on the day period (day or night).

$$L_{DN} = 10.\log\left[\frac{1}{86400} * \left[\sum_{i=1}^{n} 10^{\frac{L_{AE(i)day[0700-2200]}}{10}} + 10\sum_{j=1}^{n} 10^{\frac{L_{AE(j)night[2200-0700]}}{10}}\right]\right]$$

Where: n *is the number of events.*
$L_{AE(i)day[07-22]}$ *is the SEL produced by a trajectory during the [0700-2200] period.*
$L_{AE(j)night[2200-0700]}$ *is the SEL produced a trajectory during the [2200-0700] period.*
86400 *is the day duration in seconds*

This index is widely used in the USA and considers a nighttime event ten times more disturbing than a daytime one.

9.5.5. COMMUNITY NOISE EQUIVALENT LEVEL (CNEL)

As for the **DNL**, this index corresponds to the average sound level in dB(A) of all the events of a day, and weighted depending on the day period (day+**evening**+ night).

$$CNEL = 10.\log\left[\frac{1}{86400}\left[\sum_{i=1}^{ni} 10^{\frac{L_{AE\ (i)day[0700-1900]}}{10}} + 3\sum_{j=1}^{nj} 10^{\frac{L_{AE\ (j)evening[1900-2200]}}{10}} + 10\sum_{k=1}^{nk} 10^{\frac{L_{AE\ (k)night[2200-0700]}}{10}}\right]\right]$$

Where: $L_{AE(i)day[0700-1900]}$ *is the SEL produced by a trajectory during the [0700-1900] period*

$L_{AE(j)evening[1900-2200]}$ *is the SEL produced by a trajectory during the [1900-2200] period*

$L_{AE(k)day[2200-0700]}$ *is the SEL produced by a trajectory during the [2200-0700] period*

It was introduced in the early 1970's by the State of California for community noise exposure, with particular emphasis on airport noise.

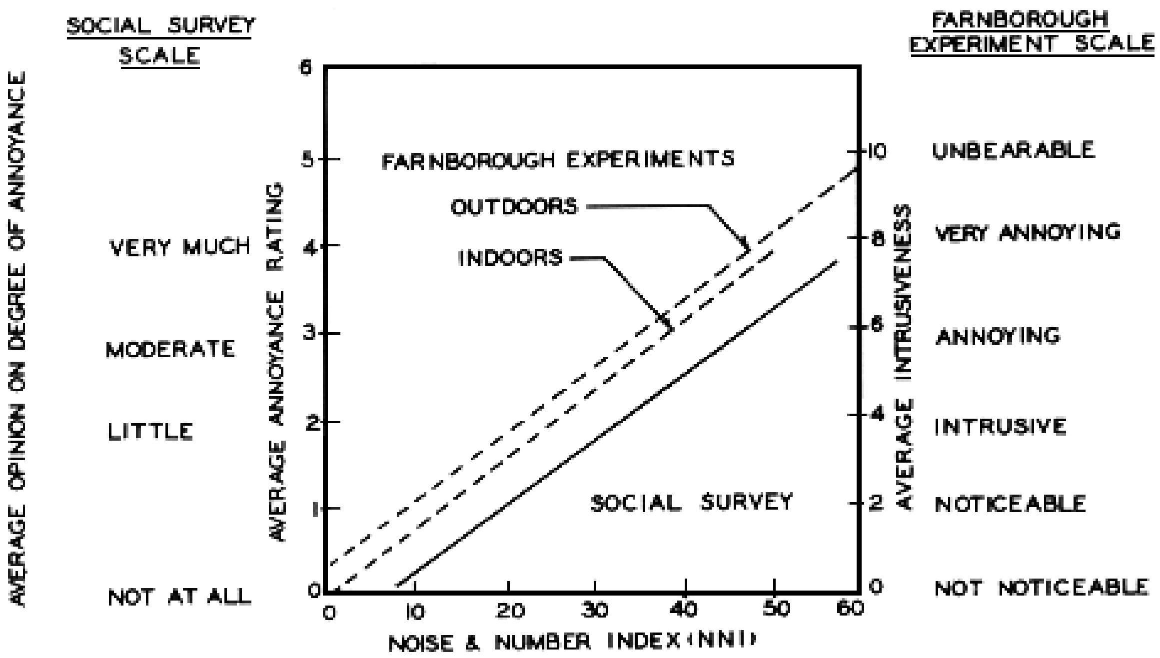
9.5.6. NOISE AND NUMBER INDEX (NNI TERMED L_{NNI})

