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A COMPARATIVE ANALYSIS OF AIRCRAFT NOISE PERFORMANCE

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ABSTRACT

This paper presents a comparative analysis of aircraft acoustical performance based on the definition of a noise performance indicator called ENSA (equivalent number of standard aircraft). ENSA methodology is based on the choice of a standard aircraft, then ENSA's values are obtained by comparing the generic aircraft's performances with the standard aircraft's performances. The performance evaluation is performed by analysing for each aircraft the equivalent number of standard aircrafts movements generating a noise level corresponding with one standard aircraft movement. This comparative analysis permits the evaluation of aircraft noise performance by comparing the ENSA values for different aircrafts.

Keywords: aircraft noise, performance, environmental impact, sustainability, ENSA.

INTRODUCTION

Aircraft noise has traditionally been considered the most important environmental problem at airports (A. Graham, 2003) and is probably the single most important issue affecting the operation and development of airports around the world and hence their capacity (Upham *et al.*, 2003).

The last twenty years have witnessed a tremendous improvement in aircraft noise performance that has been estimated in a decrease of 20 dB in single event noise which implies a reduction of around 75% of annoyance induced into people (A. Graham, 2003). But the unexpected air traffic growth and the increasing environmental standards in people expectation have outstripped the benefits from noise reductions. Aircraft noise and aircraft noise management represent hence an important issue in air transport and in particular this is the case of airport which are the front line operators representing the conjunction between air transport and local communities. Airport operators tend to adopt a proactive policy in order to guarantee a development of air traffic adopting locally the most effective techniques to mitigate noise impacts (Gualandi and Mantecchini, 2008).

The aircrafts circulating in Europe are conforming to the ICAO Annex 16 Chapter certification provisions which comprise the aircrafts certificated since the 1977. This implies a wide differentiation in aircraft noise performance which reflects the technological improvement of more than two decades. Considering for instance two typical aircraft widely used in medium haul routes such as the Md 80 equipped with 2 JT8D-209 engines and the Airbus A320 equipped with two CFM 56-5A1 engines the difference in certification values, expressed in dB(A) is about 12,5 dB(A).

This paper analyses the different aircraft noise performances by introducing an indicator applicable to rate aircrafts certificated under ICAO Chapter 3 standards with the aim to quantify the differences among aircraft noise performances.

MATHERIALS AND METHODS

Airport noise is evaluated by using cumulative noise metrics which represent the average sound level of aircraft events within a given time period. In most of the cases evening and night aircraft movements are penalized in order to account for the higher disturbance in the more sensitive periods. The directive 49/2002/CE introduces the Lden as a unified noise metric for calculating environmental noise. This indicator, used also to calculate airport noise, accounts for the higher disturbance of evening and night aircraft movements by adding to the sound events a weight of respectively 5 and 10 dB.

$$Lden = 10\lg\left[\frac{12}{24}10^{\frac{Lday}{10}} + \frac{4}{24}10^{\frac{Levening+5}{10}} + \frac{8}{24}10^{\frac{Lnight+10}{10}}\right]$$

The generic expression of a time-weighted equivalent sound level, which accounts for all significant aircraft sound energy received at a particular point, can be expressed by the formula:

$$L_{eq} = 10\lg\left[\frac{t_0}{T_0}\sum_{i=1}^{N}10^{\frac{L_{E,i}+\Delta_i}{10}}\right]$$

Where

N is the number of noise events during the time interval T_0;

T_0 is the time interval to which the noise index is Applied;

$L_{E,I}$ is the single event noise exposure level of the *i-th* noise event;

Δ_i is the decibel weighting for the *i-th* period.

