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Participative pilot study at the vicinity of airports for the construction of a noise point counter integrating instantaneous annoyance at overflight

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ABSTRACT

In France and in Europe, current regulations on transport noise are based on energetic acoustic indicators that do not adequately reflect the intensity and repetitive nature of noise peaks, particularly for aircraft overflights or rail traffic. The public debate on these issues therefore often centers on the questioning of these indicators, which are deemed to be inadequate to reflect the annoyance caused to local populations, particularly in a context of increasing traffic.

Bruitparif suggests exploring a noise events counter, the Noise Point Counter (NPC), based on existing NAX indicators but freeing itself from the threshold effect, which is a drawback to their use. The idea is to count the number of noise events, weighting each event according to the level of instantaneous annoyance it is likely to generate for residents.

To make progress on the feasibility of developing such an indicator and to confirm its relevance, Bruitparif is proposing to carry out a pilot study on three selected overflown areas in the Île-de-France region, involving around thirty residents on each location.

The paper will present the principle behind the creation of this new indicator as well as the pilot study protocol.

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1. INTRODUCTION

Since 2021, air traffic growth in France has resumed, with the associated noise nuisance for residents. In 2023, traffic levels at several major French airports even exceeded pre-covid19 crisis levels [1].

According to the study on the social cost of noise in France published in 2021 by Ademe and the French Noise Council (Conseil national du bruit - CNB) [2], air traffic noise is estimated to cost French society 6.1 billion euros a year, or 4.2% of all the social costs generated by noise in all its dimensions (transport, neighborhood, work) in France. Most of this figure (5.6 billion euros) is linked to the health impacts generated by exposure to air traffic noise. The phenomenon is more acute in the Île-de-France region, which boasts a unique airport system in Europe, with two international airports (Paris-Orly and Paris-Charles de Gaulle) and a business airport, Paris-Le Bourget. These three airports, among the largest in Europe in their category, are responsible for a significant number of flights over the region (653,905 aircraft movements in 2023 for the two international airports [3]).

According to the results of the Crédoc/Bruitparif study published in 2021 [4], nearly 17% of Ile-de-France residents cite aircraft overflights as one of the three sources of noise that annoy them most at home. Nearly 7% of those surveyed also said that air traffic noise was the most annoying of the various sources of transport noise.

According to the latest strategic air traffic noise maps published for the Île-de-France region [5], almost 2.2 million people (17.7% of the region's population) would be affected by air traffic noise at levels exceeding the World Health Organization (WHO) recommended value of 45 dBA according to the Lden indicator, and 1.08 million would also be affected by the recommended value at night (40 dBA according to the Ln indicator). Almost 480,000 people (3.9% of the Ile-de-France population) would even be exposed to levels exceeding the regulatory limit value of 55 dBA according to the Lden indicator, and 192,000 people (1.6%) would be affected by night-time levels exceeding the regulatory value of 50 dBA for Ln. According to the same study, 459,000 Ile-de-France residents would be severely annoyed by air traffic noise, 174,000 would experience serious sleep disturbance and 122,000 would suffer from cardiovascular or metabolic diseases because of air traffic noise, representing some 36,000 years of healthy life lost (DALY) every year in Ile-de-France. If we also include the other effects of air traffic noise (learning difficulties, loss of productivity and property depreciation), the social cost of air traffic noise in the Île-de-France region would amount to 5.4 billion euros a year.

