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Aircraft Noise Pollution: a Model of Interaction between Airports and Local Communities

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***Abstract*—**Air transport represents a dynamic and fast growing industry that fits well with the needs of nowadays society. The process of liberalization and deregulation in the air transport market introduced by the European Commission in the last decade, has deeply modified the structure of aviation at Community level. The growths in importance of carriers with a different economic structure along with the growth of regional airports are among the most important products of the changed scenario. Regional airports occupy a central role within the deregulated market since they represent preferred destinations for low-cost carriers and spokes for network carriers. However aviation represents a source of environmental externalities, especially at local level, which interferes with human activities. If on the one hand the impact of emissions at local level is under study and deserves a better understanding, on the other hand noise has always been a serious problem for dwellings located near the airports. Even if there has been a tremendous improvement in aircraft noise performances during the last twenty years the growth of the aviation market has outstripped these benefits. The enforcement of recent noise policies by the European Commission shifts the problem of noise impact from annoyance for people living near the airports to a constraint of airports growth. It is essential for airport operators to manage the variables that affect airport acoustical capacity in order to maximize the number of aircrafts that an airport can handle within a given noise level.

***Keywords*—**Airport, noise contours, noise impact, sustainability

I. INTRODUCTION

THE air traffic growth and the development of regional airports represent one of the most important by-product of deregulation. The traffic analysis shows that low costs carriers have been largely responsible for strong passenger growth and increased passenger load at a number of regional airports (Graham and Dennis, 2006) along with the increased presence of network carriers that use secondary airports as spokes of their routes. This scenario has determined a redistribution of air traffic in favor of underused regional airports that had been characterized by high rates of growth during the last years. Moreover it is widely recognized the importance of regional airports for local communities in terms of increase in air accessibility that determines profound repercussions in the economic development and in the growth of employment. However the prolonged low traffic at regional airports and the insufficiency of land use planning have determined, in many cases, that the suburban sprawl expanded until the airport boundaries. Traffic expansion due to the causes previously described had caused a situation difficult to handle because of externalities generated by air traffic and noise is the principal.

The last twenty years have witnessed a tremendous reduction of airplane noise at source. However this benefit, mostly dependant on aviation industry improvements on the engine noise performances, has been outstripped by the high increase in the demand for air transport. Recent psychoacoustic studies have shown that annoyance is strongly influenced not only by the maximum sound level but also by the number of events. It has been proven that a given level of annoyance can be generated by a low number of noisy aircrafts or by a much higher number of events characterized by a lower level. Moreover the higher expectations of living along with the welfare economic conditions in most of the western countries have induced people to adopt a more careful approach towards environmental issues. This easily explains the opposition of local communities to airport expansions and the strong protests by local residents to air traffic increase in most of the airports.

The adoption of the Directives n. 49/2002/CE and n. 30/2002/CE embodies the purpose of the European Commission of reducing airport noise within the EU, by introducing common noise metrics and by introducing a series of measures to reduce noise among which airport operating restrictions at Community airports in case of the noise generated by air traffic exceeds the acoustic limits established by national legislations. The introduction of airport operating restrictions represents a serious threat for airports expansion especially in the cases of regional airports where the benefits deriving from the deregulation of the aviation market could not be fully exploited, with the consequence of not only a strong penalization for airport operators but also for the communities that would be deprived of the positive consequences of an increase in air accessibility. Many international organizations such as IATA or EUROCONTROL recognize the importance of environmental issues as a threat to the growth of aviation market in Europe, unless airport environmental capacity is efficiently managed. Since noise represents the principal externality of aviation at

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local level, acoustical capacity seems to be one among the first constraints to airport growth. The need to investigate the variables that affect airport noise with special regard to the parameters closely related with airport management are discussed in the following paragraphs.

