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The increase of aircraft noise annoyance in communities. Causes and consequences

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Note: this is a slightly updated version which is different from the one distributed on the USB flash drive as part of the congress package

ABSTRACT

Field research data indicate an ongoing increase of aircraft noise annoyance in communities at given L_{pAeq} levels. The paper discusses several potential causes of this process:

1. Methodological changes in the studies,
2. Contextual changes reflected in the studies,
3. General increase of the number of aircraft movements,
4. Changes in the composition of aircraft fleets, and
5. Attitudinal changes in the residents.

At present, several consequences can be drawn:

1. Recommendations with respect to intolerable levels of continuous noise for aircraft and railway traffic should be adjusted. Within this process, it seems recommendable to distinguish between low rate and high rate change airports.

2. Since the increase of the number of flight movements, as well as the change in fleet mix seem to be systematically related to the annoyance increase, assumptions of the energy-equivalent long-term continuous sound pressure should be re-evaluated and amended or supplemented by additional acoustic variables.

3. We should keep an eye on the development of socially shared values and attitudes related to personal autonomy, as well as to the evaluation of airports, and their noise policy.

INTRODUCTION

This lecture considers long-term noise annoyance as observed in systematic surveys in the vicinity of a transportation noise source. The surveys mostly use standardized questionnaires, standardized response scales, and standardized sound exposure assessment. The observed effect variable "noise annoyance" is a retrospective judgment, comprising past experiences with a noise source over a certain time. In theory, the single individual noise annoyance response is driven by three elements:

1. an often repeated disturbance due to noise (repeated disturbance of intended activities, e.g., communicating with other persons, listening to TV or music, reading, working, sleep), often combined with behavioural responses in order to minimize disturbances,
2. an emotional/attitudinal response (anger about the exposure, and negative evaluation of the noise source), and
3. a cognitive response (the distressful insight that one cannot do much against this unwanted situation).

Data from early and late field research indicate an increase of per cent highly annoyed people in communities at given continuous aircraft sound levels for many years now. An example is given in Fig. 1, adapted from the latest meta-analysis prepared by [1] for the European section of WHO. The 12 studies used were published between 2000 and 2014; their data points show a considerable dispersion. However, most of them are fairly above the old curve estimated by [2], based on 20 studies published between 1967 and 1992. The black curve in Fig. 1 represents a rough exposure-response estimation by means of the quadratic regression on published aggregated data of the 12 WHO studies, weighted according to sample size. This curve shows an almost linear relation between L_{den} and %HA. “Highly annoyed” individuals are defined here as respondents exceeding 72% of the response scale. The %HA curve of the new review lies well above the old Miedema & Oudshoorn curve from 45 dB L_{den} onward. According to this analysis, 25%HA are seen at 54 dB L_{den} – compared to 64 dB according to the old analysis. This is a difference of 10 dB L_{den}. It should be mentioned that the surveys from the NORAH study [3], including 4 airports get exactly the same relation between %HA and Lden for three of the airports: 25%HA at 54 dB L_{den}. An exception is Frankfurt Airport: 25%HA at 49 - 51 dB L_{den} in three measurements 2011-2013.

