Methodology of statistical model results verification in a high traffic airport

Bassanino M., Mussin M., Deforza P., Lunesu D., Telaro B.

1. ABSTRACT

The main activity of the Lombard airport system is concentrated in the Malpensa Airport of Milan. It is the only intercontinental airport in Northern Italy and it is localized close to the Ticino Regional Park, a protected area of high natural relevance. The airport traffic is mainly constituted by international flights. Malpensa is the first Italian node for goods shipping and the second for total aerial movements and passengers moving.

For airports with such traffic flows it is mandatory to perform an exact evaluation in terms of noise pollution, in order to establish proper procedures aimed at environment and population protection, according to sustainable development policies.

According to this, the “Environmental Protection Agency Airport Technical Bureau” of Lombardia has carried on the analysis of the INM statistical model in order to verify his forecasting capabilities.

The study approach consists in two separated steps. The first one concerns the analysis of a single model input data: the slightest procedure of the model algorithms consists in the correct “weight stage” attribution for the simulated aircraft. This parameter is strictly related with the thrust power computed for the aircraft and then to the noise produced. The INM model describes every stage by giving a climbing, speed and thrust power graph profile. By analysing radar tracks it is possible to obtain the “real” climbing and speed profiles. Therefore, a comparison between real and estimated profiles has been performed for the two of the most operational aircraft models in the Malpensa traffic flows: the MD82 and the A320.

During the second step, a comparison has been carried out between model simulation results and measured data collected by the Malpensa noise monitoring system, for each stage associated to the aircrafts, concerning noise as L_{den} and single event noise as SEL for each monitoring station.

This analysis highlighted the higher INM model sensitivity for certain input variables and some inadequacies between forecasted profiles and the mainly adopted in the Malpensa case, allowing the evaluation of the gap arisen in measured and forecasted data.

2. INTRODUCTION

The main simulation model goal concerns the determination of interesting variables, in a determined spatial and/or temporal context (output), simplifying a more complex phenomenon with a set of relationship and algorithms constituting the physical-mathematical model, by seeking and using a certain amount of controllable parameters, describing the system state and the boundary conditions (input).

In the acoustic field, the system state is characterized by the source parameters and the emissive attributes; the model determines the investigated variable (ex. noise level) propagation properties for the values evaluation (in time) in the receptor proximities.

The general model validation criteria consists in comparing the output results with a experimental data set, acquired under strict control, in terms of boundary conditions knowledge and evaluation of measure error.

Furthermore it is necessary a preliminary sensibility analysis of the model itself to establish the accuracy and precision level for each input parameter.

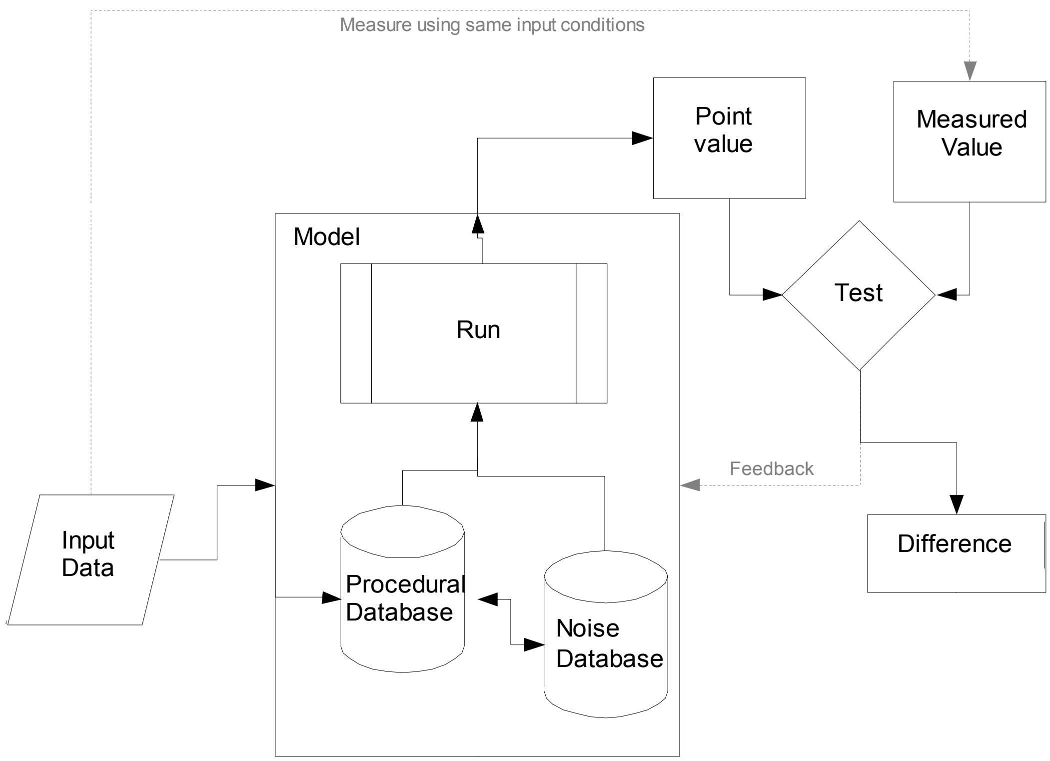


Figure 1: difference evaluation procedure (validation) for a noise statistical model.

Because of the number of variables involved and the difficulty obtaining a satisfactory evaluation, the airport noise simulation models need a very simplified approach.

In operational terms, the validation process should consist:

a) measuring noise level in one or more location opportunely chosen and non influenced by other noise sources;
b) obtaining suitable information concerning the attributes of the sources involved in the measured variable estimation.

The airport noise evaluation is a very complex problem, because of its dependence from a large number of factors and two main approaches could be performed to attempt to solve him:

1. Evaluate every single source contribution near the receptor;
2. Elaborate a statistical model to establish the steps of a simplified procedure in the noise computation near the receptor;

The first hypothesis is based on the complete and very accurate knowledge of input data, i.e. every single flying operation. The thoroughness refers to the fact that all the data should be known; the accuracy refers to the precision needed for data collection.

The second hypothesis requires a theoretical model study, reproducing a single airport operation with the minimum possible error. For this purpose, a convenient technique consists by working with central estimators: elaborate a model with input and output data relatives to long period averaged values, to minimize the single event evaluation error.

In the airport noise, the information required by point b) concern both flying procedures and the aircraft noise emission factors; the availability of such parameters is particularly hard to obtain. What are usually available are databases containing parameterized performance and noise data for every aircraft class and category. The actual most complete database has been developed and constantly updated by the Federal Aviation Administration (F.A.A.). These data constitute the main source information core needed for the Integrated Noise Model (INM) application.

It's under a developing phase a recent European project (ENHANCE – SOURDINE) for the creation of a new parameterized database (concerning parameters for European specific aircrafts) for a better noise pollution evaluation in a European context.

In fact, in the actual state, the approach proposed by the F.A.A. and ECAC is the only one operatingly functional for aircraft noise evaluation near airports.

3. AIRPORT NOISE SIMULATION MODEL VALIDATION CRITERIA. FUNCTIONAL PRICIPLES

To identify a uniform methodology for the airport noise evaluation, the International Civil Aviation Organization (ICAO) has written up a paper[3] resumed and deepened, in European context, from European Civil Aviation Conference (ECAC).

From 1978 the United States F.A.A. has distributed a software for the airport acoustic impact evaluation: the Integrated Noise Model (INM), today an international standard, both for computational algorithms thoroughness, and for a good quantity of available data, strictly related to acoustic certification procedures.

