AIRCRAFT NOISE MODELS FOR ASSESSMENT OF NOISE AROUND AIRPORTS – IMPROVEMENTS AND LIMITATIONS

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Noise pollution around airports continues to be the most significant cause of adverse community reaction towards airports[1]. Fifteen years ago, aircraft noise assessment and management was focused on so called "close in" areas around airports; those that were exposed to the highest levels of aircraft noise, typically exceeding 55 dB(A)L_{DN}. Today, community opposition to airport growth is increasingly coming from residents living in areas outside of the traditional "close in" noise contour areas[2]. This has happened because of a fundamental change in the public reaction to aircraft noise. Evidence shows that increased annoyance levels have been measured in the last decade at European airports. For example, recent studies of the airports in Manchester, Paris, Amsterdam, and Frankfurt have shown that public reaction to noise is much higher than that predicted by the conventional noise indices.

The ICAO goal in aircraft noise control is to limit or reduce the number of people affected by significant aircraft noise. ICAO Document 9829, *Guidance on the Balanced Approach to Aircraft Noise Management*, was developed for this purpose. It covers four elements, namely: land-use planning, reduction of noise at source, noise abatement measures, and as a last resort, aircraft operating restrictions. The decision on the choice of noise mitigation measure or the combination of measures to be used is based on a robust data set, including the calculated number of people exposed to aircraft noise for any possible flight scenarios using sophisticated software installed on GIS (Geographic Information System) platform, which helps focus mitigation actions on the highest priority zones.

Two different approaches to aircraft noise modelling exist. Both ICAO[3] and the European Civil Aviation Conference[4] documents provide recommendations for aircraft noise calculations. Their methodologies apply to long-term average noise exposure only. Current versions of noise modelling software (INM, SONDEO, ANCON, IsoBella, AcousticLab, etc.) are consistent with these recommendations. However, a number of States require single noise event measurement or indicator via L_{Amax}, or SEL (single Event Noise Exposure Level), or other noise descriptors.

Aircraft Noise Modelling Characterization

Aircraft noise modelling around airports serves multiple purposes. The models can estimate cumulative noise exposure, or they can identify and describe the size of annoyed population in certain areas; all of which can be used to identify dose-response relationships[5]. ICAO provides guidance on the use of these types of models and provides methods for assessing the acoustical characteristics of the various sources associated with aircraft noise events[6].

The models differ in terms of structure, the number of required parameters, and the initial information necessary to implement each one. The simplest type of model structure includes the definitions of noise footprints (contours for specified values of noise indices and areas bounded by these contours) for any type of the aircraft and particular flight mode.

Two approaches to analysis of aircraft noise phenomena have been defined and computerized. The first approach is based on I/3-octave band spectra noise analysis of any type of aircraft, in any phase of flight in the vicinity of, or inside an airport. In this case, the assumption is that sound waves spread along the shortest distance between the aircraft and the point of noise control. The second approach is based on the concept of "noise-power-distance" (NPD) or "noise radius" (Rn)[5] and provides calculations of aircraft noise maximum and/or exposure levels around the airport, or at any noise monitoring point.

With the second approach, the resulting predictions are location-specific and are not only dependent on flight parameters. It has been utilized in computer programs like ANCON (UK), Fanomous (Netherlands), INM, NOISEMAP (both USA), IsoBella (Ukraine), and AcousticLab (Russian Federation), among others.

Prediction of Noise in the Vicinity of an Airport

Airport noise maps that result from complete airport noise modelling are an essential noise management tool. For example, they form the basis for noise zoning policies and land-use planning decisions. They also contribute to the performance of Environmental Impact Assessments at airports. Such modelling combines the specific features of both flight path and ground aircraft noise models. Important input parameters are the atmospheric temperature, pressure and humidity, all of which may influence both the flight performances of the aircraft and the sound propagation. In addition, aircraft specific data and airport operational information are required to compute the noise of each individual operation.