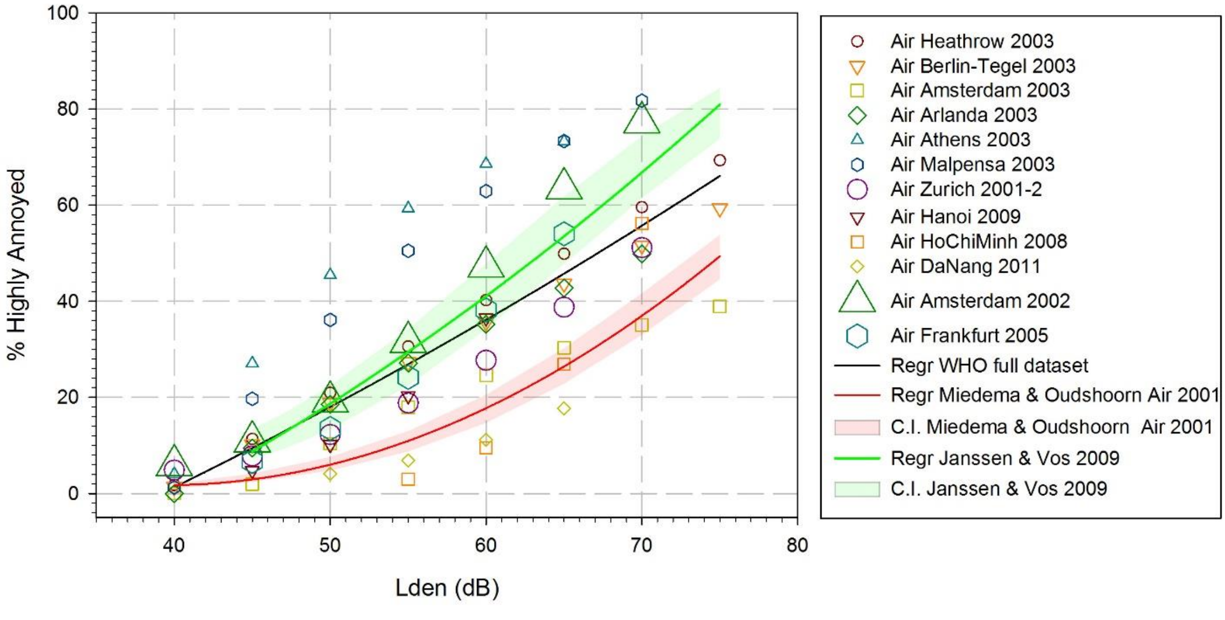

Figure 1: Scatterplot and quadratic regression of the relation between L_{den} and the calculated % Highly Annoyed for 12 aircraft noise studies, together with exposure-response function by [2] (red continuous line), and the curve published by [4].The size of the data points corresponds to the number of study participants.

Three years ago, I was confident that the increase in %HA is unique to aircraft noise, and that it reflects an increase of aircraft noise annoyance in general [5]. Today, both beliefs stagger, and especially the first one, the uniqueness of the increase of %HA by aircraft noise, cannot longer be maintained due to the fact that we got a similar increase of %HA by railway noise, too: while [2] estimate 25%HA at 76 dB L_{den} railway noise, we estimate 25%HA at 65 dB L_{den} in our review for the WHO [1]. The difference amounts to 11 dB L_{den}. On the other hand, we did not observe a comparably large increase of %HA with respect to road traffic noise. We observed only an increase of %HA at the lower end of exposure (40-60 dB L_{den}), especially if we include the Alpine road traffic noise studies. If we exclude them, the estimated new exposure-response curve for road traffic noise mostly lies well within the confidence interval of the old curve – except for the lower end of exposure levels. The reasons for the increase of %HA at given noise levels may be different for the three transportation noise sources. I will discuss the increase with respect to aircraft noise here.

The second question, whether the observed increase of the percentage of residents highly annoyed by aircraft noise at given noise levels indicates a general increase of aircraft noise annoyance over time, cannot be answered here due to lack of published data. For instance, most of the studies containing exposure-response data report %HA vs. L_{pAeq}, and skip mean annoyance vs. L_{pAeq} or other acoustical exposure descriptors. I still like to mention five different aspects of this question:

1. We assume that residents who answer survey questions about annoyance are able to translate their inner feelings and judgments into a given response scale. That is, they are able to grade their internal annoyance judgment on an external scale, e.g., a verbal or numerical scale, and this external response is the main observable data we have. In surveys, we generally don't know anything else about the internal states and processes associated with internal annoyance. We have to take the external response as an indicator of internal processes.

2. We further assume that respondents use the steps on the response scale in a way that is shared by the large language community. The latter assumption cannot be tested individually, but in view of the scaling experiments made before the introduction of the verbal ICBEN/ISO scales [6], this assumption is fairly plausible.