3.1. ECAC 29 and ICAO Circ. 205

The aim of these documents, both based on statistical approach, is to illustrate a methodology to compute the contours shapes for different acoustical indexes, in the airport proximities. The needed steps to gain such goals are:

- Step 1: determination of noise level generated from single aircraft movements in a exposition point near the airport;
- Step 2: single noise level sum or composition, computed in respective points, accordingly with the chosen index formulation;
- Step 3: chosen index values interpolation and contour shapes graphic representation;

The ECAC document constitutes an integration and an ICAO document deepening.

In first place, a statistical model is based on the main hypothesis to find out a *reference* acoustical indicator, such as for example L_{AE}, for every aircraft class.

The sound propagation is influenced from the meteorological condition variability: in the specific case, we assume such reference value precisely determined taking into account long period averaged meteorological conditions. For a good model application, the reference values are used without any correction within the condition range defined by:

- Air temperature <30°C;
- Air temperature (°C) -- Relative humidity (%) > 500;
- Wind Speed < 8 m/s (15 knots);

The needed input data, in compliance with the computational algorithms established from the ECAC document, could be grouped as follow:

- Aircrafts operating near the airport;
- *Noise Power Distance* data: they contain the noise indicator pattern (typically LAE e LAmax) as a function of distance and various thrust power settings for each determined aircraft category. They refer to the flight line ground projection (leveled flight, max speed 160 knots), configuration and thrust constants, without banking maneuvers (turning);
- *Performance Data (PD)*: they give, for every aircraft model, the power and flight configuration parameter values for every operation to correctly query the NPD tables;
- Take-off & landing routes, and eventually their vertical and horizontal dispersion;
- The number of aircraft movements for each routes in the period selected for simulation (day hour included);
- Operational data and flight procedures for each routes (including information on mass, power level, speed and aircraft configuration during the different flight segments);
- Airport data (weather average conditions, runway number and orientation);

For the noise level evaluation *L(x,y)* in a single exposition ground point (Step 1), the area in analysis is covered with a grid, which nodes constitute the computed points, then the values obtained are interpolated to compute the contour shapes characterized by the same noise level. The noise level in a single ground point *(x,y)* is obtained from the equation:

$$L(x,y) = L(\xi,d) + \Lambda(\beta,l) + \Delta_L + \Delta_V + \Delta_T \qquad (1)$$

where

L(ξ,d) : depends from distance *d* between the exposition point and the routes, and from the thrust power *ξ*; it's obtained interpolating the NPD table values,

Λ(β,l) : sound lateral attenuation term propagating perpendicularly to the aircraft direction, defined by *l* (distance between receptor and route projection) and *β* (angle between the receptor distance from route and the receptor distance from the round projection).

Δ_L , Δ_V , Δ_T: corrective terms for, respectively, g*round-rolling directivity* during take-off manoeuvres, *speed* compared to NPD data and *sound event duration during turning* (the last two terms are non-zero only if sound descriptor is L_{AE}).

Once computed all the contributors for each grid point (step 2), it is possible to draw the noise contours trough an interpolation process (Step 3).

3.2.INM Error sources and sensibility evaluation

In the ENHANCE European project context, the Eurocontrol research center has conducted a sensibility analysis[4] of the INM fundamental computational algorithms.

Had been checked two main variables groups and it has been evaluated the influence on simulated acoustical levels:

- Local condition: meteo-climatic variables, especially pressure that become involved in a certain amount of operation and relationship;
- Aeronautical parameters: the aircraft performance characteristics, especially the take-off weight value and the aerodynamic coefficients related to flap configuration.

Some approximations, even if mandatory for a statistical model, lead to discrepancies with measured data, particularly considering the Single Event Level (SEL), for every value set in a generic day.

For every flight segment, the major sensibility is observed for the following variables:

Procedure segment	***Most influent Variable***
Take-off	Aircraft weight
Take Off Initial Climb - TOIC	Database coefficients
Acceleration	Speed

With a variation of 1% in the input parameters, the corresponding variation in output parameters is determined to a maximum of 6%. More interesting is to verify what is the sensibility for the SEL value: all the errors are confined within 0.5 dB but:

- NPD interpolation errors: lead to an error minor of 0,8 dB
- "Noise fraction adjustment" errors, (<1,4 dB)

4. PROCEDURAL PROFILES

4.1.Real profiles

The radar assistance performed by the different Air Traffic Control (ATC) is aimed to verify each aircraft position in different flight states: take-off, cruise, landing. Consequently the radar tracks give integrative information for many parameters needed for aircraft-generated noise evaluation.

The radar tracks are constituted usually by a series of spatial-temporal information (x,y,h,t), correlated with more generic flight info (company, aircraft model…)

For the profile analysis it's necessary compute the distance covered from the take-off beginning phase; this permits a useful comparison between the real profile and the modeled ones, especially for INM. In the majority of cases the take-off initial point coincides with the runway start-point, but in some case, there may be a "displaced threshold", a peculiar runway point in correspondence with a link between *taxiway* and *runway*.

The weather conditions had to be acquired contextually to radar tracks, to verify their influence on profiles. An important variable is the wind speed, particularly the component parallel to the runway orientation and with direction opposite to the take-off one (the so called *head-wind*).

Last, it's necessary to acquire detailed information regarding the runway use in function of wind direction.

4.2.Aircraft procedural profiles

One of the most important aspects to determine the acoustic source position consists in modelizing the aircraft trajectory in each flight phase, specifying the engine thrust. These two kinds of data, position and thrust, are indispensable in order to use the acoustical data expressed as NPD.

The Society of Automotive Engineers (SAE), technical standardization organization in USA, in the 1986 written up a document (SAE-AIR 1845) for the parameterisation of each flight phase, in order to determinate an aircraft trajectory. The same algorithms are used from INM for the aircraft trajectory computation, utilizing a specific parameter set for each aircraft model stored in the INM model. These parameters are optimised in function of the previewed operations.

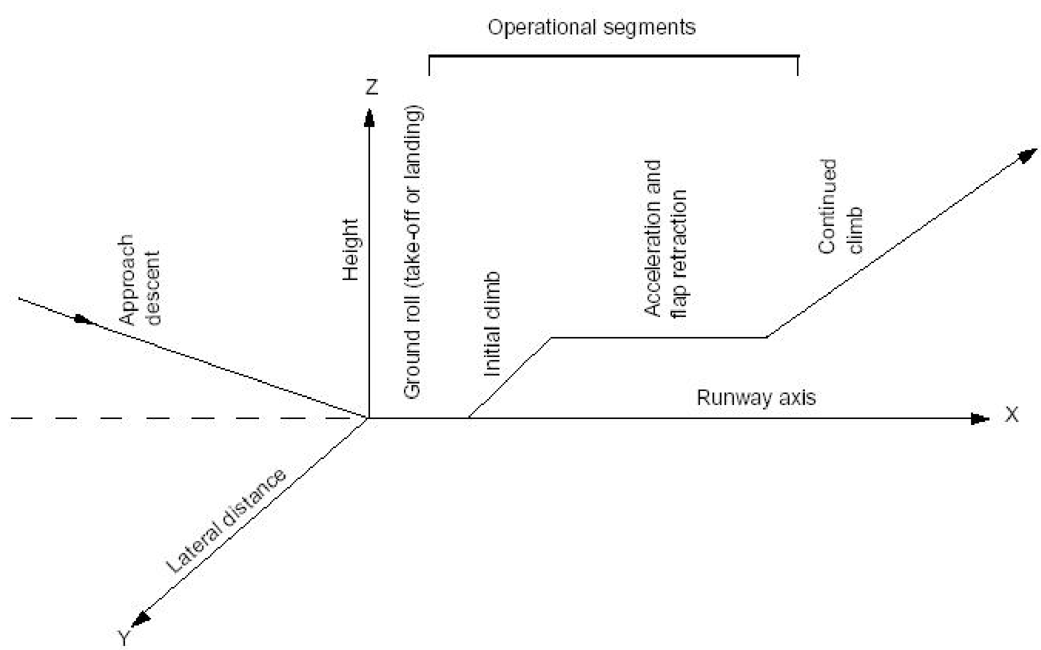


Figure 2: Typical procedural profile description (from [1])

Eurocontrol developed a trajectory simulation tool-kit for each flight phase, based on the Total Energy Model (TEM): considering the forces acting on aircraft in a peculiar flight phase (power thrust, weight, air resistance, portance) it's possible determine the aircraft trajectory utilizing certain specific parameters, collected analyzing the data referring to different aircraft models (representing nearly the 90% of European traffic) and comparing them to the procedures indicated by flight companies. By the way, the main goal of this tool is the movement's simulation for traffic control.