Typically, the final results of these computations are presented as noise contour diagrams. Noise contours illustrate how the specific noise index varies from location to location as the result of a given aircraft traffic pattern at an airport.

When analyzing the noise situation around an airport in a particular region, or to compare noise exposure from several noise sources in the region, non-acoustical parameters are also taken into account. A widely used such indicator is the amount of population exposed to noise. This can be calculated by counting the number of dwellings exposed to a certain noise level (inside the zone between two specified noise contours) and multiplying that by the average number of inhabitants per dwelling. Often, these data are grouped into classes of 5 dB(A); that is the difference between the noise indictor values on the outer and inner noise contours of the zone under consideration is equal to 5 dB(A).

Measurements of aircraft noise levels or specific noise indicators around airports are the result of many factors including:

- acoustical characteristics of the aircraft;
- intensity of flight traffic around the airport;
- scheme of routes and tracks (both on the airfield and for departure and arrival);
- distribution of aircraft between routes;
- recommended operational procedures used on various routes for each type of aircraft;
- operational factors including the in-flight mass of the aircraft;
- meteorological characteristics;
- runway characteristics;
- presence of acoustic screens;
- topographic conditions at the airport location; and
- any other factors that might cause diffraction and interference between propagated and reflected sound waves.

The main factors that affect the accuracy of the modelling are wind and temperature, as well as variability in the operational procedures employed during take-off. The existing models do not include any corrective factors for wind and temperature, even though these can cause significant changes in ground-to-ground attenuation, and can even result in so called shadow zones, where the noise cannot be observed because the sound waves are refracting upward in some specific wind and temperature conditions.

In view of the large number of variables and the necessary simplifications due to absence of initial data for some significant variables it is desirable to standardize procedures for computing airport noise contours. There is a need to provide guidelines for such a standard method, to identify the major aspects and to supply specifications in respect of each of these.

For an airport noise study, the calculations methodology includes the following steps:

a) Determination of the noise levels from individual aircraft movements at observation points around the airport.
b) Addition or combination of the individual noise levels at the respective points, according to the formulation of the chosen noise index.
c) Interpolation and plotting of contours of selected index values.

Calculations are usually repeated at a series of points around the airport and then interpolations are made between those points of equal noise index values (i.e. noise “contours”).

The noise levels for individual movements are calculated assuming flat terrain from noise-power-distance and aircraft performance data for given atmospheric conditions, based on the yearly averages observed at a range of world airports. However, ambient parameter values have an impact on the flight mode parameters, thus affecting the noise emitted by aircraft. Specifically, atmospheric conditions tend to influence aircraft noise levels, in particular, air temperature causes changes in flight path parameters, sound absorption parameters, and noise generation characteristics.

This confirms the necessity to account for certain operational factors when calculating noise levels around airports. If these calculations are connected with noise zoning and land-use planning, the worst possible operational conditions (from the noise point of view) must be considered. If models are used for monitoring purposes, NPD-relationships must be derived in accordance with actual values of meteorological parameters in the routine mode. This requires use of specific calculation modules (for example a module RADIUS in designed software tool IsoBella) including application of basic acoustic models of the aircraft of particular types with identified transfer functions. The software module is called the NPD-generator (or RADIUS-generator). Flight paths for the aircraft under consideration are built with the so called FLIGHTPATH-generator, which assumes the common flight dynamics models (e.g. as in the INM model).

Similarly, modelling of noise at ground locations near the airport runway during the take-off roll requires several modifications of the basic noise-power-distance data. The modifications result from the fact that the aircraft is on the ground accelerating from essentially zero velocity to its initial climb speed, whereas the basic data are representative of overflight operations at constant airspeed. To accommodate these differences, consideration must be given to: changes in generated sound resulting from jet relative-velocity effects, varying directivity patterns from the moving aircraft, the modified effective duration with increased speed, and the extra attenuation of sound during over-ground propagation at near-zero elevation angles. The directivity patterns are necessary for both taxiing aircraft and engine testing. As one can see from **Figure 2**, the directivity patterns of noise generation are specific to each engine type. Differences between these specific directivity patterns and the generalized relationship proposed by ICAO or ECAC guidances[3,4] may be as large as 10 dB(A) in certain directions.