3. In comparing annoyance responses over time, we further assume that their meaning and their use keeps stable over time. This may be relatively plausible with respect to the meaning of numerical ratings. However, with respect to verbal ratings, we know that the meaning of certain verbal expressions may change within a language community over time. For instance, the English word "nice" 50 years ago used to mean "silly, foolish, simple." Far from the compliment it is today! We also know that the use of numerical expressions, as well as the use of verbal expressions has changed. For instance, you will find today more numerical expressions like "100 percent" in a common sentence than 50 years ago, and the same is true for verbal expressions like "Wow", "crazy" and "wonderful", to name but a few, We don't know much about the history of numerical or verbal ratings in annoyance surveys; however, we should be careful in assuming that their use has been stable over time.

4. A related issue is the relation between %HA (or certain other sections of the response scale) on the one hand, and mean annoyance on the other. The exposure-response relations shown by Miedema & Oudshoorn [2], using continuous sound levels on one side, and %HA, %A, or %LA on the other, are not parallel. The relations between noise levels and observed %HA often show the form of a "J", that is, they show an increase of the slope with increasing sound levels. The relation between noise levels and observed %A (>50% of the response scale) often is an almost flat "J", and the relation between noise levels and %LA (>28% of

response scale) if reported at all, often shows a decreased slope at higher sound levels. Different forms of exposure-response relations may be expected, given certain cut-off point and certain distributions of raw annoyance scores with respect to sound levels. If you know the distributions, you may be able to estimate %A and %LA from %HA, as done by [2]. However, if we don't know the distribution of raw scores, we can't tell whether the change in %HA indicates a general change in annoyance judgments, or not. In addition, if we continue to report only %HA in our papers, we may miss ongoing changes in the large proportion of residents who are annoyed in a medium grade.

5. The ICBEN/ISO annoyance question asks "how much does noise from (..noise source..) bother, disturb, or annoy you"? That is, it assumes that the terms "bother", "disturb", and "annoy" belong to the same core content. This may be true in many languages, and I very strongly support the idea of a common annoyance question which is shared in different cultures. However, the exact meaning of these words is slightly different, and if we only have data about the core content, we are not able to analyse whether the so-called annoyance trend relates to all of the three meanings in the same manner, or not.

METHODOLOGICAL CHANGES IN AIRCRAFT ANNOYANCE SURVEYS

In the history of community annoyance surveys, there have been several methodological changes, especially with respect to sampling strategies, assessing the acoustical exposure, and response data gathering. At the beginning, sample selection in terms of extreme exposure groups (so-called contrast groups, e.g. "noisy" and "quiet" areas) were rather common. Today, a stratification according to noise levels seems to be more common, and a complete random sample in a circumscribed area is a rare exception. Unfortunately, the Wyle catalogue of 628 social surveys [7] does not contain a category called "sampling strategy". Therefore, I could not find enough data in order to test the hypothesis that low and medium exposed people were not well represented in the old studies. However, if we compare exposure response curves from old and new transportation noise studies, there is some indication that the largest increase in noise annoyance happened in areas of low and medium sound exposure. This may be due to the fact that earlier surveys often used higher sound levels as starting points in their reports about exposure-response relations, for instance, 45-50 dB continuous sound level, as compared to 40 dB we often find today. In other words, due to lack of data, the old annoyance data on lower noise levels may not be as reliable as the new ones seem to be.

Assessing the aircraft sound exposure by means of acoustical measurement or calculation procedures in the context of a social survey has changed considerably. In the early days, e.g., until 1980, study areas around an airport were selected (more or less by "guessing" their importance), and a measurements station was located in the centre of this area. These measurements provided the basis of estimating the long-term "noise load" of the area in terms of NNI, L_{pAeq} values (including derived indices, like CNR and DNL) for 24 hours or smaller time slices. The estimation of long-term noise loads near an airport involves a knowledge of the number of specified types of planes flying at specified routes in specified altitudes and specified directions. This knowledge has been rather imprecise before the widespread introduction of computer programs for calculating aircraft noise, e.g. the Integrated Noise Model (INM), which was introduced in 1978, and underwent a series of upgrades, until FAA adopted the Aviation Environmental Design Tool (AEDT) as of May 2015. Beginning about 1980, socio-acoustic aircraft noise surveys could in principle base their sample selections and statistical analyses on aircraft noise calculations. However, these calculations require local data on flight tracks, aircraft fleet mix, aircraft profiles, and terrain as inputs, to name but a few, and such data often were not available with sufficient quality in the early days. In addition, some of the upgrades in computer programs led to a decrease of continuous sound levels. For instance, some of the continuous sound levels calculated between 1990 and 2008 by means of the old German AzB (1975) were up to 3 dB higher as compared to the new AzB (2008). The Swiss FLULA initially did not correct for thrust reduction after takeoffs until 1999 – which means that continuous sound levels at larger distances from the airport are lower now as compared to before. In both cases, some of the calculated continuous sound levels were higher at former times than they are calculated today. In other words, the calculated continuous sound levels today are not exactly comparable with those calculated 10-20 years before. There is some indication that they have been some decibels too high, especially at large distances from the airport.