Formula (2) can be expressed by introducing a multiplier coefficient of the number of flights that accounts for the decibel weighting imposed in evening and night periods. This coefficient in general can be expressed as:

$$g_i = 10^{\frac{\Delta_i}{10}}$$

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Then the equivalent time-weighted sound level results:

$$L_{eq} = 10\lg\left[\frac{t_0}{T_0}\sum_{i=1}^{N} g_i 10^{\frac{L_{E,i}}{10}}\right]$$

Considering a generic aircraft type *i* it is possible to introduce a weighted number of operations *Mi* which can be perceived as a multiplier factor that express the equivalent number of day movements corresponding to an ensemble of day-evening-night movements.

$$M_i = \left(g_{day}\cdot N_{i,day} + g_{evening}\cdot N_{i,evening} + g_{night}\cdot N_{i,night}\right)$$

The cumulative sound level *Leq* at the generic observation point *(x,y)* produced by a given number of aircrafts within the aircraft category *i* can be expressed as:

$$L_{eq} = 10\cdot\lg\left[\frac{t_0}{T_o}\sum_i M_i\cdot 10^{\frac{L_{E,ijk}(x,y)}{10}}\right]$$

The equivalent number of standard aircrafts ENSA is presented as a mean of comparing aircraft noise performance by calculating an equivalent number of standard aircraft operations corresponding to a singular aircraft type operating only day movements.

Considering a particular type of aircraft the evening and night weighting factors introduced by cumulative noise metrics such as the Lden, can be considered as multipliers of the number of movements as above shown. If the weights for evening and night period adopted by noise metrics are 5 dB and 10 dB the multiplier coefficients are:

$$g_{evening} = 10^{\frac{5}{10}} = 3{,}1622$$

$$g_{night} = 10^{\frac{10}{10}} = 10$$

The number of equivalent day movement corresponding with evening and night movements is respectively 3, 16 and 10, in the case a cumulative noise metrics with a 5dB and 10dB weights, such as the Lden is adopted. This implies that an evening movements accounts for 3, 16 day movements and a night movement accounts for 10 day movements.

Once a standard aircraft is chosen for instance the noisiest aircraft within a given fleet mix, the ENSA values are based on the calculation of the equivalent number of standard aircraft movements of different aircrafts. This methodology permits to evaluate the aircraft noise performances of different aircrafts within a fleet mix operating at an airport or operating by a given airline.
The number of standard aircraft equivalent movements N can be expressed as:

$$N = 10^{\frac{\Delta l}{10}}$$

Where

N is the number of equivalent aircraft;
Δl is the difference between the single event sound level of the standard aircraft with a the sound level of a generic aircraft.

If a particular aircraft is chosen as the standard reference aircraft for the evaluation of the performance of an entire fleet mix, *Δl* is the difference between the sound level of the chosen aircraft with the generic aircraft's sound level. The number N represents the equivalent generic aircraft's number that generates a sound level equal with the reference aircraft. In this case the number of equivalent aircraft is expressed as the ENSA index:

$$ENSA = 10^{\frac{SELj - SELi}{10}}$$

Where

ENSA is the number of equivalent standard aircraft;
SEL_j is the SEL (sound exposure level) of the aircraft chosen as the standard reference aircraft *j*;
SEL_i is the SEL of a generic aircrafts *i*.

The ENSA index gives an indication of the performance of a generic aircraft compared with the performance of an aircraft chosen as the basis for the calculation this performance indicator expresses the number of equivalent aircraft producing the same cumulative sound level. ENSA values calculated for different mid-sized aircraft are presented in Table-1. The calculation is based on the SEL's certification values expressed in dB (A) contained in the FAA's Advisory Circular AC 36 1H.

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Table-1. ENSA take-off value.