II. AIRPORT ACOUSTICAL CAPACITY

Airport capacity takes several forms depending on the component of the system that limits the maximum number of operations within a given airport. Normally the concept of airport capacity has been referred to components of the system such as the geometric characteristics of the runways, aprons, taxiways, the dimension and the number of gates and terminals and the characteristics of the ATM (Upham et al., 2004; Graham and Guyer, 1999). Overall airport capacity hence can be defined as the maximum number of aircraft operations during a specified time corresponding to a tolerable level of average delay (Horonjeff and McKelvey, 1994). However environmental criteria induce to reconsider the definition of airport capacity by introducing a concept of capacity related with environmental issues and noise in particular.

The concept of airport acoustical capacity represents a limit to the number of movements within a given time period, so using a more practical approach, airport acoustical capacity can be defined as the maximum number of movements that can be handled within a given time period that generates the maximum ground noise level compatible with acoustic zonings for areas near the airports.

Airport acoustical capacity is influenced by a great number of variables that can be grouped in endogenous factors and exogenous factors. Endogenous factors on the one hand largely depend on the traffic characteristics and on the airport layout; on the other hand exogenous factors are strongly dependant on the environment in which an airport is located. From an airport management prospective, endogenous factors are easier to modify or to adjust, in order to obtain a gain in acoustical capacity, on the contrary exogenous factors are seldom modifiable and an accurate long term planning represents the best way to avoid that exogenous factors interfere with traffic growth at a given airport.

The need to investigate endogenous factors reflects the capability of obtaining a gain in acoustical capacity, or an increasing number of aircraft handled within the same time period. A previous study of the authors has pointed out that among the endogenous factors the most important ones in influencing airport acoustical capacity are the type of aircrafts and the day evening night distribution of flights.

TABLE I
ENDOGENOUS AND EXOGENOUS FACTORS THAT INFLUENCE AIRPORT ACOUSTICAL CAPACITY

Exogenous Factors	Endogenous factors
Fleet mix	Regulatory scenario
Traffic	Tyoe of dwellings
Day/Evening/Night distribution	Position of Dwellings
Load factor	Distance runway - dwellings
Airport layout	Meteorological conditions
Runway length and airport surface	

Airport noise is calculated with cumulative noise metrics in which noise events within a given time period are considered and in most of the cases night and evenings movements are penalized with a weight in order to account for the higher annoyance. The software INM (Integrated Noise Model) has been used to simulate the ground noise level due to different aircrafts and to a different day-evening-night distribution of flights in order to evaluate the contribution of these variables in determining acoustical capacity. The concept of airport acoustical capacity is than represented graphically by the means of noise contours that identify the maximum noise level, in the case 65 dB, corresponding to residential zonings.

A. *Quantification of the variables*

The type of aircraft is the variable that affects the most airport acoustical capacity since the ICAO Annex 16 Chapter III comprises a wide range of aircrafts with different noise performances. By way of example it is worth mentioning that a marginal conform chapter III aircraft, such an MD 82, generates a take-off noise about 10 dB higher than an A 319; that implies that the acoustical sensation perceived during a flyover of an A 319 is less than one-forth in comparison with an MD 82. The day-evening-night distribution of flight represents as well a determinant variable in the evaluation of airport acoustical capacity since a shift of day movements into evening and night movements can results in a strong decrease of capacity. The European noise metric Lden, introduced by the Directive n. 49/2002/EC, as the unified noise metric to calculate environmental noise, considers the average day for traffic and meteorological condition as the time period for calculating airport environmental noise. In order to account for the higher annoyance generated by sound events in noise sensitive periods such night and evening, this metrics adds a penalty of respectively 5 dB and 10 dB to the sound events. It implies that for a given number of aircraft movements, the higher is the percentage of evening and night events, the lower is the capacity. The analysis of the variables has been conducted by simulating with INM noise contours generated by landings and take-offs of different types of aircrafts and considering different day-evening-night distributions and than analyzing the results. The 65 dB noise contour has been taken as the reference for the maximum sound level residential dwellings.