There are other methodological differences between old and new aircraft noise annoyance surveys: [8] made a comparison of 22 aircraft noise surveys, 15 of them were used by [2], and 7 were new studies. Some comparison data relate to type of contact, response rate, and type of annoyance scale. It turned out that all of the three study characteristics showed a change over the years 1967-2005. “While in previous years the type of contact was primarily face-to-face and sometimes through telephone, recent surveys usually involve postal questionnaires. Also, response rates were higher in some of the older surveys than in later surveys. Another study characteristic that has changed over the years is the type of annoyance scale” ([7], p. 1958). While earlier surveys often used verbal scales with 4 or 5 categories, more recent surveys either exclusively used scales with 11 categories, or used a verbal scale together with a numerical 11-point scale. In meta-analyses the type of contact proved to be a source of heterogeneity: both face-to-face interviews and telephone surveys were associated with lower annoyance compared to postal surveys. Also, in the 19 studies for which the response rate was known, higher response rates were significantly associated with a decrease in reported annoyance, and annoyance judgments on the 11-point scales were significantly higher compared to verbal 4-point or 5-point scales. Although the use of scales was associated with the study year in the main analysis, a separate analyses of studies involving either verbal or numerical scales still showed an increase in mean annoyance over the years. Recently, [9] also reported higher annoyance scores associated with 11-point scales in comparison to 5-point scales in postal interviews.

CONTEXTUAL CHANGES REFLECTED IN THE STUDIES

In the discussion about possible causes of the so-called annoyance trend, an early guess was related to airport expansions as a situational context influencing annoyance judgments of residents. It was known from surveys on road traffic noise that annoyance increases sharply in situations of a stepwise increase of road traffic noise (e.g., [10]), and it is plausible to assume a comparable change effect in situations of a stepwise air traffic noise increase, too. However, a notable stepwise increase of airport noise levels is extremely rare. Much more often, a gradual increase of aircraft movements from year to year was observed at many civil airports – at least until 2009. In combination with the gradual change of the aircraft fleet composition from more noisy to somewhat quieter aircraft, the increase of aircraft movements did not increase the annual continuous aircraft sound levels considerably. Some airports proudly reported a decrease of continuous sound levels. However, during systematic interviews, residents reported that noise was getting worse over the years, and spontaneous noise complaints of residents increased especially in situations of impending operational changes at the airport, i.e., even before the operational changes were executed.

At this stage, some noise effect researchers were not happy with the concept of “stepwise change” in terms of stepwise exposure change. It was felt that airports underwent gradual changes from year to year, sometimes in combination with public announcements of stepwise operational changes in the near future. Noise effect researchers approached the concept of “rate of change”, i.e. the speed at which a variable changes over a specific period of time – usually one year. However, neither a consensus about the variables to include in this concept, nor about the definition of “public announcement” is reached until today. [8] asked “whether the observed trend in annoyance may partly be explained by a larger rate of expansion of airports during recent surveys compared to earlier surveys” (p.1960). However, the paper did not allow a testing of the role of expansion of the airports due to the absence of clear data and criteria on the basis of which the change-status could be attributed to an airport.

In this unclear situation, [11] proposed (p.8) “to call airports “low-rate change (LRC) airports”, as long as there is no indication of a sustained abrupt change of aircraft movements, or the published intention of the airport to change the number of movements within 3 years before and after the study. An abrupt change is defined here as a significant deviation in the trend of aircraft movements from the trend typical for the airport. Each trend is calculated by means of total movement data during a five year period. If the typical trend is disrupted significantly and permanent, we call this a “high-rate change (HRC) airport”. We also classify this airport in the latter category if there has been public discussion about operational plans within 3 years before and after the study."