Today, we have increasingly reliable and convergent results concerning the health impacts of air traffic noise. The most important study carried out around European airports is HYENA (HYpertension and Exposure to Noise near Airports) [6][7]. Its aim was to measure the impact on blood pressure and cardiovascular disease of noise generated by air and road traffic among 4,800 people aged between 45 and 70 and living for at least 5 years near one of six major European airports (Milan/Malpensa, Berlin/Tegel, Stockholm/Arlanda, London/Heathrow, Amsterdam/Schiphol, and the new Athens airport). Another European study, RANCH (Road Traffic and Aircraft Noise and Children's Cognition and Health: Exposure - Effect, Relationships and Combined Effects), was carried out around the airports of Amsterdam/Schiphol, London/Heathrow and Madrid/Barajas [8]. It focused on the impact of aircraft noise exposure at school on children's quality of life and learning. A study called NORAH (Noise-Related Annoyance, cognition and Health) has also been launched in Germany [9]. The aim is to improve knowledge of the effects of transport noise in general on health (hypertension, cardiovascular disease, sleep disturbance), and aircraft noise in particular. Specifically, the aim is to compare noise annoyance and quality of life before and after the opening of a fourth runway at Frankfurt airport, with noise annoyance in the vicinity of other airports. The study also examined the impact of noise exposure on children's cognitive performance and quality of life. In France, the DEBATS study (Discussion autour des effets du bruit du trafic aérien sur la santé) was the first large-scale research program to examine the effects of aircraft noise exposure on the health of people living near airports. It combined three complementary methodological approaches (ecological, individual longitudinal and clinical sleep) [10]. The study looked at the deleterious effects of aircraft noise exposure on perceived health, psychological health, annoyance, sleep, and the endocrine and cardiovascular systems.

In October 2018, the WHO published a summary of the health impacts of noise that can be considered scientifically established based on studies published up to 2014 [11]. The effects that have been retained for air traffic noise are annoyance, sleep disturbance and learning difficulties. They have been the subject of strong recommendations by the WHO not to exceed 45 dBA Lden and 40 dBA Ln to avoid the deleterious effects of air traffic noise on human health. In France, the National agency for sanitary security of food, environment, and work (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail - ANSES) published a summary of scientific knowledge on the health effects of exposure to air traffic noise in 2020 [12]. This also considered scientific publications published after 2014, many of which highlighting the cardiovascular impacts of air traffic noise (particularly hypertension for men).

2. THE INDICATORS ISSUE

Research in psychoacoustics since the 1960s has focused on sound perception. This work has led to the development of specific acoustic indicators such as loudness [13] or, more specifically for aircraft noise, the Perceived Noise Level (PNL) expressed in PNdB and the Effective Perceived Noise Level (EPNL) expressed in EPNdB [14][15][16]. These quantities and units have the advantage of better representing noise as perceived by human beings but have the disadvantage of being complex to understand and difficult to implement operationally, particularly in the context of air traffic noise modelling (impact studies, mapping, etc.). These are the reasons why the French psophic index, which combined aircraft-generated noise levels in PNdB for the day and night periods [17], was abandoned in 2002 and replaced by Lden-type indicators in the context of establishing Noise Exposure Plans around airports.

Most epidemiological studies on the health effects of transport noise have been based on energetic noise indicators such as Lden or Ln. These energetic indicators have the advantage of being relatively easy to produce through measurement or noise modeling tools. Their use has, moreover, been generalized by European Directive 2002/49/EC, which requires member states to produce noise strategic maps using these indicators within major urban areas and in the vicinity of major transport infrastructures. On the basis of scientific work (International Commission of Biological Effects of Noise - ICBEN in particular), and then of the work of experts convened by the European Commission between 1998 and 2002, directive 2002/49/EC recommended using Lden as an indicator of transport noise (road, rail and air) to predict long-term overall annoyance in the case of stable noise situations, and Lnight (Ln) to predict long-term sleep disturbance. With the Lden indicator, the European Commission has introduced a weighting of noise levels in the evening (+5 dB) and at night (+10 dB) to take account of people's heightened sensitivity during these periods.

Although a link has been established between Lden-type energy indicators and long-term annoyance, it is accepted that this only explains between 30% and 40% of the annoyance expressed by people, as many other non-acoustic modulating factors (socio-demographic/economic and cultural factors, contextual factors, personal history, and individual sensitivity) play a part in individual reaction [18].