The analysis of noise contours shows that marginal Chapter III aircrafts, such the Md 82, are characterized by appreciably lower performances in comparison with more modern aircrafts with the same seats capacity. It is worth mentioning that the 65 dB noise contour generated by 100 take-offs of Md 82 is comparable with the one associated with 500 take off of Airbus 319, considering all the movements within the day period (Fig. 1).

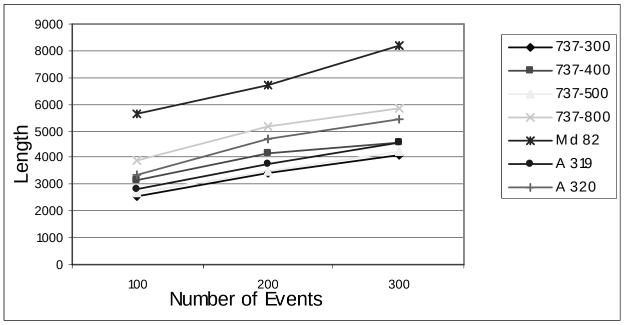

Fig. 1 Lenght of the 65 dB noise contour due to a different number of day takeoffs.

The same results can be observed by analyzing the simulations of take-offs during night periods (Fig. 2). The only difference that emerges is the much higher territory within a given acoustical level or within the same noise contour. The same conclusions can be drawn by analyzing the area within the 65 dB noise contour for day and night movements (Fig. 3).

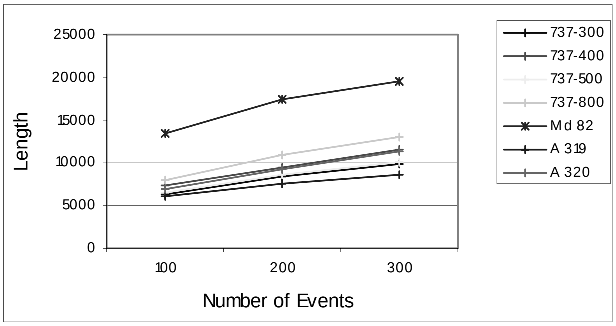

Fig. 2 Lenght of the 65 dB noise contour due to a different number of night takeoffs.

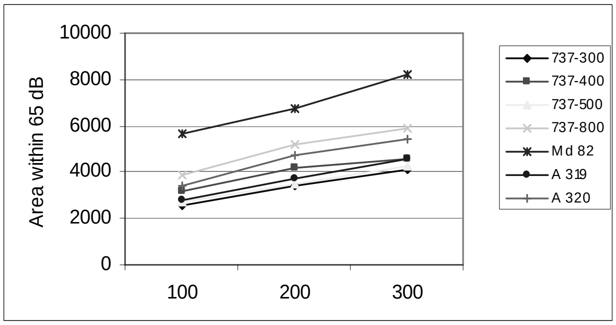

Fig. 3 Area within the 65 dB noise contour due to a different number of day take-offs.

Take-off noise is mainly dependant on engine performances and on the geometric design of airplanes, these differences emerge when considering the contribution of different aircrafts in determining acoustical capacity, with a significant reduction in the number of movements available even when the percentage of marginal Chapter III traffic is low. On the contrary landing noise is mostly influenced by the design of aircrafts and by the configuration that aircrafts assume during this phase of flight with the gear lowered and flaps extracted. However the simulations of landings for different types of aircrafts show that the range of differences among aircrafts is smaller. On the contrary noise contours generated by Md 82 is comparable, and even smaller, with noise contours of more recent aircrafts and this is mainly due to the narrow fuselage and to the rear engines (Fig. 4 and 5).