Although this definition is not clear-cut in all its aspects, it has been applied in a small number of publications, including the new WHO evidence review on noise annoyance. In the latter review, we found 5 studies published between 2000-2014 which were clearly done at LRC airports, and 5 other ones which were done at HRC airports. All 10 studies are of good scientific quality according to the scoring systems used in the review, and used comparable data assessment methods, and their definition of “High Annoyance” relates to >72% of the response scale. Figure 2 shows the distribution of %HA over L_{den} values in the 10 studies selected, together with separate regression functions for mean %HA in HRC and LRC studies. It seems evident that mean %HA values for HRC studies are higher than those for LRC studies. At HRC airports, 25 %HA are seen at 52.4 dB L_{den}; at LRC airports, 25%HA are seen at 59 dB L_{den}. The difference amounts to 6.6 dB L_{den}. However, both regression functions are higher than the old Miedema & Oudshoorn function. In other words, it seems that part of the increase of the %HA at comparable L_{den} values over the last 20 years may be due to the change-context of the aircraft noise annoyance survey, but it is only a partial explanation, and as such no sufficient explanation of the annoyance increase.

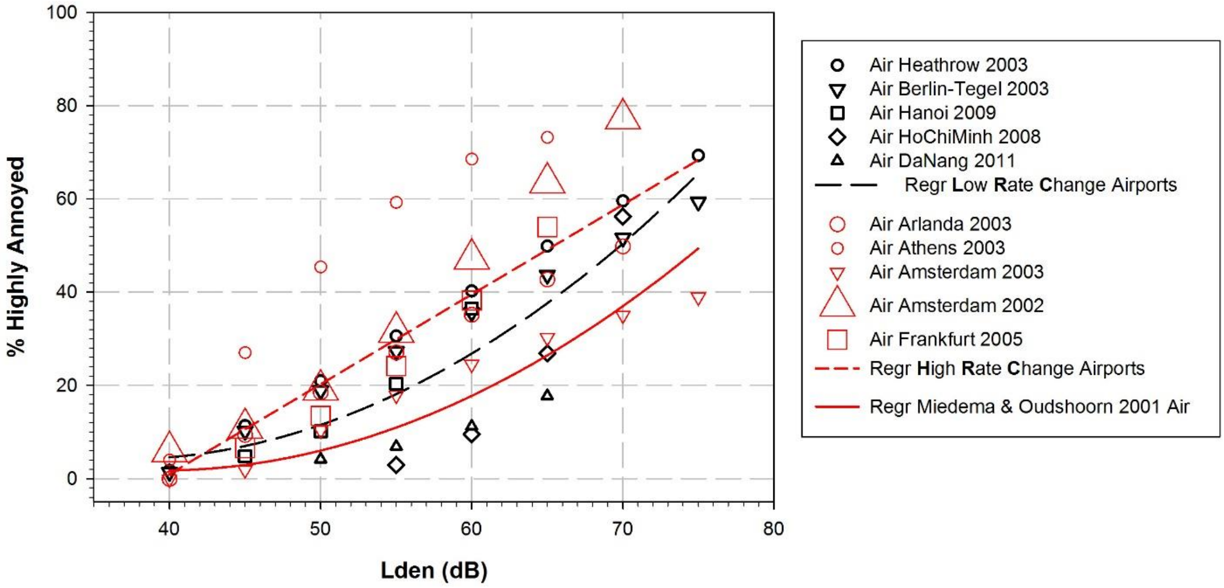

Figure 2: Scatterplot and quadratic regressions of the relation between L_{den} and the calculated % Highly Annoyed for 5 low-rate-change (black data points, black dashed regression line) and 5 high-rate-change (red data points, red dashed regression line) aircraft noise studies, together with exposure-response function by [2] (red continuous line).The size of the data points corresponds to the number of study participants.

