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The impact of civil versus military aircraft noise on noise annoyance

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ABSTRACT
The noise characteristics of civil and military aircraft operations differ significantly. For example, the difference in flyover noise from a fighter aircraft and jet plane is easily heard. Civil traffic also tends to be spread out relatively evenly over a day, whereas military training operations can often be characterized by short periods of high activity followed by long periods of comparative silence. Such clearly noticeable differences are disregarded in commonly used noise dose indicators, but may be expected to significantly affect noise annoyance levels within a community. Therefore, an attitudinal survey was conducted by means of telephone interviews in the vicinity of the airports of the Norwegian cities Trondheim and Bodø. While those living near Trondheim's airport are predominantly exposed to noise from civil air traffic, Bodø has a runway that is shared by the city's civil airport and a military airbase. The focus of the study was not on demographic factors, which is typical for an attitudinal study, but instead on acoustical and operational aspects. This study is part of an ongoing research project with the aim of explaining why observed dose-response relationships differ widely from one community to the next.

Keywords: Noise, Aircraft, Annoyance I-INCE Classification of Subjects Number(s): 63.2

1. INTRODUCTION

Noise, by its very definition, is annoying. To quantify an emotion is non-trivial, but ICBEN's "Community response to noise" team has provided researchers with standardized survey question in a variety of languages, to allow noise annoyance results from different studies to be compared internationally (1). This comparison is further facilitated by the wide acceptance and use of standardized units for noise doses, including most notably the Average A-weighted Sound Level L_{AeqT}, and its Day-Night (L_{DN} or DNL), and Day-Evening-Night (L_{DEN} or $DENL$) weighted counterparts.

Data from a large number of separate noise annoyance studies carried out globally has been used to produce dose-response curves, relating L_{DEN} and L_{DN} to annoyance (2). The so-called 'Miedema curves' have been adopted by the European Commission in their 2002 Environmental Noise Directive and references to them in the literature are plentiful. Similar dose-response curves are also presented in ISO 1996-1.

With such tools available, one may expect consistent average results, even if individual responses vary widely. However, the average dose-response curves were created from a large cloud of scattered data points. Dose-response curves obtained at different communities differ significantly, most likely due to local circumstances.

To find which local circumstances affect noise annoyance, many have studied the impact of demographic factors. A large number of these factors, like age, gender, home ownership, employment and education, have been shown to have little or no statistically significant effect on an individual's noise annoyance (3–6). Those variables that do matter, are generally related to the feeling of control (like fear, and ability to cope, e.g. by closing windows), or a personal sensitivity to noise in general.

Such personal factors will however not cause the community's average dose-response curve to move away from the Miedema curves, unless the entire community is on average say highly noise sensitive, or very fearful of aviation. Furthermore, causality is not necessarily as expected. For

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example, concerns about the negative health effects of noise do not cause annoyance; instead it's the annoyance that results in concerns regarding health (7).

It is often forgotten that dose indicators are in many ways poor descriptors of noise. An infinite amount of starkly different noise situations can lead to the exact same noise level. Are a low number of loud events and a continuous presence of low-level noise equally annoying? Although it has been shown that dose levels only contribute about 20 % to an individual's measured annoyance (5,8), this doesn't necessarily mean that noise is not the main cause of noise annoyance.

Operational adjustments like runway alteration can greatly reduce annoyance, even if noise dose levels remain unaltered (9). Noise annoyance was in some studies stronger related to the number of flight events and maximum exposure, than to the average exposure levels (10,11). Shortcoming of noise dose indicators may also explain:

- **The *consistent* discrepancy between recent studies of major European airports and the older EU curve** (12). While these airports are in many ways very similar to each other (and thus cause similar annoyance), they differ significantly from their former selves. Traffic has increased drastically, but individual planes are quieter than when the average exposure-response relationships were established.
- **The different dose-response curves found for separate airports of different sizes** (13). The number of flights is generally lower for smaller airports. This is a factor that is observed by all residents of a community, and therefore its effects can be expected to be visible on the community's average exposure-response relationship.
- **The different dose-response curves found for different types of transport** (2). Both railway and road noise are considered to be less annoying than aircraft noise. Is this purely attitudinal, or is it because these types of noises are very different from each other?

However, it is not obvious as to what would be a better noise indicator, especially since such an indicator will always compromise between descriptiveness and practicality. More importantly, it is unknown which acoustical properties a noise descriptor should depend on, to be as strongly related to annoyance as possible.

To investigate this, annoyance responses from airports that are operationally, and therefore acoustically, very different from another, were compared. An aircraft noise annoyance survey was conducted at two locations: near a civil airport and near a runway that is used for both military and civil air traffic. A multitude of acoustical and operational variables was examined, together with reported annoyance and answers to questions that attempted to identify causes of annoyance. This paper discusses the preliminary results.

The discussed project falls under the Norwegian Aircraft Noise Annoyance Study, which aims to obtain a deeper understanding of the relation between aircraft noise exposure, and aircraft noise annoyance.