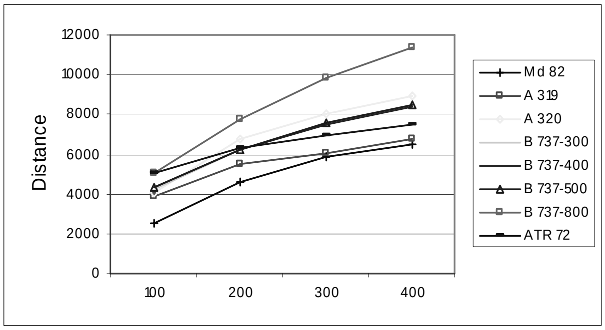

Fig. 4 Area within the 65 dB noise contour due to a different number of evening landings.

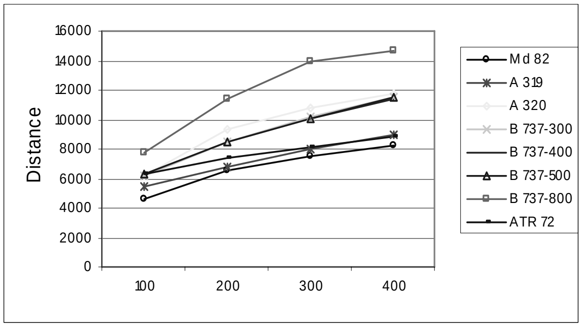

Fig. 5 Area within the 65 dB noise contour due to a different number of night landings.

B. *Characterization of noise contours*

Noise contours represent the effect of airports endogenous variables in areas affected by aircraft noise nuisance. The characterization of noise contours is hence a paramount aspect in land use planning and in airport management. Take-off noise contours differ from landing noise contours for a given number of aircrafts operations, because of the geometrical characteristics. If on the one hand landing noise contours are quite stretched along the territory but with a small width, on the other hand take-off noise contours are shorter but wider.

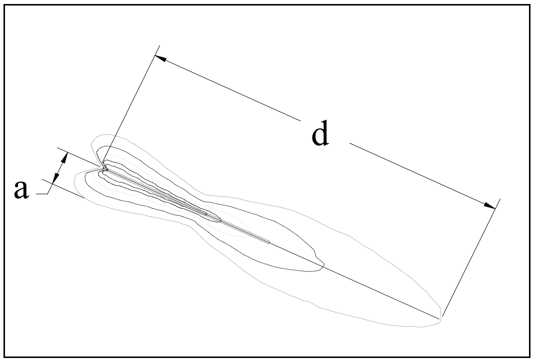

Fig. 6 Take-off simulation of n=300 B737-800 movements within the

day period.

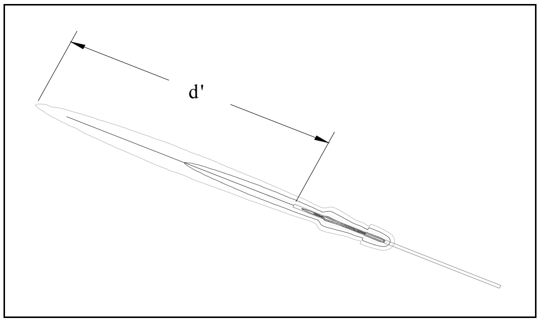

Fig. 7 Landing simulation of n=300 B737-800 movements within the day period.

It is possible to characterize landing noise contours by the only dimension d (or d') (Fig. 6 and 7) which identifies the distance between the runway threshold and the noise contour itself, while take-off noise contours require at least tree parameters: the area A, the length d and the width a. The length of a take off noise contour by itself is not a univocal parameter in defining noise contours. Moreover different aircrafts are characterized by different take off noise contour both in terms of d both in terms of A.