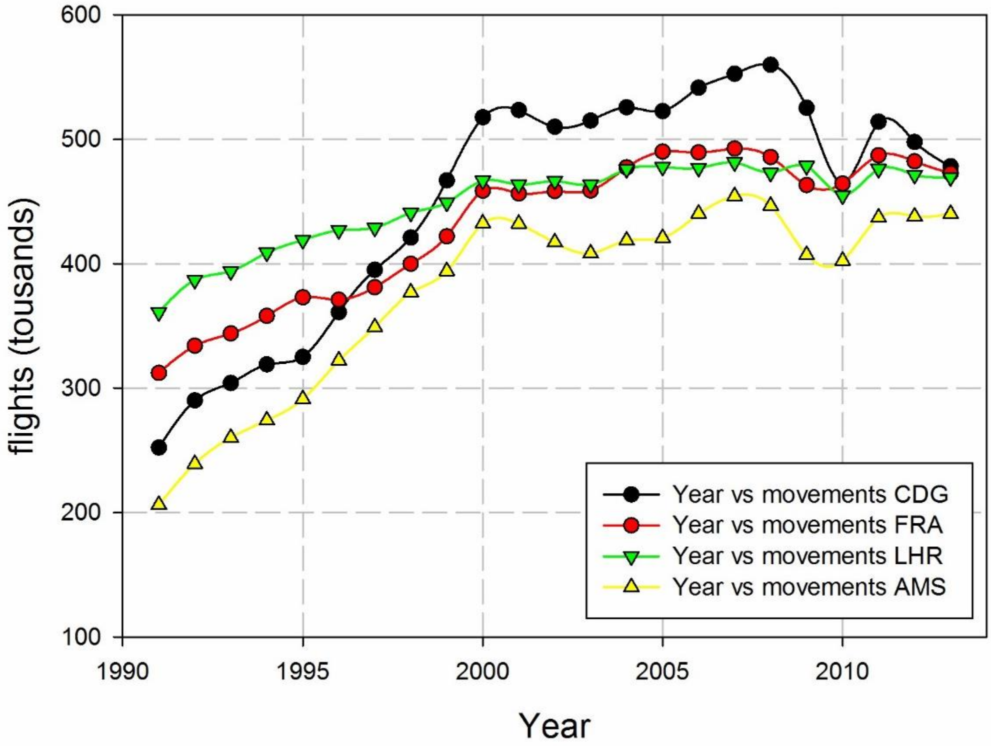

Figure 3: Annual numbers of flight movements at 4 different airports in Europe. CDG: Cologne/Bonn; FRA: Frankfurt; LHR: London/Heathrow; AMS: Amsterdam-Schiphol. Data source: ACI.

GENERAL INCREASE OF THE NUMBER OF AIRCRAFT MOVEMENTS

Many civil airports report an increase of passengers over the last 20 years, most of them report an increase of aircraft movements, too. In the discussions about possible causes of the annoyance trend, several authors – including me - tended to attribute parts of the annoyance trend to the increase in aircraft movements. Today, a closer look at the data shows that the increase of aircraft movements stopped about 2008 at many airports, leading to a decline until 2010, followed by a slight increase (see Fig. 3).

In considering the effects of the number of aircraft movements on annoyance, we must acknowledge that a number term is already included in the L_{pAeq} type of level descriptions. The common energy equivalent continuous sound level assumes that each doubling or halving of the numbers of noise events is equivalent to a 3 dB increase or decrease in average sound levels (k=10). In his analysis of 7 aircraft noise annoyance studies performed between 1961 and 1976, [12] concluded that there is much variability between studies, and if we assume any equivalence between numbers and levels at all, a smaller k-Factor would fit somewhat better to the annoyance data. In contrast to that, the ANASE study ([13], chapter 9.18) concluded that a k-Factor of >20 would be more appropriate, because "People are more sensitive to increased aircraft numbers than assumed by LAeq" ([14], p. 8). The authors of ANASE suggest that there would be no trend in aircraft noise annoyance over time in case the number of movements would be given more weight in the L_{pAeq}-formula. The recent study [14] compared 32-39 aircraft noise surveys (1973-2015) with respect to the total number of flights at the surveyed airports and concluded that CTL-values (i.e., the DNL-value at which 50% of the respondents are highly annoyed) decreased with increasing numbers of flight movements. In other words: especially at large airports with high numbers of aircraft movements, more survey participants were highly annoyed at lower DNL values.