4.3. Procedural profile simulation.

The methodologies for the aircraft take-off/landing profile simulation are essentially two: the INM/SAE 1845 model [12] and the TEM model[8].

In the following section only the take-off profile determination method will be analyzed in detail. The take-off initial phase, indeed, is the most delicate segment for a correct airport noise modelization.

In order to correctly use the methodology it is necessary to determine each fundamental variable utilized inside the model computational algorithms with the most possible precision

- take-off weight: the movements frequency for each take-off weight defined in INM must be precisely known;
- weather parameters: it's useful consider different situations where the weather variables could be effectively considered as constant.
- Procedural parameters: the procedures stored in INM model must be chosen with care, verifying the most adapted to the airport in analysis, in order to avoid particularly "un-real" simulation.
- Parameters database: even if INM allows to adding or deleting some database values, it's opportune limit the choice of already existing values in the profile built-up. Modifications should be operated only in very peculiar situation and applied only after a well-documented costs/benefits analysis. The quantity of the information checked is one of the main and positive INM features.

5. RESULTS VERIFICATION METHODOLOGY – PROCEDURAL PROFILES: THE MD82 AND A320 AIRCRAFT MODELS

In order to define and experiment a procedural criteria statistically meaningful to verify the INM application results, it has been established to achieve a detailed analysis of the Milan Malpensa (LIMC) movements, considering two aircraft models (MD82 and A320), performing an evaluation of the difference of measured data from those computed with simulations.

For an INM procedural profiles correct identification, it has been conducted a comparison between the simulated profiles and the "real profiles" extracted from the radar tracks, always for the two aircraft models MD82 and A320.

The flights analyzed refer to a limited number of flight companies, in order to minimize climbing profile differences caused by specific company-dependent take-off instructions. All the aircrafts selected, taking-off from Malpensa, follow the ICAO A procedure.

Once set the procedural profile, selected from those offered in INM database, it must be correctly chosen the *stage* by determining the number of aircrafts flying with a take-off weight similar to one of those proposed by INM.

The tip reported in the model *User's Manual* state that the *stage* needs to be selected in function of the aircraft destination distance, in 500 nmi (nautical miles) classes. However, it's possible that the aircrafts take-off with a major weight to the necessary one, for example loading fuel for more ports of call. It must be taken into account that the "*stage 1*" is, for INM, the *stage* corresponding with a maximum distance of 500 nmi, while "*stage 2*" corresponds with a distance included between 500 and 1000 nmi: therefore, considering just the Italian destinations, the departures from Malpensa to Fiumicino (LIRF) should all belong to "*stage 1*", while the others should always result in "*stage 2*".

The relationship between weight and stage is based on the following hypothesis[6]:

- *Representative length of the draft:*
  Minimum range + 0,7*(maximum range – minimum range)
  For example, for stage 2 it acquires the value 500 + 0,7 * (1000 - 500) = 850 nmi
- *Payload Factor*: between 65% and 75% of maximum payload
- *Fuel:* needed quantity for draft + reservoir
- *Cargo:* already considered in the payload factor

According to such formulation the weight determination depends exclusively from the draft length, although the take-off weight is also connected to the maximum cargo capacity, function of the needed fuel quantity.

This methodology, as shown in the following sections, applied to Malpensa airport, will lead to a systematic attribution of a inferior *stage* (aircraft lighter, faster trajectory) and consequently to a noise ground level underestimation.

5.1. The MD82 profile examination

Having a good data series for the Malpensa airport, to reduce the variability related to weather parameters, in the three week of highest aircraft traffic in the period 2001-2002, they've been selected just the operations effectuated in "normal" weather condition, corresponding to pressure values between 990 and 1008 mbar and temperature between 15 and 30 °C. The sample selected comprehends approximately 700 radar tracks, whose data have been elaborated in order to make a comparison of the parameters related to the INM *Performance Data* with those effectively observed.

The radar track is generically composed from a series of *nodes* recorded every 3-4 seconds. The precision in the radar measure is estimable in 1 second concerning Time, 1/64 nmi for the x,y plane and 100 ft for the height measure.

5.1.1. Slope

In the previous pages it has been possible to see some of the typical parameters in the first fraction of the climbing profile: especially the weight factor. This information is not indicated in the radar track data, therefore the *slope* of the first climbing segment has been analyzed, in terms of height *h*, function of the covered distance from the start point on the runway. Using the first 10 radar *nodes* for computation, the trajectories in the *d,h* plane result effectively rectilinear, with correlation index (R^2) between 0.750 and 0.999 (average 0.986).

Therefore it has been carried out an analysis of the interpolated straight line slope to emphasize eventual aggregation tendencies. For this it's been conducted a cluster analysis (non-hierarchical) to force a 4 group construction (being, in fact, 4 the *stages* for this aircraft model in INM) on the basis of the regression angular coefficient, identifying the average take-off initial climb angle (TOIC angle).

In figure 3 is shown a *box-whiskers plot* for the variable "TOIC angle" for each statistical group. The graph reports as box the interquartile (75° percentile – 25° percentile), with a black line indicating the median value; the whiskers represents the extreme values (non-out layer, i.e. within 3 times the interquartile distance): this viewing representation could offer a good idea of the main parameters describing the sample statistical distribution.