Aircraft	**Engine**	**TOGW 1000lbs**	**Take-off SEL**	**Take-off flaps**	**ENSA Take-off**
MD-80	JT8D-217A	160,00	83,7	2	1,00
MD-80	JT8D-217C	160,00	83,1	2	1,15
MD-80	JT8D-219	160,00	82,1	2	1,45
MD-80	JT8D-217	149,50	81,4	0	1,70
MD-80	JT8D-209	140,00	80,3	0	2,19
MD-80	JT8D-217	140,00	78,7	0	3,16
MD-80	JT8D-219	140,00	77,5	0	4,17
B-737-300	CFM56-3-B1	139,50	78,2	1	3,55
B-737-300	CFM56-3B-2	139,50	75,6	1	6,46
B-737-300	CFM56-3-B1	124,50	73,6	1	10,23
B-737-300	CFM56-3B-2	124,50	71,5	1	16,60
B-737-400	CFM56-3-B1	142,50	80,4	5	2,14
B-737-400	CFM56-3-B1	138,50	77,7	5	3,98
B-737-400	CFM56-3B-2	138,50	75,3	5	6,92
B-737-500	CFM56-3-B1(R)	132,80	78,4	-	3,39
B-737-500	CFM56-3-B1	139,00	77,9	-	3,80
B-737-500	CFM56-3-B1(R)	115,50	72,2	-	14,13
B-737-500	CFM56-3-B1	115,50	71,0	-	18,62
B-737-600	CFM56-7B18	143,50	73,7	1	10,00
B-737-600	CFM56-7B22	143,50	71,1	1	18,20
B-737-600	CFM56-7B18	124,00	69,2	1	28,18
B-737-600	CFM56-7B20	124,00	68,2	1	35,48
B-737-600	CFM56-7B22	124,00	66,9	1	47,86
A319-112/P	CFM56-5B6/P	166,44	73,3	10	10,96
A319-112/P	CFM56-5B6/P	123,45	64,9	10	75,86
A320-211	CFM56-5A1	162,00	73,7	-	10,00
A320-211	CFM56-5A1	149,90	70,7	-	19,95
A320-214/P	CFM56-5B4/P	132,27	65,2	10	70,79
A321-211	CFM56-5B3/P	205,02	77,1	-	4,57
A321-211	CFM56-5B3/P	165,34	69,8	-	24,55

Table-2. ENSA approach values.

Aircraft	Engine	MLW 1000lbs	Approach SEL	Approach flaps	ENSA Approach
A 319-112 P	CFM56-5B6/P	149,91	85,4	40	3,39
A 319-112 P	CFM56-5B6/P	121,25	84,9	40	3,80
A 320-111	CFM56-5A1	139,90	85,9	35	3,02
A 320-111	CFM56-5A1	139,90	85,2	20*	3,55
A 320-211	CFM56-5A1	142,20	85,6	35	3,24
A 320-211	CFM56-5A1	142,20	84,4	20*	4,27
A 321-211	CFM56-5B3/P	166,44	86,7	25	2,51
A 321-211	CFM56-5B3/P	143,29	85,2	21*	3,55
B-737-400	CFM56-3-B1	121,00	90,4	40	1,07
B-737-400	CFM56-3-B1	121,00	90,4	40	1,07
B-737-400	CFM56-3-B1	121,00	88,3	30*	1,74
B-737-400	CFM56-3-B1	121,00	88,3	30*	1,74
B-737-400	CFM56-3B-2	124,00	90,7	40	1,00
B-737-400	CFM56-3B-2	121,00	90,4	40	1,07
B-737-400	CFM56-3B-2	124,00	88,5	30*	1,66
B-737-400	CFM56-3B-2	121,00	88,3	30*	1,74
B-737-400	CFM56-3C-1	124,00	90,7	40	1,00
B-737-400	CFM56-3C-1	121,00	90,4	40	1,07
B-737-400	CFM56-3C-1	124,00	88,5	30*	1,66
B-737-400	CFM56-3C-1	121,00	88,3	30*	1,74
B-737-300	CFM56-3-B1	121,00	90,4	40	1,07
B-737-300	CFM56-3-B1	110,00	89,5	40	1,32
B-737-500	CFM56-3-B1	114,00	89,8	40	1,23
B-737-500	CFM56-3-B1	105,00	89,1	40	1,45
B-737-500	CFM56-3-B1	114,00	88,0	30*	1,86
B-737-500	CFM56-3-B1	105,00	87,5	30*	2,09
B-737-600	CFM56-7B22	120,50	86,2	40	2,82
B-737-600	CFM56-7B22	120,50	86,2	40	2,82
B-737-600	CFM56-7B22	120,50	84,0	30*	4,68
B-737-600	CFM56-7B22	120,50	84,0	30*	4,68
B-737-700	CFM56-7B20	129,20	86,7	40	2,51
B-737-700	CFM56-7B20	128,00	86,6	40	2,57
B-737-700	CFM56-7B20	129,20	84,5	30*	4,17
B-737-700	CFM56-7B20	128,00	84,5	30*	4,17
B-737-800	CFM56-7B24	146,30	87,5	40	2,09
B-737-800	CFM56-7B24	144,00	87,4	40	2,14
B-737-800	CFM56-7B24	146,30	85,5	30*	3,31
B-737-800	CFM56-7B24	144,00	85,4	30*	3,39
B-737-900	CFM56-7B27/B1	146,30	87,4	40	2,14