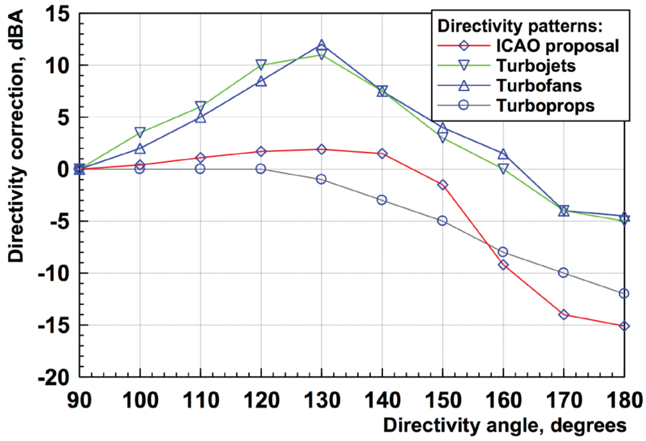


Figure 1. Generalized Directivity Corrections for Characteristic Engine Types.

Excess attenuation due to ground effect is not constant for every condition like it is defined by ICAO or ECAC guidances[3,4], but it is dependent from a locally reacting plane surface. In fact, differences between the predicted attenuation effects on overall A-weighted levels L_A can be as much as 12 dB(A) due to the spectrum variations between aircraft engine types, or even for one type of the engine, but in various directions (see **Figure 2**). The magnitude of the predicted variation is the same, or even greater, as that for NPD variations due to temperature of the air.

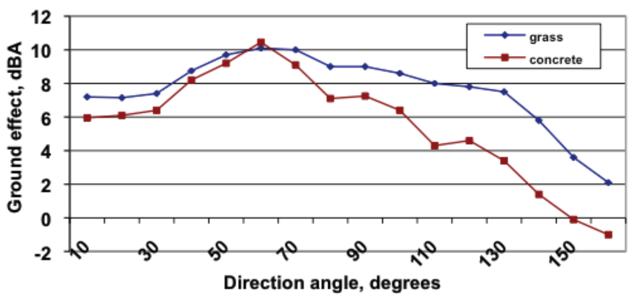


Figure 2. Ground Effect as a Function of The Angle of Engine Noise Radiation.

Examples of noise contour predictions are shown in **Figures 3 and 4**. The calculations use identical initial operating conditions to enable better comparison. **Figure 3** shows the results without any of those changes or improvements. **Figure 4** shows the results obtained with the factors and improvements mentioned above.

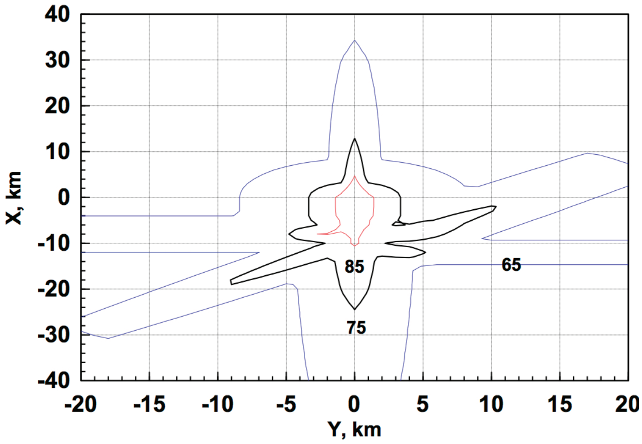


Figure 3. Noise Contours Predicted By Means of an Existing Calculation Method.