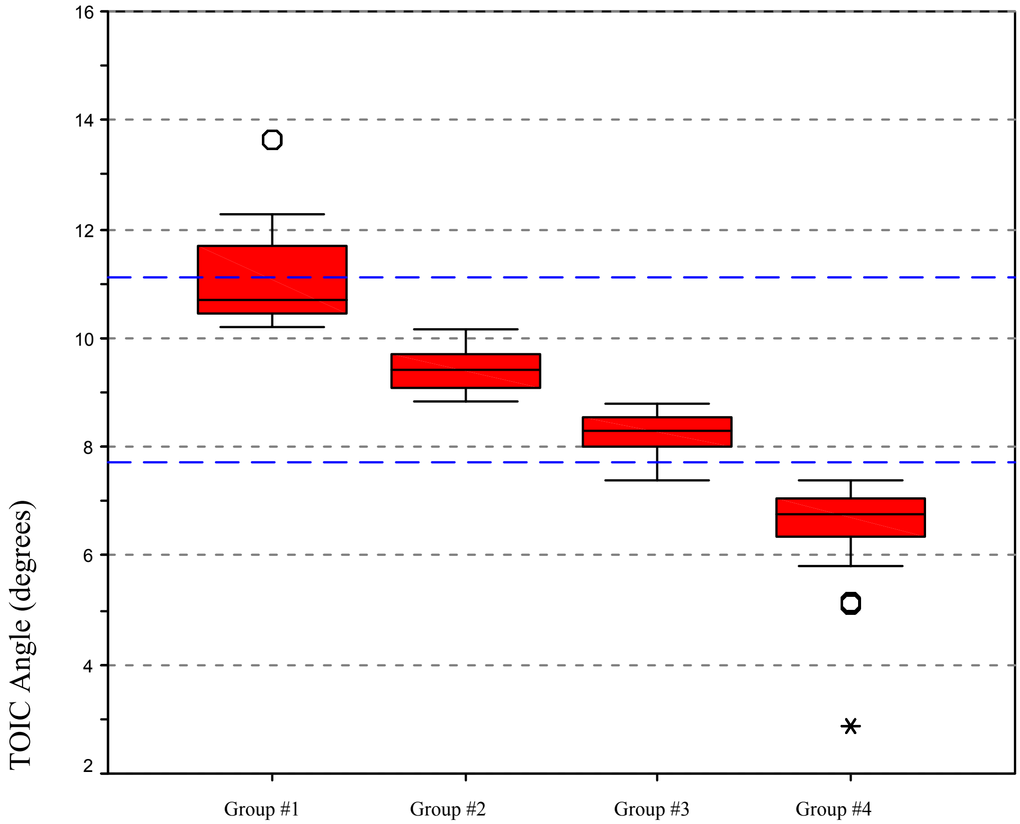


Figure 3: trajectory slope box-plot for identified groups with cluster analysis: horizontal lines represent the max and min INM estimated.

The groups elaborated did not fully correspond to the variability estimated from INM model, particularly the 4th group show a median value significantly inferior to the minimum value considered by the model (blue dashed lines).

In order to verify if the identified groups have an effective correspondence with the INM *stages*, a profile assignment to different *stage* has been done, considering some peculiar aircraft final destination, leaving unidentified the other ones:

- *Stage 1:* Roma Fiumicino (LIRF);
- *Stage 2:* Catania (LICC), Madrid (LEMD);
- *Stage 3:* Helsinki (EFHK);

Therefore it had been analysed the "TOIC angle" statistical variability within each group. In figure 4 is shown the TOIC angle distribution as a function of *stage* (destination) assigned.

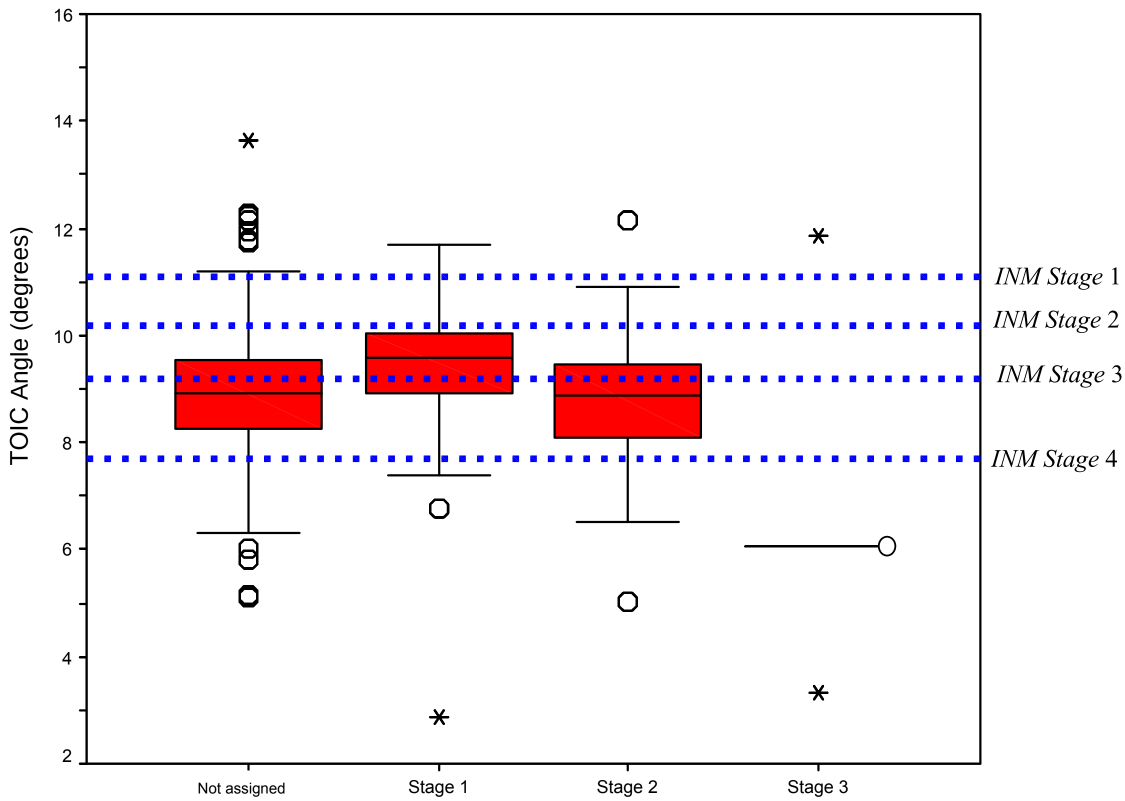


Figure 4: Trajectory statistical distribution in the first climbing segment, case MD82, with INM *stage* assignment formulation. Blue dashed lines define INM values.

The greater part of values (inside the box) is indeed comprised in the INM estimated interval (blue dashed lines) and the *stage 2* values are generically inferior to that of *stage 1* (average and standard deviation comparison statistical test).

However, the *stage 1* and *stage 2* values are quite distant from the INM proposed values; those belonging to *stage 3,* although the less numerous group, have a median value really different (lower) compared to one estimated by INM.

Furthermore it's possible to notice many isolated cases where the *stage* assignment formulation, as a function of distance, do not lead to coherent results: in the group referring to *stage 3* there are two out layer values at 3° and 12°, while in the *stage 1* group there's a take-off with TOIC angle inferior about approximately 8° to the value indicated by INM.

In conclusion, the median value of the analyzed data TOIC angle does not coincide with the values proposed by INM and assigned by the *distance-stage* formulation.

The comparison shows that, even with a parameter determination throughout a detailed radar tracks analysis and INM procedural profiles study, it is not always possible to obtain a good *stage* assignment.

5.1.2. Speed

The 358 take-off route from runway 35R of Malpensa airport is substantially parallel to the runway axis and it offers the possibility to analyze a take-off profile almost ideal, without interferences produced by climbing rate loss caused by turn (banking).

The speed variation, computed from radar tracks from a *node* with the immediately following one, is between 10% and 25%, therefore with a high uncertainty (caused by errors relative to height determination, position in x,y plane and time).

Anyway, computing the speed between two *nodes*, one in the ground proximities and the other at approximately 3000 ft, the obtained values are substantially equal to those computed on the speed average on 10 radar *nodes*. This demonstrates that the instantaneous speed variance is exclusively random.

It has been considered adequate to compute the speed as a weighted (and translated) average, through the combination of the 4 previous and next values, for each *node* defining the radar track. In this way, it has been possible to filter the instantaneous variations caused by the uncertainty in establishing the effective aircraft position, without losing relevant information.

From the profile analysis (in figure 5 some examples), it is possible to note immediately a deep difference in the take-off profile between the INM procedure and the real one, especially as far as concern speed trend. However, it becomes evident that the procedure followed by the Malpensa aircrafts sample matches with the ICAO A, that is: constant speed between 1500 and 3000 ft, "downing nose" at 3000 ft and consecutive acceleration.

None of the analyzed profiles (approximately 700) shown a procedural trend similar to that proposed by INM, especially in relation with speed.