The dose-response relationships published in October 2018 by the WHO also highlight that noise with a strong event component, such as air or rail traffic, has more marked health effects than road traffic noise (at least when the latter is relatively continuous), for the same equivalent mean level expressed in Lden or Ln. Reviews [19] and recent scientific publications as part of the DEBATS study [20][21] confirm that certain biological effects, such as changes in heart rate at night and sleep disturbance, are more closely linked to noise events than to average noise. In Switzerland, the SiRENE study launched in 2013 looked at the short and long-term effects of exposure to transport noise (road, rail and air) on health, and in particular on annoyance [22]. It introduced a new unit of measurement to describe the event-driven nature of noise nuisance: the Intermittency Ratio (IR), which expresses the contribution (in %) of individual noise events to overall noise. The SiRENE study concludes that the event-related nature of noise plays a role in the deterioration of health, but that further studies are required to confirm the trends observed, or whether other descriptors are needed to explain them.

The hypothesis can be formulated that an improved description of noise exposure through event-based indicators that take greater account of the acoustic factors involved in the instantaneous annoyance associated with aircraft overflight (intensity, duration, emergence, spectral content, etc.), as well as the repetitive nature of the nuisance, would enable us to better translate the long-term annoyance felt by residents, and better explain the health effects.

People living near airports have long been calling for greater consideration to be given to the number and characteristics of noise peaks, using event-based indicators, which they consider more representative of the annoyance experienced and the health impacts.

Already in 2004, the French High Council for Public Health (Conseil Supérieur d'Hygiène Publique de France - CSHPF) recommended the introduction of the LAmax index and made a recommendation not to exceed more than 10 night-time noise peaks of over 70 dBA LAmax, i.e. a recommendation value of NA70,22h-6h<=10 [23]. In its 2005 activity report, the French Airport Nuisance Control Authority (Acnusa) also recommended the use, in addition to the Lden and Ln indicators, of a NAX-type indicator, as already used on Australian airport platforms and recommended by the Federal Interagency Committee On Noise (FICON, USA), as part of prospective studies.

In its opinion of June 12, 2019, the CNB also encouraged the use of event-based indicators to complement energy indicators [24].

In 2023, the CNB and Acnusa set up a national working group to formulate recommendations on the introduction of new air traffic noise indicators in regulations, to better take into account the effects of air traffic noise on health. Bruitparif contributes to these discussions.

Event-based indexes such as LAmax and SEL, as well as NAX indicators, are beginning to be used operationally in the field of air traffic noise. In addition to energy indicators, they are used for consultation of air traffic noise measurement data on the vicinity of certain airports, such as that of Bruitparif (http://survol.bruitparif.fr), as well as in the monthly or annual reports on the operation of measurement networks produced by certain airport managers (for example, the reports produced by Airports of Paris (Aéroport de Paris - ADP), which are available on the Internet).

While NAx-type indicators can go some way to improving information for residents, and are relatively easy to understand, they do have some major shortcomings that prevent their widespread use and translation into regulations.

The first shortcoming is the threshold effect they introduce. On the one hand, the choice of threshold (NA62, NA65, NA70, etc.) is relatively arbitrary. In a context of expected growth in air traffic combined with fleet renewal, resulting in an increase in the number of overflights by aircraft generating slightly less noise than before, NAX-type indicators could prove inadequate to reflect changes in people's perceptions. To illustrate this point, let's take a theoretical but sufficiently demonstrative example. Whereas 100 overflights each generating an LAmax of 66 dB(A) leads to a NA65 value of 100, a doubling of traffic with aircraft each generating 2 dBA less (i.e. heard only slightly less loudly), i.e. 200 overflights of LAmax 64, would lead to a NA65 value of 0! So, using the NA indicator and a threshold of 65, the noise problem would miraculously disappear! The situation would have been quite different if, for example, a threshold of 62 has been chosen, where the modifications introduced would have raised the

NA62 value from 100 to 200, which would certainly be more in line with the evolution of local residents' feelings and annoyance, but would not reflect the improvement brought about by fleet renewal.

The second major shortcoming is that all events with a LAmax value above the set threshold are given equal weight in the indicator's calculation. Thus, when applied to contexts of very high noise exposure, such as those encountered in the vicinity of airports, where almost all noise peaks exceed 70 dBA in LAmax, the NA65 indicator in fact corresponds to an air traffic counter and proves very limited in terms of demonstrating the benefits brought by a fleet renewal for example.