On the other hand, there is at least one case where the simple assumption of a direct relation between the actual number of flights and %HA can be questioned: the socio-acoustic part of the NORAH research group [3] got a considerable increase of the exposure-response curve for different acoustic descriptors and %HA at Frankfurt airport between 2005 and 2011-2013. However, the total number of flights was quite similar at 2005 and 2011, as you may have observed in Fig. 3. The number of flights at Frankfurt Airport increased slightly in the years before 2005, decreased considerably between 2008 and 2010, increased again in 2011, and decreased somewhat between 2011 and 2013. On the response side, the %HA due to aircraft noise at comparable daytime noise levels increased considerably between 2005 and 2011-2013 (Fig. 4), and this cannot be explained by a simple change effect, because already in 2005 the residents expected an expansion of the airport – which took place in October 2011, followed by a night flight ban shortly afterwards.

In my view, the results presented in this section point to an unsolved problem in the discussion of the relation between acoustic descriptors of the noise exposure and community noise annoyance: The assumption of equivalence between effects of levels and effects of numbers has been questioned since the introduction of the L_{pAeq}, and current data remind us to think about alternative concepts of a single acoustic descriptor of the aircraft noise load, e.g., generally increasing the weight of actual numbers of movement, or weighting actual numbers differently at different noise levels (as Fields [12] already proposed in 1984), adding a separate term for the actual number of flights to the L_{pAeq}, or adding a separate term for the increase or decrease of flight numbers during the last year (or years), to name but a few.

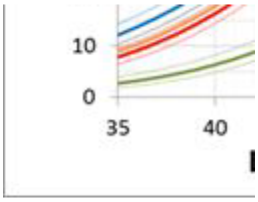

Figure 4: Exposure-response curve for %HA vs $L_{pAeq,06\text{-}22h}$ at Frankfurt Airport 2005 - 2013. Source: [3].

CHANGES IN THE COMPOSITION OF AIRCRAFT FLEETS

The airline industry is continuously exploring ways of efficiently and economically operating their fleets in order to cope with the economic and financial pressures of a competitive operating environment. In response to these challenges, airlines are introducing aircraft into their fleets with lower fuel consumption and geometric characteristics to improve aircraft performance and efficiency. Several parameters can be used in order to describe and compare aircraft types, and these may eventually be used in order to describe the composition of aircraft fleets. With respect to noise in the vicinity of a civil airport, one of the largest contributors to noise is the engine, often associated with seating capacity and wing aspect ratio. Airlines may choose between a few large noisy aircraft and somewhat more smaller less noisy ones. At present, we do not know which choice would be less annoying for residents – given similar annual L_{pAeq} values; however, we should keep an eye on this issue. A rather simple indicator of the fleet composition can be seen in the percentage of large (and heavy) aircraft. Cointin et al. [16] used the ratio of light to heavy aircraft to indicate the aircraft fleet mix. Rylander et al. [17] reported a higher correlation between number of heavy road traffic vehicles (buses and trucks) and high annoyance, compared to numbers and levels in the total group of road traffic vehicles. It seems worthwhile to explore the trend of aircraft noise annoyance over time in relation to the fleet mix of an airport as a whole, or even under certain flight paths.

ATTITUDINAL AND VALUE CHANGES IN THE RESIDENTS

In political contexts, it is sometimes heard that people may have become more sensitive to noise in the last years. Whatever this expression may mean exactly, there is no indication in past noise surveys that personal noise sensitivity generally has increased over time. However, there is an international trend that may be related to the increase of aviation and railway noise annoyance: The World Values Survey [18] reports an increase in emancipative values, they combine "an emphasis on freedom of choice and equality of opportunities. Emancipative values, thus, involve priorities for lifestyle liberty, gender equality, personal autonomy and the voice of the people." This is by far no proof of a connection between the increase of personal autonomy and voice of the people – as stated in surveys – on one side, and the increase of noise annoyance in surveys on aircraft and railway noise at the other. It might be that the effects of an increase in personal autonomy and voice is restricted to the minority of politically active citizens, and does not carry over to annoyance judgments of many residents taking part in noise surveys. However, we should keep an eye on this issue.