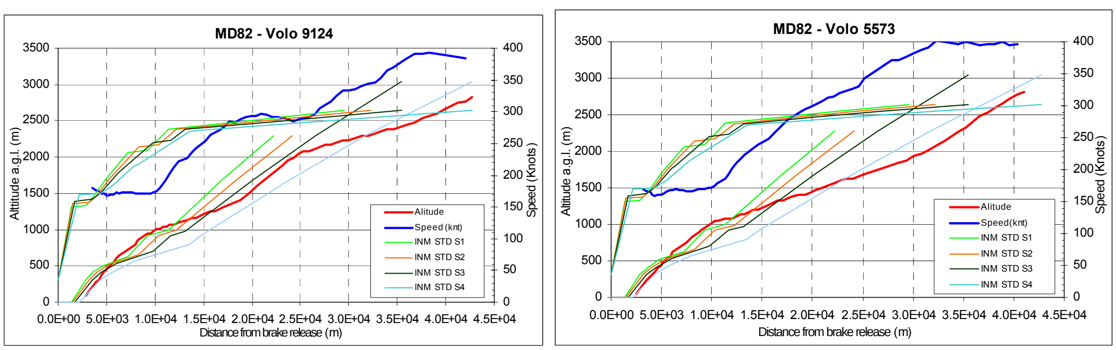


Figure 5: Speed (blue) and climbing profile (red) trend compared with INM procedural profiles.

5.2. The A320 profile examination

5.2.1. Slope

From the A320 aircraft radar track analysis (more than 1300 aircrafts executing the ICAO A take-off) it emerges that the TOIC angle distribution is nearly Gaussian, centered around 8° with standard deviation of 1,4°. The INM model estimates instead, for the same ICAO A procedure, a TOIC angle values set included, as a *stage* function, from 1st to 5th, respectively between 12,5° and 9.5°(Figure 6).

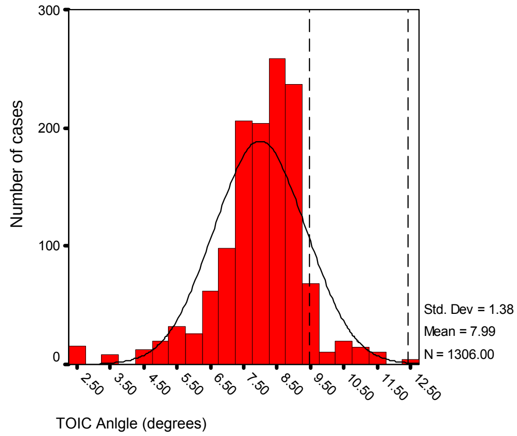


Figure 6: Take Off Initial Climb angle distribution in A320 case; dashed vertical lines define values corresponding to INM *stage 1* and *stage 5*.

5.2.2. Speed

Concerning the Airbus A320, it's possible to see how the speed profiles well match the ones used by INM for the ICAO A procedure in the acceleration segment, while there's a INM systematic underestimation in the first take-off segment.

About the spatial profile, it's well recognizable the aircraft "nose downing" at 3000 ft to achieve the previewed acceleration, and, although not so evident as the first one, the previous "nose downing" at nearly 1500ft, caused by the need to maintain the aircraft speed constant while changing power from Max Thrust to Climb Thrust and retracting flaps. The x-axis trend (take-off track ground projection) compared to INM profiles seems to be systematically affected by a 1 km offset. This discrepancy could be understood considering that the aircraft rolling start point could not coincide with the runway edge, but with the interception with a taxiway, effectively at nearly 1 km from the runway edge. The differences observed concerning the measured data and the simulated INM procedure find an explanation in the fact that, keeping a lower slope (about 2°) it is necessary to increase speed (from 160 knots to 180 knots), to follow the right procedure. Experimentally, therefore, the airbus A320 taking-off from Malpensa, follow the ICAO A procedure, adopting less climbing rate (involving indeed a better passengers comfort) than the one estimated by INM.

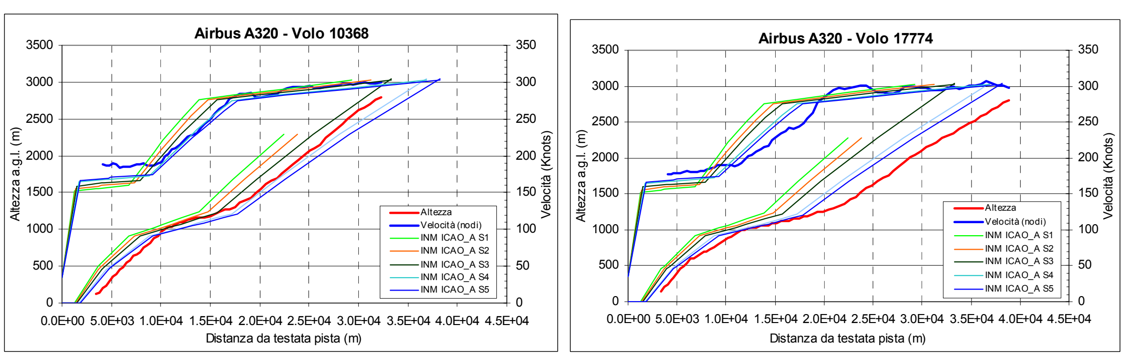


Figure 7: Speed (blue) and climbing profile (red) trend compared with INM procedural profiles.

6. RESULTS VERIFICATION: COMPARISON BETWEEN MEASURED AND SIMULATED DATA

6.1.General case

The Malpensa airport network consists in 17 remote noise monitoring terminals, and it offers a good chance to test and verify the model simulation applications.

The airport has two runways, oriented to 349°. Take-offs and landings, approximately 650 per day, are uniformly distributed on two runways.

In Figure 17 are shown the monitoring terminals locations and the take-off routes; to this trajectories has been assigned a conventional ID, recalling the corresponding SID (Standard Instrumental Departure). These SID procedures (358, 319, and 320), characterized from small turning angles, had been selected to keep low the aircraft climbing rate loss while turning, not considered by INM.

In order to make a comparison between simulated and measured data, it has been chosen the week in 2002 characterized by the most high traffic flows (18^{th}-22^{nd} August): the movements had been used as INM input, simulating each day separately. The measured events, identified as aircraft (correlating with the radar tracks), had been used to compute the "real" noise indexes (such as LVA_j- Italian index very similar to DNL -, Lmax, SEL, …).

For example, figure 8 shows the comparison between measured and forecasted data (LVA_j and SEL) in two monitoring terminals (Somma Lombardo – "L. Da Vinci" School and Arsago Seprio) selected from the others because of their peculiar characteristics.

In the Arsago Seprio Terminal, located under the 358 SID, the difference between forecasted and measured data appears small, while in the Somma L. terminal the INM values underestimate the measured one.

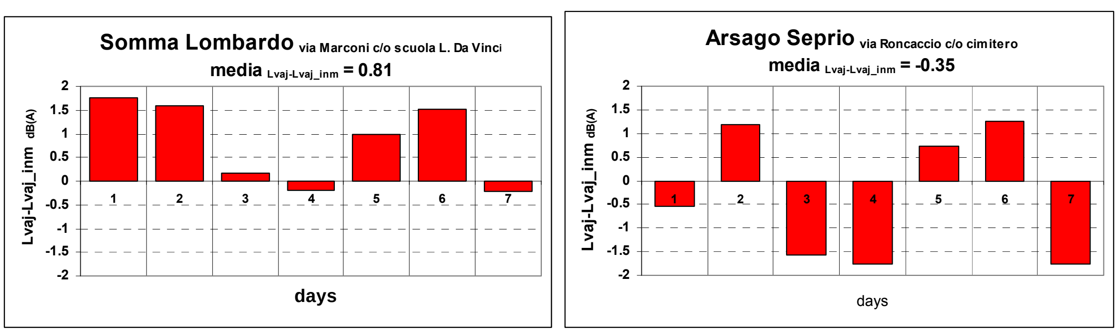


Figure 8: L_{VAj} compared in Somma L. (under 358 SID e 320 SID) and Arsago S. (under 358 SID) remote monitoring terminals.