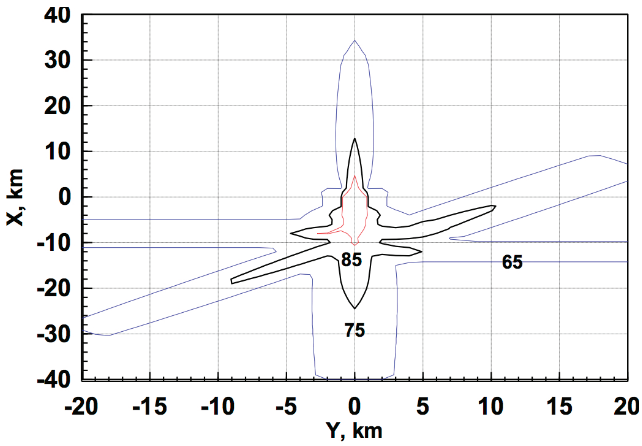


Figure 4. Noise Contours Predicted By Means of the Improved Calculation Method.

Single Aircraft Noise Event Prediction

It is well-known that calculation results for single events differ from actual measurements. On average, mentioned before integrated models provide predictions about 5-10 dB(A) lower than measured values SEL (less inaccuracy closer to runway, larger - far from runway). Such patterns are typical for most analyses, because an acoustical base consists of line sources representing the time-integrated noise from a complete flyover. Noise data are generally supplied by the aircraft manufacturers in the form of NPD curves, which are fixed to standard temperature and humidity. Such models account for geometric spreading, air absorption and ground effect. All existing models represent the same physical phenomena, but do so with different levels of detail and some different choices in particular algorithms. Flight profiles are defined by software via solutions of equations for aircraft balanced motion (in real practice aircraft flight is slightly unbalanced usually), which are recommended by existing methods [3,4], using the data for necessary coefficients from the ANP database, which is supported by Eurocontrol (www.aircraftnoisemodel.com).

As shown in **Figure 6**, flight profiles of real-life operations tend to differ greatly from predictions for balanced motion[7].

The differences are observed not only for the height-distance, but for the flight speeds and thrust settings, which also contribute significantly to the predicted levels of noise. The same is observed for arrivals [3,4], where the thrust setting is usually higher than in the balanced motion predictions.

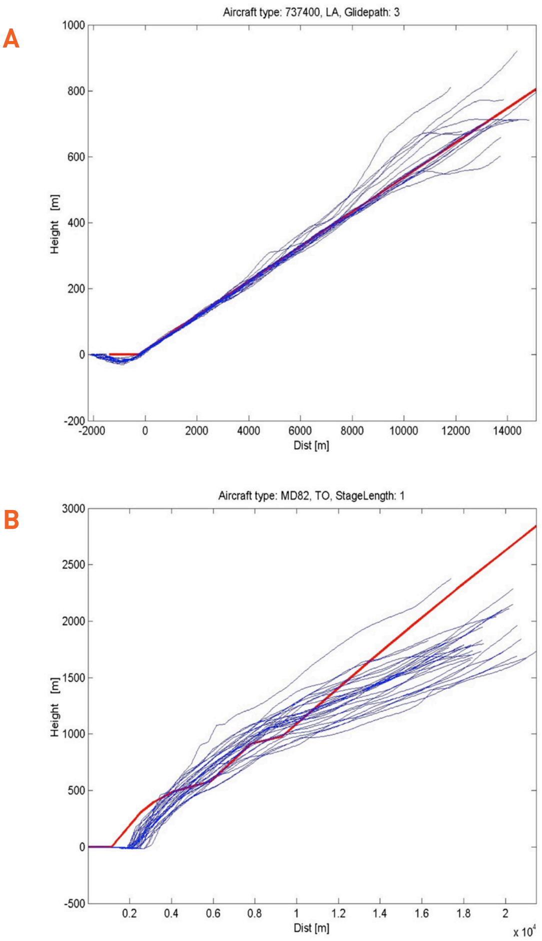


Figure 6. Flight Profiles (Height Via Distance) Observed In Operation (blue lines) In Comparison With Balanced Prediction (red lines): A – Arrival; B – Departure.[10]

There were many results obtained when comparing measurement data with calculated data[11]. It is possible to show large amounts of measured noise data in noise contour presentations and compare those with calculated values. **Figure 9** presents these results using data for A-320 and B-737-400 aircraft. It shows that the measured contour for the maximum level 75 dB(A) is up to the 4 km longer than the calculated contour!