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B-737-900	CFM56-7B27/B1	147,30	85,5	30*	3,31
Md-80	JT8D-209	130,00	83,9	40	4,79
Md-80	JT8D-209	128,00	83,8	40	4,90
Md-80	JT8D-209	130,00	83,5	28*	5,25
Md-80	JT8D-209	128,00	83,5	28*	5,25

The ENSA values in the tables above have been calculated considering the noisiest aircrafts in take off and landing. In detail for take off the reference standard aircraft chosen is the Md 80 equipped with JT8D 217- A engines with a TOGW of 160 (1000 lbs) and for landing the aircraft chosen is the B737-400 with CFM 56-3C-1 with a MLW of 124 (1000 lbs) and a fla setting of 40.

The lover is the ENSA value the poorer the performance of a generic aircraft tends to be similar with the one of the noisiest aircraft, the higher the ENSA value the higher the performance of a generic aircraft.

Certification values if on the one hand are not representative of the real noise propagated during normal operations on the other can be used to rate aircraft noise performance because they are calculated with standardize conditions such as flap settings, thrust, take off and landing procedures and meteorological conditions.

RESULTS AND DISCUSSIONS

The analysis conducted is aimed to quantify the acoustical performance of a set of mid-sized aircrafts widely used in short-medium haul European routes. The ENSA values calculated for take-off movement's highline the difference in noise acoustical performance between marginal chapter 3 aircrafts and other aircraft certificated under the ICAO Annex 16 Chapter 3. Comparing an Md 80 (JT8D-217) with a more recent aircrafts as an A 319-112/P (CFM 56-5B 6P) emerge that the ENSA value of the latter is 10, 96 which implies that an Md 80 is comparable with almost 11 A 319.

The variability in take off ENSA values reflects not only the technological improvements in aircraft noise performance during the last twenty years, but also variability depending on different operating conditions. At first impression emerges a difference between take off and landing value so that the two different stages of flights will be analyzed separately.

Take-off noise is mainly affected by the type of the engines and the weight of the aircraft on the contrary landing noise is mainly influenced by the flap setting, by the weight and by the geometry of the aircraft (Figures 1 and 2).

The analysis conducted in general shows a less variability among ENSA approach values in comparison with take off values especially if a singular aircraft category as the B 737, for instance, is chosen.

A comparison in the ENSA values of two take off movements operated with an identical aircrafts for instance a B737-300 (CFM 56-3-B1) but with different take-off weights shows that for a weight of 139,50 (1000 lbs) the ENSA is 3,55 compared with a weight of 124,50 (1000 lbs) with an ENSA value of 10,23. This shows the high influence of take off weight in aircraft noise performance and highline the efficacy of noise abatement measures based on limiting take off weigh in order to limit the noise impact at noise sensitive airports.

Table-1 reports the take off ENSA values in function of the different TOGW for the aircraft types of the category of the Boeing 737. Approach values show a different trend. The variability in ENSA value and hence in noise performance is less marked in aircraft with different weights. The variability most depends on the flap configuration during approach rather than on the engines type or on the landing weight. Considering a singular aircraft type, for instance the 737-400 the Average ENSA landing is 1, 37 with a deviation standard of 0, 35 with a CV index of 0,255 with a significant difference of values reflecting the different landing flap configuration.