Finally, the use of NAx indicators proves laborious to implement in the context of noise measurements or impact studies. For map representations in the form of noise contours in particular, the multiplicity of noise thresholds and the number of associated events rapidly leads to the production of a large number of maps (NA62/200, NA65/100, NA70/10, NA62/10, NA62/25, for different periods of the day, etc.), which can confuse impact studies and make difficult to exploit the changes highlighted.

3. PRINCIPLE OF THE POINT-BASED NOISE EVENT COUNTER

For these reasons, Bruitparif proposes to study the principle of a “Noise Point Counter” (NPC), which would be inspired by NAX-type indicators, but would avoid the shortcomings of the latter. The idea would be to count all noise peaks generated by aircraft overflights (thus eliminating the threshold effect of NAX-type indicators), weighting each peak according to its acoustic characteristics and period of occurrence, which can influence annoyance.

3.1. Principe

This indicator could be calculated in two main stages.

During the first stage, a number of points (NP) would be assigned to each noise peak, based on the calculation of a unit indicator. For this, a first proposal is to convert the sound energy of the noise peak expressed in terms of the SEL index into a number of points, using available knowledge of the physiological equivalence rule found in the scientific literature [25][26], according to which a difference of 5 to 10 dB between two sounds would be required to generate an auditory sensation doubled or halved. The variation factor (between 5 and 10 dB) has yet to be specified and is noted as X at this stage. The SEL to NP conversion formula could thus take the following form (X and SELref to be specified):

$$NP = 2^{(SEL-SELref)/X} \quad (1)$$

During the second stage of calculating the NPC indicator, the number of sound events assigned to the number of points calculated in the first stage would be counted by day/evening/night periods, and an aggregate counter would be set up using a set of weightings by period of appearance (day, evening, night), possibly also taking into account a distinction between working days and weekend days, or even by season. The formula for the daily aggregated NPC could thus take the following form:

$$NPC_{den} = NPC_d + \propto * NPC_e + \beta * NPC_n \quad (2)$$

With: α and β the weighting coefficients to be determined

$NPC_d = \sum_{i=1}^{Nd} NPi$

$NPC_e = \sum_{i=1}^{Ne} NPi$

$NPC_n = \sum_{i=1}^{Ne} NPi$

in which Nd, Ne, Nn represent respectively the number of noise peaks identified during the day (d for day), evening (e for evening) and night (n for night) periods.

The aim is to build a new aggregate indicator that is easy to understand and implement, and that can account for changes in people's annoyance as a result of changes in air traffic management over time.

3.2. Main challenges to be overcome

The development of such an indicator essentially involves overcoming two main scientific hurdles:

1. Firstly, the determination of the rule for calculating the number of points (NP) to be assigned to a noise event, to best reflect the variability of the instantaneous annoyance felt by residents as a function of the acoustic characteristics of overflights (loudness, duration, frequency content, etc.).
2. Secondly, the determination of the weighting coefficients to be used to take account of differences in sensitivity to air traffic noise depending on the time of day, the day of the week and even the season.

3.3. Aim of the COGEN'AIR feasibility study

The aim of the COGEN'AIR feasibility study is to validate this approach and adjust the calculation formula for the point-based noise event counter, with the involvement of people living in the vicinity of airports. Progress will be made on the following three points:

- Relevance of the SEL unit indicator as a reference index for acoustic characterization of noise peaks generated by aircraft overflights.
- Proposed values for parameters X and SELref for adjustment of the SEL to NP conversion formula.
- Determination of weighting coefficients for different periods, to take account of the variability of short-term annoyance to overflown populations.

4. DESCRIPTION OF THE COGEN'AIR PROTOCOL

The COGEN'AIR study will be coordinated and implemented by Bruitparif, the Île-de-France noise observatory, which operates a large noise measurement network and participates in numerous studies and research programs (notably DEBATS [20][21], BROUHAHA [27], SOMNIBRUIT [28], GENIFER [29]) aimed at advancing the characterization of noise and its health and socio-economic impacts. For this study, Bruitparif will rely on the support of stakeholder associations (France Nature Environnement Île-de-France regional federation and associations fighting against air traffic noise) for citizen participation actions.