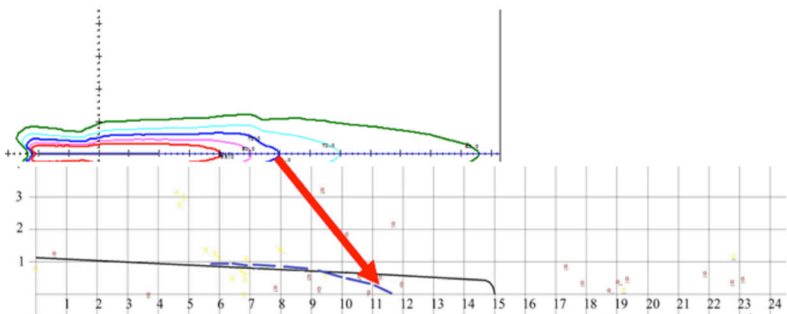
During the arrival phase of a flight, the difference between results observed during operations and the balanced data for flight parameters (See **Figure 8a**) is 2-3 dB(A) higher than the maximum levels calculated by models in accordance with current requirements [3,4]. The same differences may be found for contours produced by the IsoBella model, as shown in **Figure 8b**. Results based on flight input data parameters observed in operation approach/landing contours are longer than for balanced flight data, with an appropriate difference of L_{Amax} ~2 dB(A) at a distance of 1,000 m from the runway end.

For the take-off/climbing phase of flight noise contour for L_{Amax}= 75 dB(A), which is derived from input data for flight parameters observed during actual operations, the difference in contour length is more than 1.5 km than those calculated (see in **Figure 8b**).

Noise Impact Management

Reduction of noise at the receiver point is not an end in itself, but a means to reduce the effects of noise. For ICAO, this translates into limiting or reducing the number of people affected by significant aircraft noise.

There is a difference of around 5-6 dB(A) between the average annoyance curves of recent studies and those using older data. As **Figure 9** depicts, the newer studies indicate that a higher number of people exposed to given noise levels are considered annoyed, compared with a few decades ago[8]. These results are critical for determining the relevance of the of current exposure-annoyance relationships for aircraft noise, and whether these need to be updated.



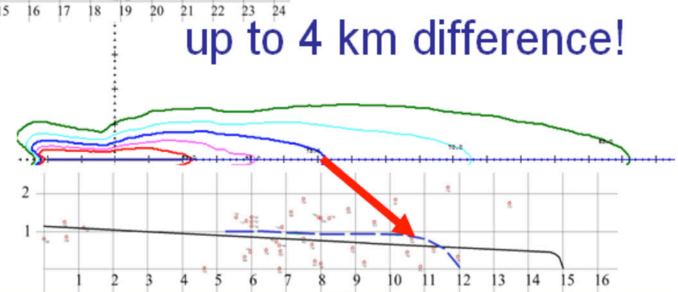


Figure 7. Comparison of Measured and Calculated Noise Contours for A-320 and B-737-400Aircraft In Take-off/Climbing Phases.