Figure 8 could be understood taking into account that the Somma terminal could be influenced by two different SID (320 and 358), while the Arsago terminal measure exclusively the 358's operations. The differences between measured and forecasted LVA_j, in Arsago are fluctuating within +1 and –1.5 dB(A); on Somma L. terminal instead, these values are clearly greater than zero in the 57% of cases (4 on 7).

In order to gain information statistically significant, it could be necessary to amplify the sample in time: anyway, a statistical test on averages difference has revealed a low significance value for the null hypothesis (equal averages), this confirms the supposition that the INM forecasted values in the two sites (terminals) are substantially different.

The difference observed in the values is a consequence of the INM elaboration for each aircraft pass-by, characterized in acoustical terms from the SEL value; the model permits to evaluate, for each aircraft, the SEL value in a specific location. Thanks to this opportunity, it's possible to built-up a frequency distribution for SEL class, that could be easily compared with the measure collected.

Figure 9 shows the difference between the two distributions obtained: in the Somma L. terminal, the forecasted value did not correspond with the main accumulation group; difference equal to 8 dB(A). The model simulate a second accumulation group, around 65 dB(A) not measured by the terminal probably because this value is under the monitor acquiring threshold.

For the Arsago terminal, the correlations between measured and estimated values are extremely better. As the other terminal distribution, it's possible to identify a low noise accumulation group caused by aircraft movements on other SID than 358, but not detected by the terminal.

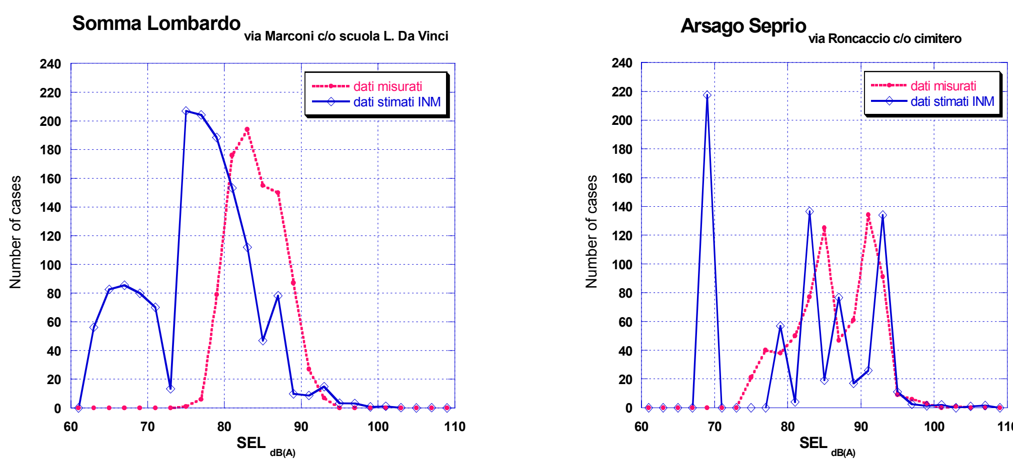


Figure 9: Measured and estimated SEL distribution in two sites.

6.2. Case MD82

The noise propagation model, as described in the ECAC document, must preview a lateral attenuation (cfr Eq.1), function of minimal distance between receptor and aircraft (or better its plane projection l) and the β angle between the trajectory and the receptor, measured at the minimum distance corresponding point (Point of Closest Approach – PCA). See figure 10.

A MD82 movement's representative sample has been selected for the SID 358,320 and 310 in order to minimize the turning climbing rate loss.

For these cases it has been evaluated the difference between the measured SEL level and that one achieved through INM simulation in two opposite hypothesis: with S*tage 1* and *Stage 4* profiles.

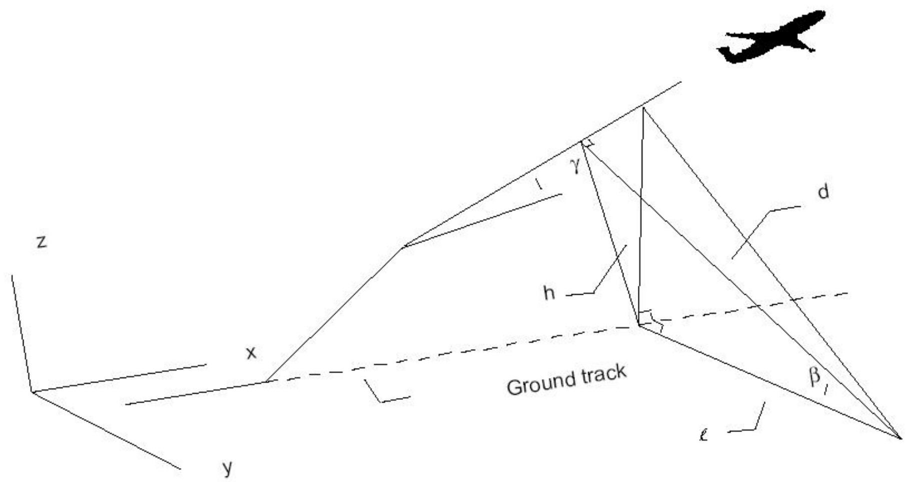


Figure 10: Representation of noise propagation with respect to trajectory (from ECAC [1])

The analyzed cases show a weak variation compared to the weather conditions, represented as temperature and pressure values. Indeed, the main dependence of the difference between measured and estimated data is in function of the *β* angle as shown in figure 11 with a simple stepwise regression or through the Pearson's correlation coefficient computation between variables (major than 0.5 for the *β* angle and minor than 0.1 for other variables).