The COGEN'AIR feasibility study is scheduled to run for two years, from October 2024 to September 2026. It will be based on contributions from residents in three areas exposed to air traffic noise in the Île-de-France region. It will be implemented in four phases.

4.1. Preparation of the framework for citizen contribution

Three pilot sites will be selected in Ile-de-France, near each of the two major Paris airports, Paris-Orly and Paris-Charles de Gaulle, as well as the Toussus-le-Noble aerodrome, in sectors where Bruitparif has been operating a permanent aircraft noise measurement station for several years.

As far as possible, we aim to have sites subject to contrasting noise levels and overflown differently according to wind regimes, days of the week and different periods of the day (day, evening, night, etc).

Based on the noise strategic maps drawn up under European Directive 2002/49/EC, care will be taken to ensure that the vicinity of the sites selected has little exposure to noise sources other than air traffic. A site survey will be carried out to ensure that no particular situation (e.g. nearby construction site) is likely to interfere with the study.

Participants in the study will be recruited from among residents at the pilot sites, with the support of the associations involved in the project and local authorities who can relay the call for volunteers. The aim is to find 30 volunteers at each of the three selected sites, for a total of around 90 participants. This is a compromise enabling to have enough people per site, while remaining manageable from a logistical point of view.

The recruitment of participants for this feasibility study is intended to contribute to the development of a new noise indicator, and not to represent the average characteristics of the population. It will therefore not follow a random sampling plan but will be based on voluntary participation. In particular, the fact that the participants in the study include people involved in the fight against air traffic noise should not be analyzed as a bias, but rather as an opportunity, insofar as these people are generally aware of the central role played by air traffic noise indicators in the debate.

4.2. Data collection

Data will be collected in three complementary ways:

1. **The completion of a general questionnaire to characterize the long-term annoyance** felt by participants in connection with their exposure to air traffic noise. It will be administered face-to-face at each participant's home and will be inspired by the questionnaires used in the DEBATS study and in the GENIFER study. The questionnaire will gather information on the participant's profile, personal and professional situation, housing, appreciation of their neighborhood and environment, living habits, annoyance linked to noise in general and aircraft noise in particular, individual sensitivity to noise and perception of air transport.
2. **Filling in a dashboard to collect daily information on short-term annoyance** during a 15-day period, that have to be the same for all participants at a site, guaranteeing an assessment of annoyance over a common period and under same overflight conditions. The dashboard will have to be completed at the end of each period of the day (day, evening, night). The participant will record whether or not he or she was at home, and if so, will be asked to fill in the following information: the main activities carried out and the main areas of the home frequented (outdoors or indoors, with windows open or closed), the average level of annoyance felt during the period in relation to air traffic noise on a scale from 0 (not at all annoyed) to 10 (extremely annoyed) in accordance with ISO-15666 [30], the times and circumstances when annoyance was greatest, any noise-avoidance measures taken during the period (closing windows, wearing earplugs, etc.) and any other observations he or she may wish to mention. The observations and annoyance levels thus collected will then be compared with the air traffic noise indicators measured at the nearest measuring station, which will enable aircraft noise events to be precisely identified.
3. **The organization of collective rating sessions, during which study participants at each pilot site will record their instantaneous annoyance levels during aircraft overflights**, under identical noise exposure conditions (same aircraft overflights). Session will be organized in an outdoor space located in the immediate vicinity of the permanent noise measurement station operated by Bruitparif. It must be in an open field, to minimize disturbance of the sound field and the effects of sound masking and/or reflection. Remote notation devices will be used to record, for each participant, a noise annoyance rating on a scale from 0 (not annoyed at all) to 10 (extremely annoyed) in accordance with ISO-15666 [30], so as to associate ratings with the acoustic characteristics of the overflight measured at the station.