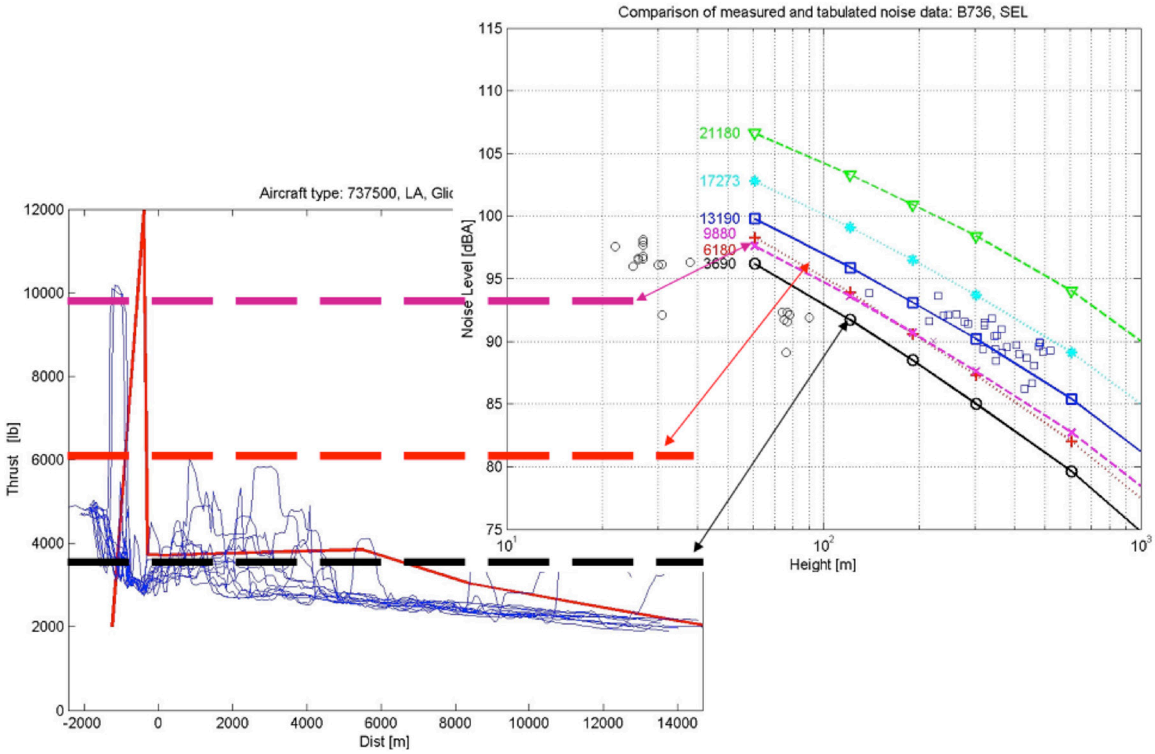


Figure 8a. Comparison of Observed in Operation (magenta) and Balanced (black) NPD curves for B-737-400/500/600 at glideslope.

Aircraft noise management policies need to take into account the evolution of annoyance curves. This is especially important because these show that, for the same noise levels, annoyance is higher for aircraft noise than noise from other sources. It is clear that annoyance levels that exceed the tolerance threshold for a specific nuisance lead individuals to complain.

It is recognized today that annoyance from noise is not exclusively correlated with noise levels. Non-auditory effects of noise give the rise to annoyance and are more complex to describe and measure. Among the non-acoustical factors the mostly contributing (with high correlation with final effect) are the following: negative expectations toward noise development; perceived control and coping capacity; Concern about negative health effects of noise and pollution, etc. There is no agreed methodology to combine all factors of annoyance into a single explanatory model, even if some social and economic factors have been identified as influencing community response to noise. Approximately one-third of the variation (only one-fifth by some estimates) in noise annoyance can be explained by acoustical factors.

As a result, noise management policies should be understood as a dynamic process, meaning that they should be assessed regularly and adapted when necessary in the light of new scientific findings. A truly effective model to measure annoyance still needs to be designed. That should be done in a manner similar to what was done to develop the appropriate models to measure the impacts of all of the elements identified in ICAO's Balanced Approach to aircraft noise management. Nonetheless, the level of noise exposure does determine perceived disturbance. Thus, the effective management and control of aircraft noise should minimize adverse impacts of aircraft noise on health and quality of life. However, investigating the relationship between actual sound levels and perceived noise levels should be a primary objective of future research. New and additional policy measures to mitigate noise impact may result as the focus shifts from noise to annoyance. For that the better communications with communities surrounding airports should improve mutual understanding and contribute to more positive responses to aircraft operations and the associated noise levels.