This index corresponds to an average sound level (in PNL_{max}) of all the events that occurred in a given period.

$$L_{NNI} = 10\log\left[\frac{1}{N} * \left[\sum_{i=1}^{N} 10^{\frac{L_{PN\max(i)}}{10}}\right]\right] + 15\log(N) - 80$$

where: $L_{PNmax(i)}$ *is the PNLmax for a procedure*
N *corresponds to the number of procedures*
80 *is a normalized constant*

It was originally devised by the *Wilson Committee on Noise* in Britain (1963). The Noise and Number Index scale runs from 0 to 60 and following the results of social surveys, the Wilson Committee assigned values of annoyance to the index as shown in the graph below. The Wilson Committee considered that exposure to aircraft noise reaches an unreasonable level in the range 50 - 60. A difference of 10 NNI corresponds either to an increase of the peak level of 10 PNdB or to a quadrupling of the number of flights in the period.



9.5.7. WEIGHTED EQUIVALENT CONTINUOUS PERCEIVED NOISE LEVEL (WECPNL TERMED L_{WECPN})

This index is relative to a cumulated noise level of all the events over a given period. Each noise event is weighed depending on the period of the day and the season of its occurrence.

$$L_{WECPN} = \frac{L_{WECPN(hotmonths)} + L_{WECPN(temperatemonths)} + L_{WECPN(coldmonths)}}{1{,}2 or 3}$$

The computation of WECPNL requires using two intermediate indices.

9.5.7.1. TOTAL NOISE EXPOSURE LEVEL (TNEL TERMED L_{TNE})

This index describes the noisiness produced by a succession of aircraft flyovers.

$$L_{TNE} = 10\log\left[\sum_{i=1}^{n} 10^{\frac{L_{EPN}(i)}{10}}\right] + 10\log\left[\frac{T_0}{t_0}\right]$$

Where: ***L_{EPN}(i)*** *is the EPNL for the procedure i*
n *is the number of movements*
T_0 *is a constant equal to 10 s*
t_0 *is a constant equal to 1 s*

9.5.7.2. EQUIVALENT CONTINUOUS PERCEIVED NOISE LEVEL (ECPNL TERMED L_{ECPN})

In the same way we have defined EPNL, we design the equivalent cumulative perceived noise level as follows:

$$L_{ECPN} = L_{TNE} - 10\log\left[\frac{T}{t_0}\right],$$

Where: ***T*** *corresponds to the exposure time*

9.5.7.3. WECPNL CALCULATION

9.5.7.3.1. Considering two periods in a day

$$L_{WECPN} = 10\log\left[\frac{5}{8}\left(10^{\frac{L_{ECPNday(0700-2200)}}{10}}\right) + \frac{3}{8}\left(10^{\frac{L_{ECPNnight(2200-0700)}+10}{10}}\right)\right] + S$$

9.5.7.3.2. Considering three periods in a day

$$L_{WECPN} = 10\log\left[\frac{1}{2}\left(10^{\frac{L_{ECPNday(0700-1900)}}{10}}\right) + \frac{1}{8}\left(10^{\frac{L_{ECPNevening(1900-2200)}+5}{10}}\right) + \frac{3}{8}\left(10^{\frac{L_{ECPNnight(2200-0700)}+10}{10}}\right)\right] + S$$

Where: ***L_{ECPN}*** *is the equivalent continuous perceived noise level for the considered period*
S *is a seasonal adjustment which values are recapitulated in the following table*