4.3. Data analysis

Annoyance will be analyzed by means of different methodologies and tools:

- For long-term annoyance, a descriptive analysis of answers provided in the general questionnaires will include an assessment of factors significantly associated with annoyance, using standard statistical analysis tools such as P-Value and odd-ratios.
- For short-term annoyance, a comparison will be made between information recorded by participants in the dashboards (daily variability of annoyance due to air traffic noise according to the period of day) and the air traffic noise indicators measured at the nearest permanent measuring station, using recalibration if necessary, according the rating conditions (outside or inside the home, with windows open or closed). The aim is to observe variations in short-term annoyance to make it possible to determine the weighting coefficients to be applied to a point-based noise event counter to take account of sensitivity as a function of period.
- Instantaneous annoyance scores and associated aircraft noise indicators will be cross-referenced using descriptive analyses (P-value and odd-ratio) and statistical analyses (analysis of variance, regression and classification algorithms, principal component analysis, mixed models). The models implemented will be designed to determine the acoustic descriptor associated with aircraft overflights that best correlates with instantaneous annoyance, and to determine the weightings to be applied to the number of points (NP) per noise event, in order to best reflect the variability of the instantaneous annoyance felt by residents as a function of the acoustic characteristics of the overflights (loudness, duration, frequency content, etc.).

The results of the analyses will make it possible to determine the most appropriate acoustic descriptor for calculating the number of points per aircraft noise event and the parameters to be implemented in the formula for calculating the point-based noise event counter, in particular:

- The weightings to be applied to the acoustic descriptor of the aircraft event to best correlate it with instantaneous annoyance,
- And the weightings to be applied according to the periods of appearance of the aircraft event in order to best correlate it with short-term annoyance.

4.4. Evaluation of the point-based noise event counter via focus groups

The point-based noise event counter developed in this way will be implemented in operational production within the data processing chains collected on Bruitparif's air traffic noise measurement stations. It will also be recalculated a posteriori on available historical noise measurement data. The results of the NPC indicator aggregated over the past year will be reconciled with the long-term annoyance scores assessed by participants during the general questionnaire.

Focus groups with study participants will be organized at each site to share the results of the indicator, and to gather feedback from residents on its ability to accurately reflect the variability of air traffic noise annoyance according to overflight periods and conditions.

5. ORIGINALITY, EXPECTED OUTCOME AND IMPACT

5.1. Originality

The originality of COGEN'AIR lies mainly in four aspects:

- The **innovative and pragmatic approach** of proposing a point-based noise event counter.
- The **scoring of aircraft overflights, both in situ and by residents concerned by the problem**, and the comparison with measurements of noise generated by aircraft overflights, to assess the variability of instantaneous annoyance caused by air traffic noise.

- The **variability of short-term annoyance** as a function of overflight conditions, time of day and type of day. The question of short-term annoyance and its evolution over time has been little explored by scientific studies, most of which focus either on long-term annoyance via standardized questionnaires [30], or on instantaneous annoyance under laboratory conditions.
- The **involvement of residents in the co-construction and evaluation of the new indicator**, as this methodology has never been implemented in France. The involvement of associations as stakeholders will facilitate the mobilization of citizens around this project.

5.2. Expected outcomes and impact

The main expected outcome of this study is to validate the feasibility of developing an operational indicator, such as a point-based noise event counter, to better consider the variability of residents' annoyance as a function of air traffic conditions and the period of occurrence of overflights. The indicator proposed at the end of the project will have been adjusted and validated by the participants, who are themselves concerned by air traffic noise. This indicator could be deployed on an experimental basis by noise observatories and proposed to airport managers. It could then be assessed on a more statistically robust basis through a large-scale study of different airports at national or European level. The assessment methods implemented as part of the COGEN'AIR project will have been sufficiently field-tested to be applied on a larger scale.

By proposing an indicator representative of the nuisance associated with air traffic noise, and developed in association with residents, the COGEN'AIR study will provide an operational tool to monitor the impact of the combined effects of changes in air traffic (number of overflights and fleet composition), changes in operating procedures (e.g. generalization of continuous descents) and any additional actions such as operating restrictions that might be introduced at certain airports, given the noise problems that remain.

The expected impact is an improvement in the quality of life within airport zones and a reduction in health impacts, by reconciling the imperatives of airport traffic management with the need to limit nuisance for residents and the communities concerned.

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