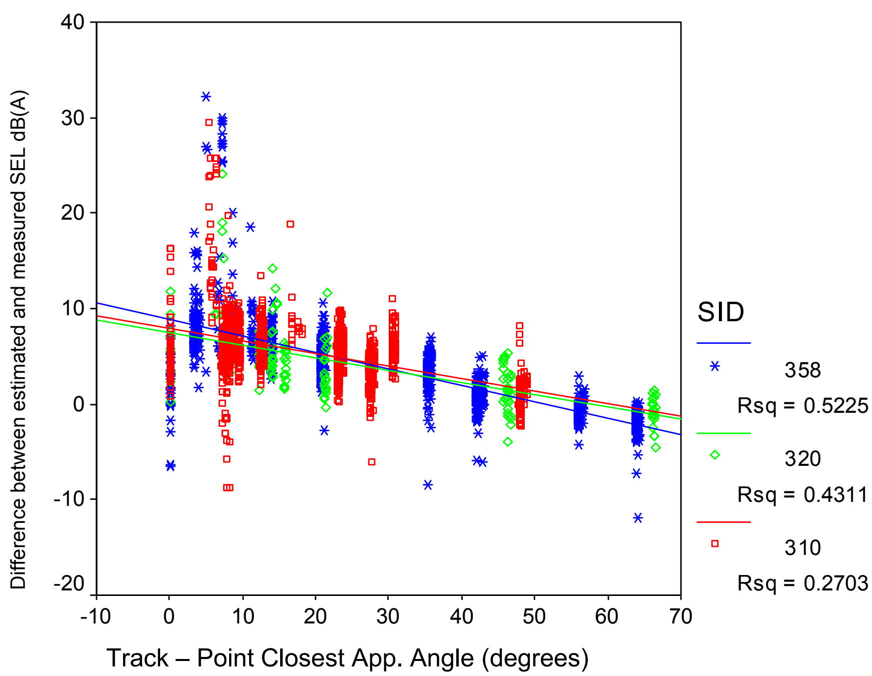
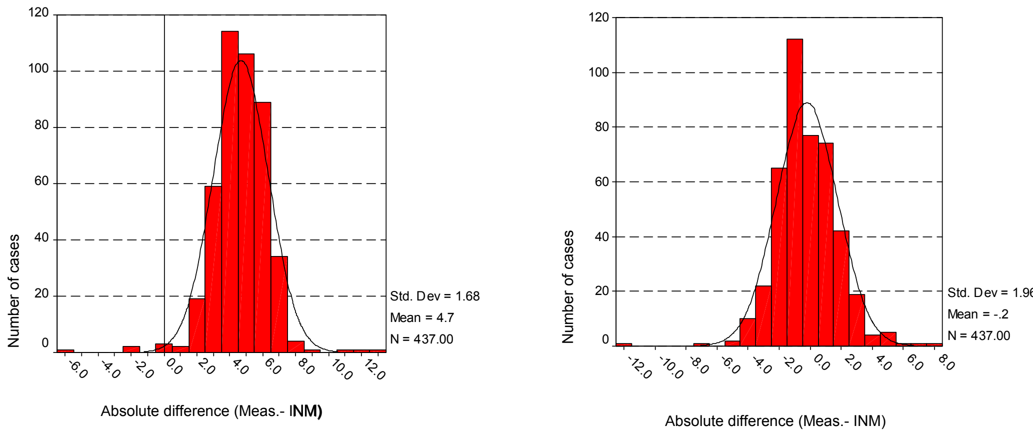


Figure 11: Measured and estimated SEL differences (separated for each SID – 310, 320, 358) as a function of *β* angle.

In order to highlight the SEL discrepancy between measured and forecasted data, in same terminals, on analogous weather conditions, they've been selected only the cases with β angle less than 45°, in order to minimize the effect of non-direct propagation and other source influences near the terminal site[10].



a) b)

Figure 12: Absolute difference between measured and estimated for a) stage 1 and b) stage 4. There are been considered cases with β angle major than 45°.

The SEL difference distribution is almost Gaussian: there's an average difference about approximately 5 dB(A) in the *Stage 1* case, while in the *Stage 4* case it's about 0.2 dB(A). However, the standard deviation indicates an emphasized dispersion, around 2 dB(A).

The error that's possible to perform through an inadequate *stage* assignment could lead to a significant difference in INM result compared to the measured data.

6.3. A320 Case

In the A320 situation, where INM considers also the A319 and A321 aircraft models, there exists the chance to analyze both the ICAO A and ICAO B procedure profiles. The comparison between SEL measured and estimated values has been carried out for the following situations:

- Climbing profile ICAO A and *Stage 1*
- Climbing profile ICAO A and *Stage 5*
- Climbing profile ICAO B and *Stage 1*
- Climbing profile ICAO B and *Stage 5*

Furthermore there are been conducted two different kind of analysis: one concerning all the A320 flight movements, the other one filtering the flights with β angle major than 45° (Figure 15 and 16).

In figure 13 (ICAO A) it's shown how the mean difference of measured and INM estimated values is close to zero considering all the flights belonging to *stage 5*. The values dispersion is emphasized, with a standard deviation about approximately 4 dB(A); however, the distribution is far to be Gaussian.

Figure 14 (ICAO B) shows an analogous phenomenon: the hypothesis that the aircrafts take-off with procedures *Stage 5* comparable, improve the mean value, even if it's followed by an increasing dispersion, around to 5 dB(A). The analysis seems to lead to the conclusion that a minimization of estimated mean could be obtained for the ICAO B case and not for the ICAO A.

However, as in the MD82 situation, it is appropriate to consider just the cases where the β angle in major than 45°, in order to evaluate just the flights almost on the monitoring terminal vertical.

Under these conditions, the distribution become more similar to a Gaussian, and the better estimation is accomplished for the ICAO A profile and *stage 5,* with an average refuse equal to 0.5 dB(A).

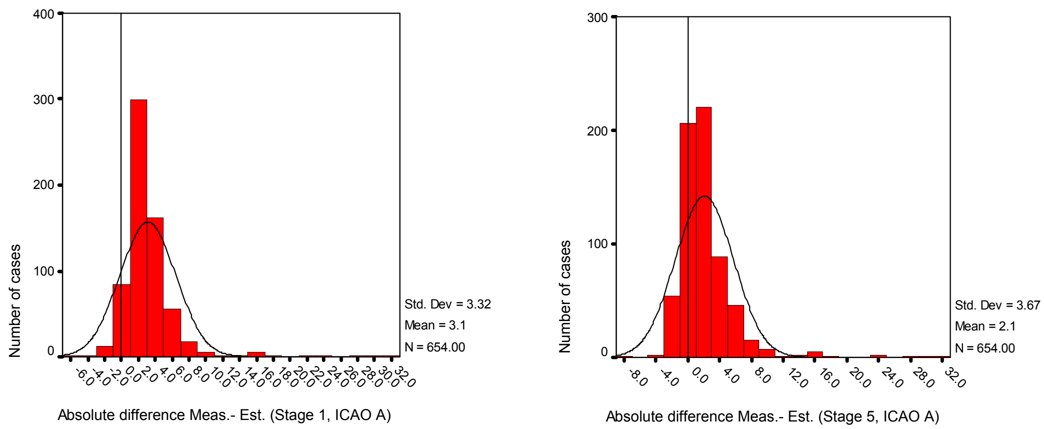


Figure 13: Measured and estimated SEL differences distribution, comparison between *stage 1* and *stage 5* for ICAO A profile.

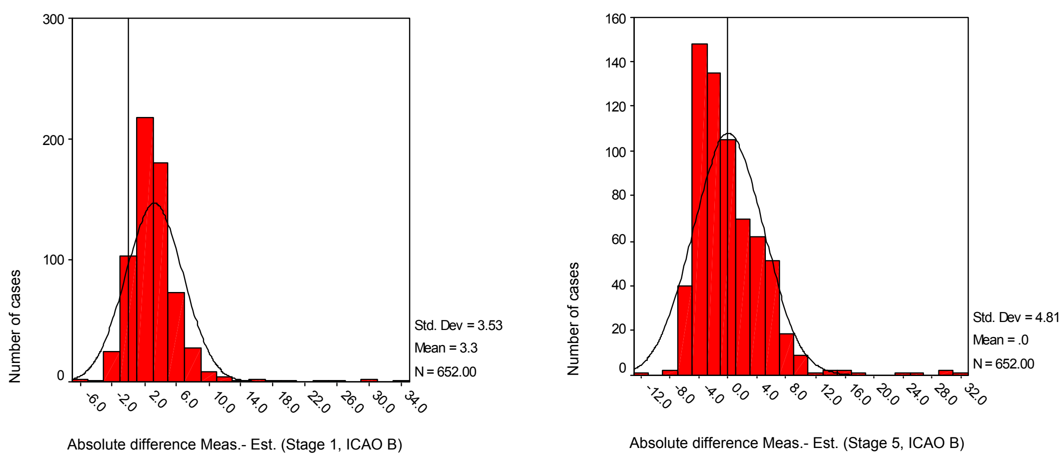


Figure 14: Measured and estimated SEL differences distribution, comparison between *stage 1* and *stage 5* for ICAO B profile.