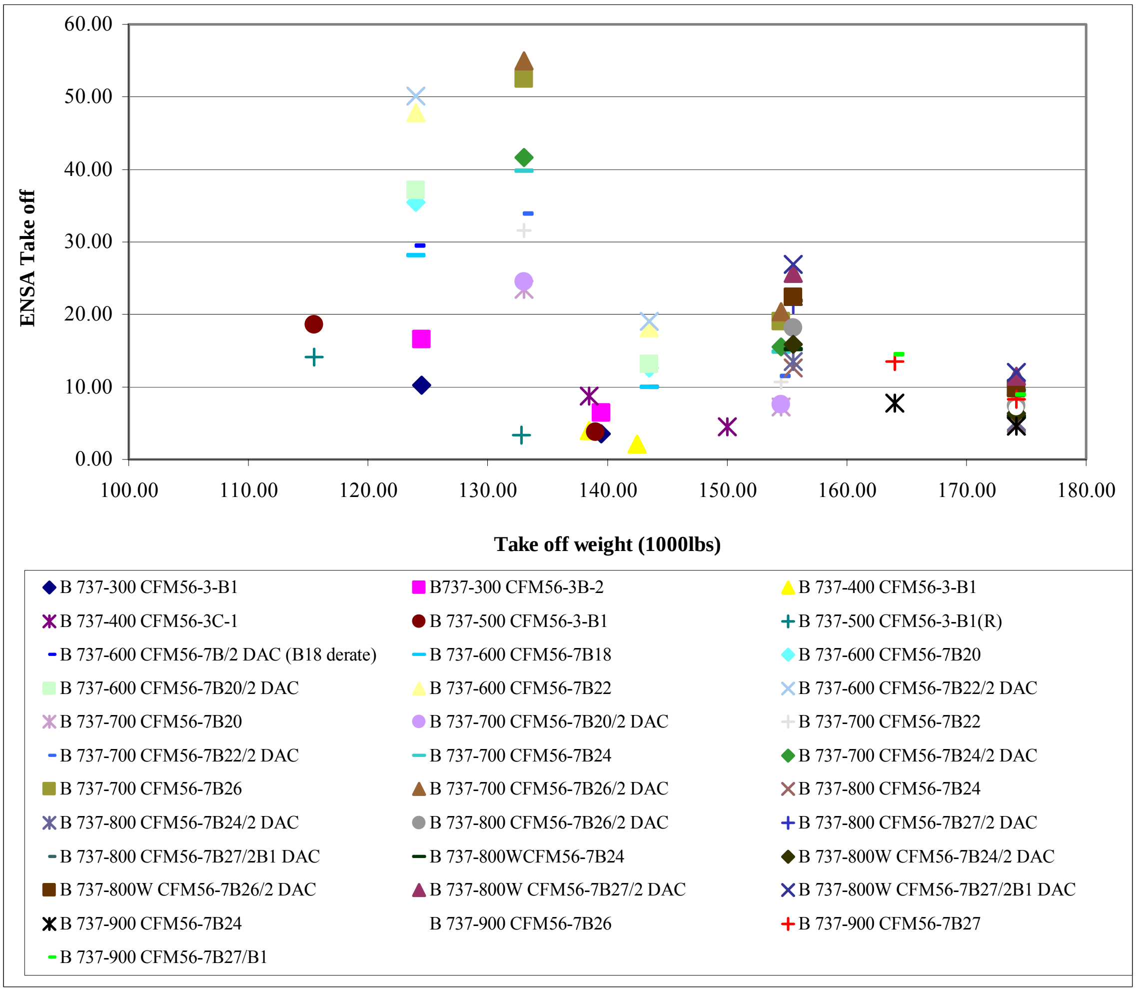

Figure-1. ENSA take off values calculated for boeing 737 series.