Cold months (temperature above 20°C for less than 100 hours per month)	Temperate months (temperature above 20°C for more than 100 hours per month but above 25.6 not for more than 100 hours)	Hot months (temperature above 25.6°C for more than 100 hours per month)
-5 dB	**0 dB**	**+5 dB**

9.5.8. DAY-EVENING-NIGHT LEVEL (LDEN)

For long-term noise exposure, **LDEN** has a proven relation with the degree of community noise annoyance and particularly with the percentage of highly annoyed respondents.
LDEN, in combination with special dose-effect relations, is also applicable in the following cases:

- Annoyance due to noise with strong tonal components
- Annoyance due to noise with an impulsive character
- Adverse effects on learning by children

The definition of the LDEN is similar to the CNEL, the weighing factor for evening only being different.

$$LDEN = 10.\log\left[\frac{1}{86400}\left[\sum_{i=1}^{ni} 10^{\frac{L_{AE}(i)_{day[0700-1900]}}{10}} + 5\sum_{j=1}^{nj} 10^{\frac{L_{AE}(j)_{evening[1900-2200]}}{10}} + 10\sum_{k=1}^{nk} 10^{\frac{L_{AE}(k)_{night[2200-0700]}}{10}}\right]\right]$$

Where: ***L_{AE}(i)*** *corresponds to the Sound Exposure Level of a given procedure.*

9.5.9. SOME INDICES USED IN DIFFERENT COUNTRIES

COUNTRY	NOISE INDEX
United Kingdom	*Noise and Number Index (NNI)*
France	*Psophic Index (IP)*
Germany	*Equivalent sound level (Leq)*
United States, (California)	*Community Noise Equivalent Level (CNEL)*
Japan	*Weighted Equivalent Continuous Perceived Noise Level (WECPNL)*
Netherlands	*Kosten Index (Ke)*
Australia	*Australian Noise Exposure Forecast (ANEF)*

10. MEASURING NOISE

This section quickly describes the basics of noise measurement.

10.1. INTRODUCTION

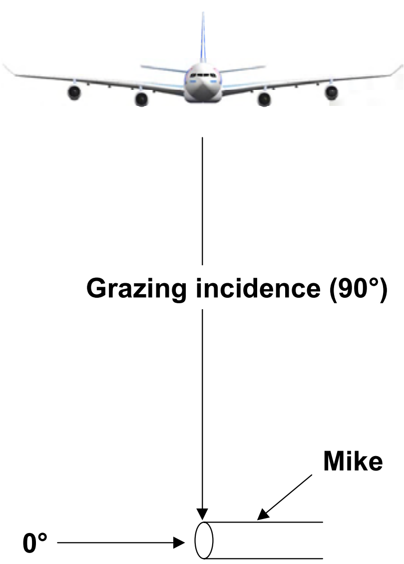
The equipment needed to quantify noise levels is basically composed of :

- A microphone for the signal measurement
- A recorder
- A spectrum analyzer for frequency distribution determination.

Though the dB(A) is directly measurable, other quantities (such as the EPNdB) have to be calculated. This is one of the tasks achieved by the analyzer.

10.2. MICROPHONES

The mikes typically used for the estimation of aeroplanes noise emissions are pressure and capacitor microphones.
Indeed the physical quantity that can be directly accessed is the air pressure (as a function of the time) through the capacity variation of a condenser.
For aircraft acoustics, the mikes will be mounted "grazing" (see picture). This configuration allows to keep an quasi-constant incidence of the acoustic wave on the mike during the event duration, which is a pre-requisite to determine the corresponding EPNL (for instance during certification tests).



10.3. ANALYSERS

Today, analyzers have adopted a digital technology allowing a real-time signal interpretation. They are needed in order to quantify the above-mentioned descriptors, as they are not directly accessible.
For certification purposes, the retained bandwidth in terms of frequency is the third of octave. In this very case, the analysis is performed for each third of octave thanks to 24 filters centered on the normalized frequencies from 50 Hz to 10000 Hz.

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