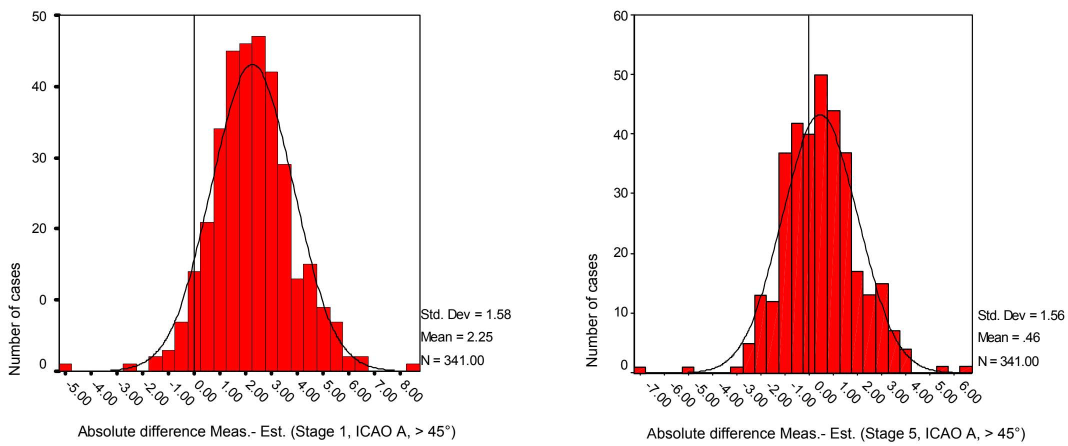


Figure 15: Measured and estimated SEL differences distribution, comparison between *stage 1* and *stage 5* for ICAO A profile and β angle major than 45°

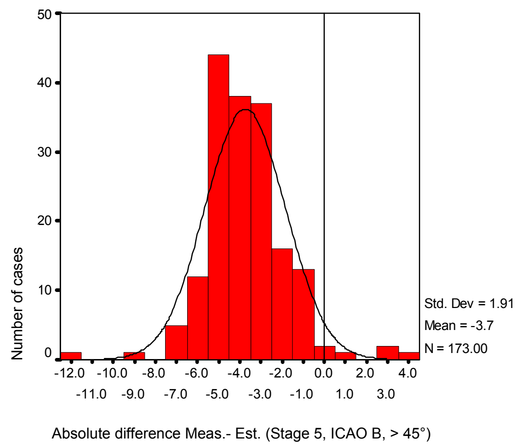


Figure 16: Measured and estimated SEL differences distribution, comparison between *stage 1* and *stage 5* for ICAO B profile and β angle major than 45°

The analysis conducted had shown the INM adequacy compared to ground measured data if the INM fundamental variables are well considered and interpreted.

7. CONCLUSION

The modelling estimation of airport noises could be divided into three phases:

1. model control according to ECAC methodology;
2. real application control considering model hypothesis;
3. comparison of obtained results with measured data; in controlled situation and checking of differences

Model producer could complete the first phase in the way to guarantee ECAC methodology application; anyhow, some specific aspects could be evaluated, for instance, NPD data presence and their solidity or the grouping capacity of different aircraft models.

It's necessary to investigate the method used by the model for the procedural profiles description to verify flexibility degree, users-data input possibility and input selection power from a pre-determined set.

Each model should be deeply analysed to perform phase 2 in the most complete way; it's absolutely required to have data related with aircrafts movements (take-off and landing profiles). The most important information are those linked with the boundary conditions that should be determine in the most accurate way.
Finally, testing measured data and their comparison with simulated ones, allows to evaluate the punctual shifting between model results and effective situation: a critical analysis is recommended, avoiding reductions and carefully considering to revise all or at least task hypothesis.

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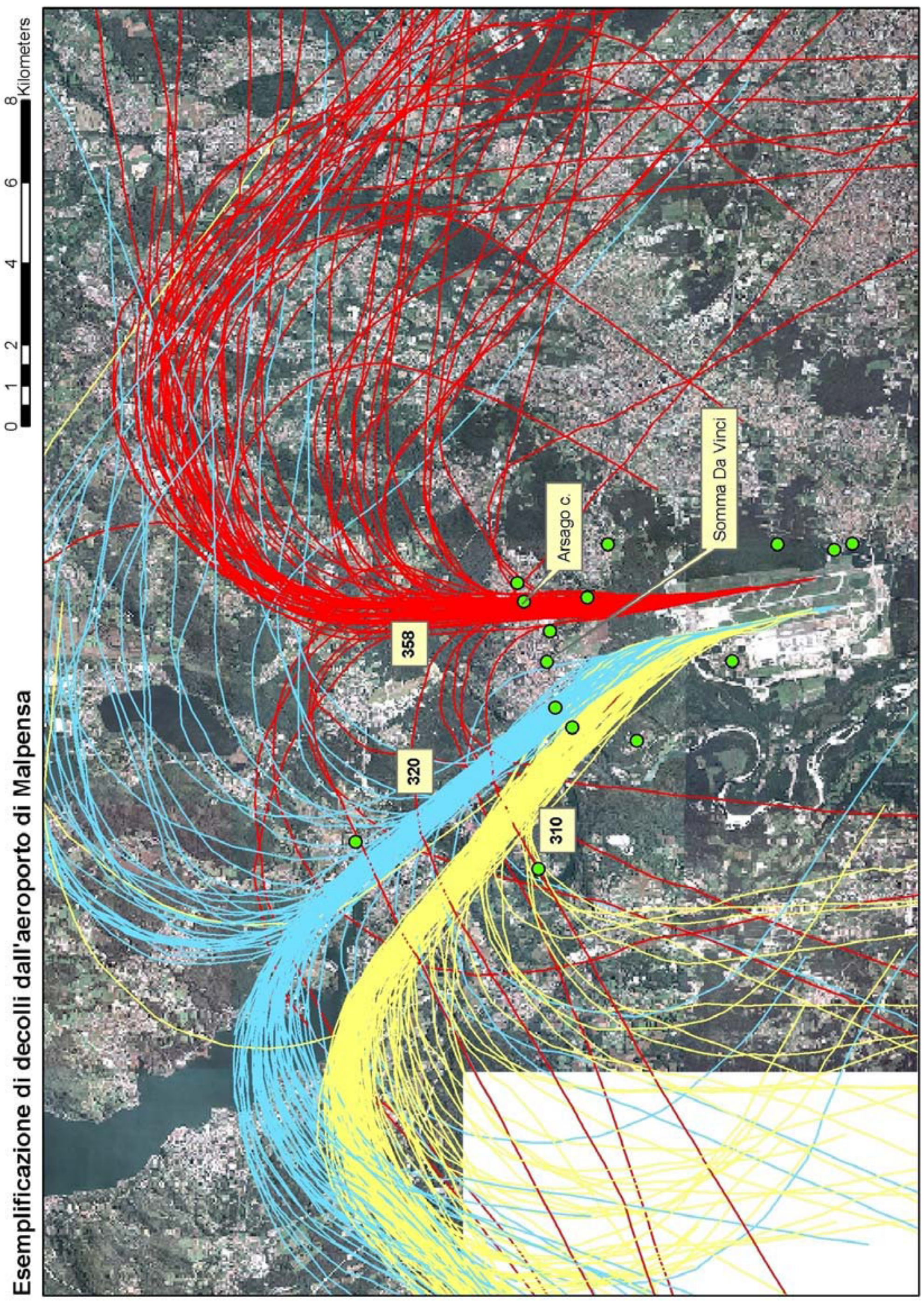

Figure 17: Takeoff tracks from Malpensa Airp.: yellow is 310, cyan is 320 and red is 358 SID.