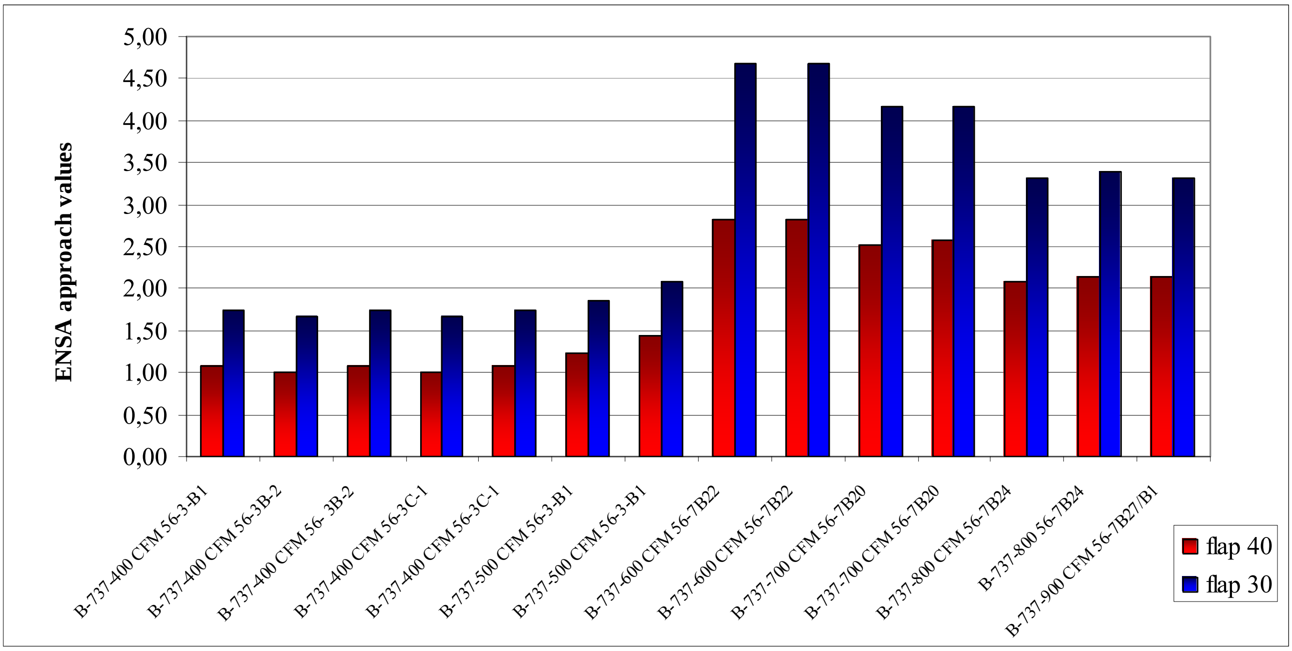

Figure-2. ENSA approach values for different approach flap configuration.

The ENSA technique can also be applicable in order to calculate the equivalent number of standard day aircraft movement at an airport. The indicator $ENSA_{apt}$ could represent a rating methodology for classifying airports by an aggregate data that accounts for all the movements within a given period of time and together with the total number of movements this indicator could be applicable in order to perform a benchmark of different airports in regard with noise issues.

The calculation of $ENSA_{apt}$ requires the evaluation of the equivalent number of take off and landing day movements per each aircraft type by using:

$$N_{i,day,approach} = (N_{i,day,app} + g_{evening} \cdot N_{i,evening,app} + g_{night} \cdot N_{i,night,app})$$

$$N_{i,day,take-off} = (N_{i,day,TO} + g_{evening} \cdot N_{i,evening,TO} + g_{night} \cdot N_{i,night,TO})$$

Where

$N_{i,day,take-off}$ is the equivalent number of day movements of the aircraft category i;
$N_{i,day}$ is the number of day movement of the aircraft i;
$N_{i,evening}$ is the number of evening movement of the aircraft i;
$N_{i,day}$ is the number of night movements of the aircraft i;
$g_{evening}$ is the equivalence factor for evening movements;
g_{night} is the equivalence factor for night movements.

The ENSA value for approach and take off can then be expressed as:

$$ENSA_{approach} = \sum_{i=1}^{N} \frac{N_{i,day,approach}}{ENSA_{i,approach}}$$

$$ENSA_{take-off} = \sum_{i=1}^{N} \frac{N_{i,day,take-off}}{ENSA_{i,take-off}}$$

Where

I is the number of aircraft categories;
$ENSA_{i,take-off}$ is the ENSA value of the aircraft type i for take off movements;
$ENSA_{i,approach}$, is the ENSA value of the aircraft type i for approach movements.

$$ENSA_{apt} = ENSA_{approach} + ENSA_{landing}$$

In order to applicate the ENSA index as a performance indicator to benchmark different airports it is necessary to calculate the ratio between the total number of movements and the $ENSA_{apt}$. The higher is this ratio, the lower the acoustical performance of the fleet mix operating at an airport.

CONCLUSIONS

In this paper has been introduced the equivalent number of standard aircrafts ENSA, as a way to compare aircraft noise performance. The index is based on the equivalent number of standard aircraft operations corresponding to a singular aircraft type operating only day movements. The ENSA technique can be applicable in order to calculate the equivalent number of standard day aircraft movement at an airport. The indicator $ENSA_{apt}$ could moreover represent a methodology to perform a benchmark of different airports in regard with noise issues.

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