The relation between the three variables that identifies take off noise contour has been studied by simulating a large number of take offs, considering different airplanes and different time of the day and than calibrating a model with a maximum likelihood procedure. The model is of the type:

$$A = f\left(\frac{a}{d}; \beta\right) + \varepsilon \tag{1}$$

where β is a vector of unknown parameters and ε is a normal random component, We can write the equation (1) compactly, using a vectorial notation:

$$\mathbf{y} = f(\mathbf{X}; \boldsymbol{\beta}) + \mathbf{e} \tag{2}$$

It is useful to consider maximum likelihood estimation (MLE) of the model (2). The likelihood function is:

$$\ell(\boldsymbol{\beta}, \sigma^2 | \mathbf{y}, \mathbf{X}) = \frac{1}{(2\pi\sigma^2)} \exp\left\{ -\frac{[\mathbf{y} - f(\mathbf{X}, \boldsymbol{\beta})]^T [\mathbf{y} - f(\mathbf{X}, \boldsymbol{\beta})]}{2\sigma^2} \right\} = \frac{1}{(2\pi\sigma^2)} \exp\left\{ -\frac{S(\boldsymbol{\beta})}{2\sigma^2} \right\} \tag{3}$$

and the log-likelihood function is given by the following expression:

$$\mathbf{L}(\boldsymbol{\beta}, \sigma^2 | \mathbf{y}, \mathbf{X}) = Ln\ell(\boldsymbol{\beta}, \sigma^2 | \mathbf{y}, \mathbf{X}) = -\frac{N}{2} \ln 2\pi - \frac{N}{2} \ln \sigma^2 - \frac{S(\boldsymbol{\beta})}{2\sigma^2} \tag{4}$$

where N is the numerousness of the sample and S is the residual sum of squares. Differentiating the log-likelihood function with respect to σ^2 settings this derivative equal to 0 and solving for σ^2 we can obtain the estimator:

$$\tilde{\sigma}^2 = \frac{S(\boldsymbol{\beta})}{N} \tag{5}$$

It is now possible to write the concentrated log-likelihood function:

$$\mathbf{L}^*(\boldsymbol{\beta} | \mathbf{y}, \mathbf{X}) = -\frac{N}{2} \ln 2\pi - \frac{N}{2} \ln \frac{S(\boldsymbol{\beta})}{N} - \frac{N}{2} = \text{constant} - \frac{N}{2} \ln S(\boldsymbol{\beta}) \tag{6}$$

Now we can obtain the maximum likelihood estimation of β maximizing the concentrated log-likelihood function.

The adopted functional form of the relation area – length of the noise contour is of the type:

$$A = \frac{d^\alpha}{\beta \exp\left(\frac{a}{d}\right)} \tag{7}$$

The results of the calibration are very good, and the model shows a good fit. In particular, both the parameters considered in the analysis are statistically significant. The fit of the model is better for small surfaces (< 20000 m^2), as you can see in the scatterplot in fig. 8, that contains the relation between observed and predicted noise areas.

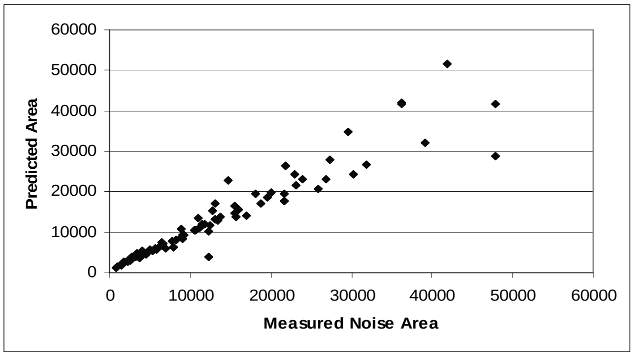

Fig. 8 Relation between observed and predicted noise areas.

III. DISCUSSION

To evaluate the contribution of the variables above defined in influencing airport capacity a value index has been considered which is based upon the selection of a standard aircraft and than comparing different noise contours generated by different airplanes. The prototypal aircraft chosen is the 737-500 which is one of the most used aircraft both by low cost carriers and network carriers. The ratio between the length of the 65 dB noise contour of a given aircraft and the length generated by the prototypal aircraft is a mean to compare different aircrafts regarding acoustical performances.