In addition, attitudes towards noise sources and towards persons or groups believed to be responsible for noise may have changed within noise affected communities, and such attitudes may have influenced annoyance judgments. In the list of potential moderators or mediators, the social importance and necessity of the source of noise, as well as trust or misfeasance with noise authorities are prominent candidates to study. Unfortunately, there are no longitudinal studies about the development of such social moderators related to aircraft noise over a long time. However, we know that the social importance of aviation has been an important variable since the introduction of jet aircraft, as well as the trust in responsible persons to avoid unnecessary noise in the vicinity of residential areas (e.g., [19], who looked at "considerateness" of authorities and pilots). Until today, trust in authorities or misfeasance often is included in surveys, and it usually shows a significant correlation both with noise levels and annoyance judgments. However, it is rarely operationalized in a comparable manner, which hinders quantitative analyses of possible changes in the course of time. I still like to mention two empirical results:

1) In a longitudinal study at Schiphol Airport [20] found that changes in attitudes (e.g. 'belief that noise can be prevented') measured at time 2 could be explained by aircraft noise annoyance measured at time 1. In other words: The analysis suggests that the prevention belief is a consequence of the annoyance judgment.

2) On the other hand, [21] analysed longitudinal NORAH data (2011-2013) with respect to the temporal order of trust in aircraft noise authorities and aircraft noise annoyance. They found that the relation between trust and annoyance is complex, and both causal directions may be true in case of Frankfurt airport.

CONSEQUENCES THAT CAN BE DRAWN TODAY

We have seen several factors to contribute to the observed trend of the percentage of highly annoyed residents at given noise levels in terms of L_{pAeq}, especially in the case of aircraft noise. We do not have sufficient data to assume a similar trend with respect to railway noise. However, we observed a similar increase of %HA with respect to modern railway noise studies in comparison with the earlier analysis of Miedema & Oudshoorn [2], and the modern road traffic noise studies also show a small increase of %HA at the lower end of the level scale. An obvious consequence to be drawn is to adjust recommendations with respect to intolerable noise levels for aircraft and railway traffic – which will probably be done by the WHO Guideline Development group in 2017. In addition, it seems recommendable to distinguish between low rate and high rate change airports.

With respect to aircraft noise, we found the largest increase in noise annoyance in areas of low and medium sound exposure (in terms of L_{pAeq}). This increase may be related to changes in the estimation of residential sound levels which seem to be more precise today than at earlier times, especially at lower aircraft sound levels, allowing for study designs which include strata with rather low sound levels. In addition, some early computer programs (1990-2008) are said to overestimate certain continuous aircraft sound levels up to 3 dB, which may have contributed to an underestimation of noise annoyance at such sound levels. As a consequence, I propose to (a) try to estimate the correct sound levels in important earlier studies, and (b) put somewhat more weight to low sound levels in future survey designs about aircraft noise.

With respect to effects of answer scales associated with the ICBEN/ISO annoyance question, there is evidence that numerical 11-point scales are associated with somewhat higher annoyance scores, as compared to verbal 5-point scores. As a consequence, I propose to follow the recommendation of Fields et al. [7] more closely: use both scales in the same survey.

In order to help answering question whether the observed trend in %HA is an indication of a general trend in annoyance judgments, I propose to report data on mean annoyance together with data on %HA in future publications.

In view of the unclear relation between the total number of flight movements and annoyance, it seems necessary to look into this issue at a more detailed level, e.g. considering the separate effects of heavy vs. light aircraft (and/or other indicators of the aircraft fleet composition), and potential contributions of the structure of flight events over time (e.g., the “intermittency ratio” [22, 23], or the length and distribution of “pauses”, a concept developed already in the early 1980s [24]).

With respect to changes in attitudes and values in the residents exposed to aircraft noise, the agencies involved in the operation of airports will certainly contribute to a decrease in aircraft noise annoyance if they increase their respective policies of information about noise issues, their openness to the demands of residents, and serious attempts to reduce aircraft noise.

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