Conclusions

Aircraft noise modelling is being continuously improved. Early models and software were based on measured data. Current methods are based on more analytical models. However, due to the simplified assumptions used in those models, there are a number of differences between calculated and measured results, especially for single noise events. This analytical method could be complemented with a set of more practical approaches, in order to provide more accurate assessments of noise indices for both separate points and footprints.

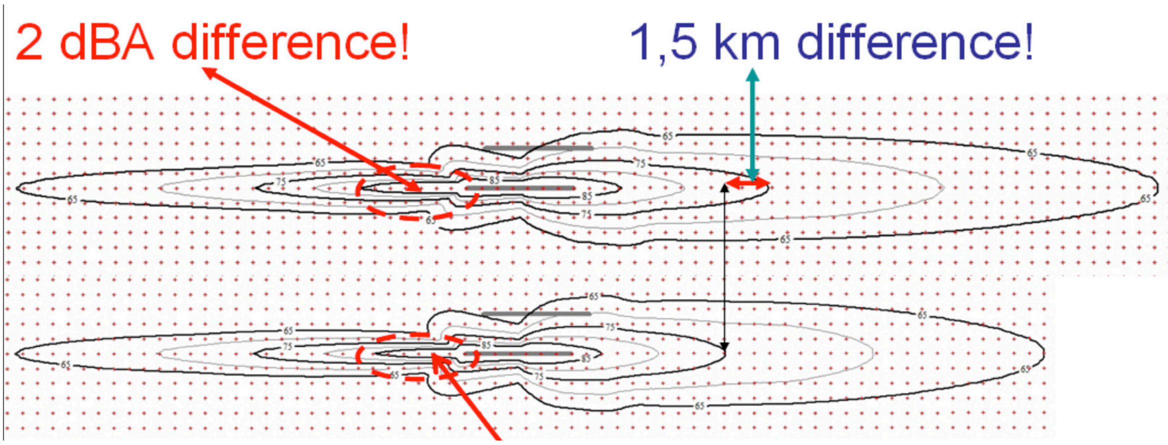


Figure 8b. IsoBellaResults for B-737-400Noise Contours (approach/landing and take-off/climbing) are Higher When Using Input Data for Flight Parameters Observed in Operations; and Lower for Balanced Input Data for Flight Parameters

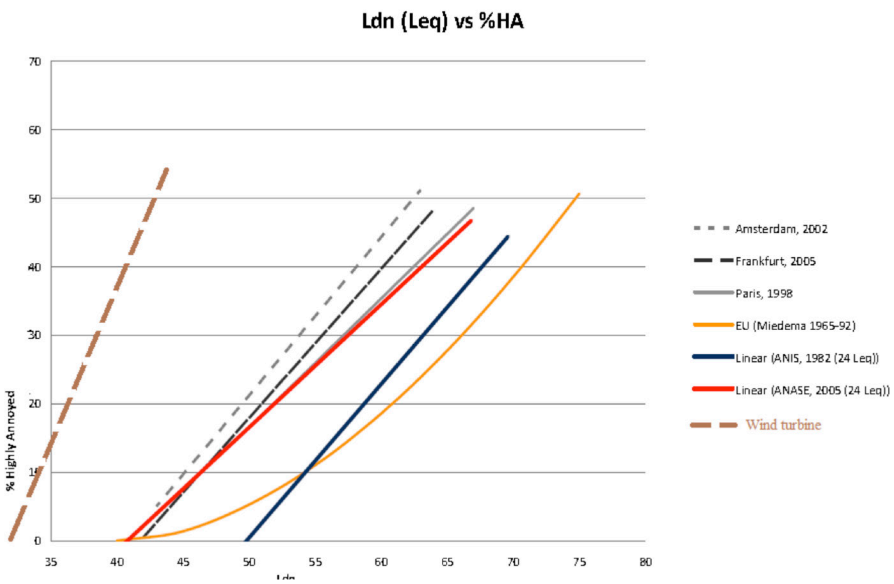


Figure 9. Annoyance Curves for Available and Comparable Survey Data Collected in 20 Different Research Studies Conducted in Europe, North America and Australia.

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