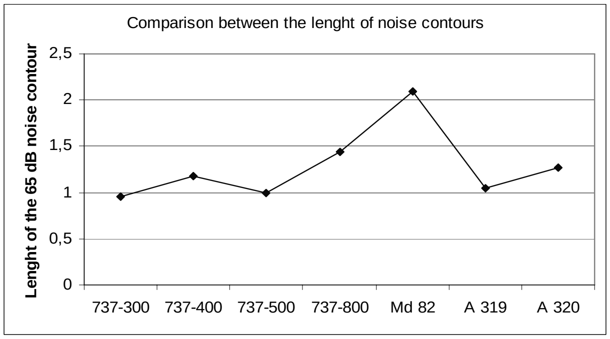

Fig. 9 Ratio between the length of 65 dB noise contours.

By analyzing the length of 65 dB noise contour generated by 100 movements within the day period is possible to notice that the variability in the ratio reflects both the presence of old aircrafts both the presence of aircraft with a greater number of seats, such the B 737-800 that are characterized by an higher weigh. Ratio between the length of a given 65 dB noise contour with the length of the noise contour generated by 100 day movements of the same aircraft

TABLE II
RATIO BETWEEN THE LENGTH OF A GIVEN 65dB NOISE CONTOUR WITH THE LENGTH OF THE NOISE CONTOUR GENERATED BY 100 DAY MOVEMENT OF THE SAME AIRCRAFT

Day	737-300	737-400	737-500	737-800	Md 82	A 319	A 320
200	1,32	1,32	1,31	1,34	1,20	1,34	1,39
300	1,21	1,10	1,21	1,13	1,22	1,22	1,16
400	1,13	1,11	1,12	1,03	1,13	1,13	1,05
500	1,05	1,09	1,05	1,03	1,08	1,07	1,03
Evening							
100	1,90	1,77	1,88	1,62	1,77	1,98	1,73
200	2,47	2,31	2,43	2,08	2,39	2,21	2,06
300	2,86	2,76	2,84	2,51	2,79	2,43	2,40
400	3,26	3,02	3,24	2,84	3,08	2,69	2,70
500	3,54	3,40	3,53	3,09	3,47	2,90	3,06
Night							
100	2,47	2,31	2,44	2,08	3,47	2,21	2,06
200	3,26	3,02	3,23	2,83	4,51	2,69	2,71
300	3,81	3,65	3,78	3,39	5,07	3,11	3,37
400	4,32	4,03	4,31	3,94	5,62	3,76	3,80
500	4,71	4,37	4,68	4,56	6,03	4,42	4,11

Table II shows the ratios between the length of 65 dB noise contour generated by a different number of a singular type of aircrafts, calculated in different time period, with the length of the 65 dB noise contour generated by 100 take offs of the same type of aircraft within the day period. It is possible to observe how evening and night movements tend to generate wider noise contours in comparison with day movements. It is also possible to observe the growth trend of noise contour with the increase of the number of movements. The value 1 has been assigned to 100 day movements. The ratio of growth in the noise contours is pretty much the same for different types of aircrafts.

IV. CONCLUSIONS

Noise is widely recognized to represent a serious constraint for airport growth limiting the expansion of the traffic levels in existing infrastructure and influencing the construction of new runways to meet future capacity. In this sense airport acoustical capacity can be perceived as limiting traffic as runway capacity or apron capacity. Airport capacity is influenced by a series of parameters and variables that constitute a tool that airport operators and the other air transport stakeholders should manage, in order to increase traffic level without an increase in noise pollution.

This paper has shown that noise contours give a representation of how the traffic related variables influence airport capacity and especially how these variables affect the communities located near airports boundaries. The analysis conducted in this study confirms that aircraft type, together with the day-evening-night distribution of flights, represent the main variables affecting airport acoustical capacity. In particular, the operation of marginal Chapter III aircraft strongly affects airport acoustical capacity, so that the number of aircraft movements is limited and the expansion of airports themselves is constrained.

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