2. MATERIALS AND METHODS

2.1 Locations

The surveys were conducted near the airports of the Norwegian cities Bodø and Trondheim. Bodø Airport (BOO) has one runway, which lies along the coast, just a few hundred meters south of the town's centre. This town has approximately 38 000 inhabitants. Trondheim International Airport, called 'Værnes' (TRD) is located circa 35 km east of Trondheim. It has one runway, directly east of the fjord, and is otherwise surrounded by a mostly rural district. The area's population density is highest directly north of the airport in the town Stjørdalshalsen, which has a population of circa 11 000.

There are approximately 65 000 flight operations (i.e. the sum of arrivals and departures) at Trondheim's International Airport per year. Very few of these are of a military nature. The number of civil flights to and from Bodø is approximately 25 % lower than at Trondheim Airport, but its runway is also used by a military air base. Only approximately 13 % of the total number of flights at Bodø is carried out by fighter aircraft, but these flights are decisive for the equivalent noise levels in the area. The presence of military air traffic causes relatively large operational and aircraft type based differences, because:

- Military aircraft are generally noisier than civil aircraft.
- Ninety percent of Military activities take place during working hours (08:00-16:00), while civil activities are more evenly spread out through the day.
- Military training sessions often involve several aircraft, which will take-off or land shortly after each other. Relatively long periods of silence ('recovery periods') then follow such periods of high

activity.

Both airports experience on average 2 to 3 flights per day during the period from midnight to six in the morning. There are no current plans for major changes in airport activity near Trondheim, but in the coming years all military flights will be moved from Bodø to another airbase.

2.2 Questionnaire

The questionnaire included the Norwegian versions of both standardized 5- and 11-point scale noise reaction questions as proposed by ICBEN (1) and ISO15666. Respondents were requested to think about the last twelve months and to only consider noise from air traffic. Respondents were also asked:

- during which period of the day and which season they were most annoyed by aircraft noise
- how often they woke up from aircraft noise during the night
- how annoyed they were by aircraft noise at night on the 11-point ICBEN question scale
- what type of flight activities they considered to be especially annoying (open question)

Additionally, information concerning age, gender, and house ownership was collected. Respondents were asked how long they had lived at their current address, if they were generally at home during the day, whether they had work related to the airport's activities, and if they had expressed themselves as being annoyed about aircraft noise publically or by contacting the airport.

2.3 Population Sample

Telephone interviews were conducted during spring 2014 by professional interviewers from Ipsos MMI until at least 300 full responses were obtained for each location. For practical reasons, residents were randomly selected from existing subdivisions of the local municipalities that were at least partly located within the 55 dB day-night average sound level contour. This simplified the selection work, but also yielded respondents with lower aircraft noise exposures.

A total of 3468 telephone numbers were called, out of which 49 % (1699) persons answered. No attempt was made to redial those that did not answer the first time around. Of those who answered, 39 % (667) were willing to take part. Out of these, 65 were screened out because the respondent did not live in one of the selected areas, was under 16, or had moved to the current address less than 12 months ago. None of the interviews were aborted before completion. Table 1 shows a statistical summary of the respondents that completed the interview.

Table 1 – Statistical summary of the population sample

	BOO	TRD	Total
# complete interviews	302	300	602
male vs female	51 % vs 49 %	49 % vs 51 %	50 % vs 50 %
age range (average age)	16-96 (57)	16-92 (59)	16-96 (58)
is usually home during day	52 %	57 %	55 %
has airport related work	9 %	9 %	9 %
has ownership of home	92 %	91 %	92 %
has previously expressed annoyance	4 %	3 %	3 %

2.4 Noise Calculations

Noise exposure levels and related operational parameters were calculated with NORTIM (NORwegian Topography Integrated Model). NORTIM's calculation core is originally based on INM (Integrated Noise Model) version 4 as developed by the FAA, but has been significantly improved regarding both calculation speed and accuracy. NORTIM has been specifically designed to take into account the effects of local topography on noise propagation.

The flight journal containing all flight activities was obtained directly from the Air Traffic Control towers of both locations for the 12 months preceding the telephone interviews (May 2013 to April 2014). This ensured that calculated noise exposures corresponded with the period respondents were asked to consider. The addresses of the respondents were matched with geographical coordinates provided by the Norwegian Mapping and Cadastre Authority. Observer points were defined to be 4 m above ground level.

2.5 Data Analysis

2.5.1 Dose-response

Answers to the ICBEN 5-point verbal scale questions ($A_{5\text{-pt}}$) were coded with integers from one to five, where one stood for 'not at all annoyed'. The following equation shows how these and the 11-point numeric annoyance answers ($A_{11\text{-pt}}$) were converted to annoyance scores for each individual.

$$\mathrm{AS}_{5\text{-pt}} = 20\mathrm{A}_{5\text{-pt}} - 10 \qquad \mathrm{AS}_{11\text{-pt}} = 10\mathrm{A}_{11\text{-pt}} \tag{1}$$

This means that the 5-point verbal scale was specified by mid-points rather than end-points.

For each 5 dB interval of L_{DN}, the percentage of highly annoyed respondents was calculated for both questions ($\%\mathrm{HA}_{5\text{-pt}}$ and $\%\mathrm{HA}_{11\text{-pt}}$). For the 5-point scale, those who answered 'very' or 'extremely' were counted as highly annoyed. For the 11-point scale, the answer had to be 8 or higher to meet the 'highly annoyed' selection criteria. There is no standard method for combining the two scales, so further analysis was based on the 11-point scale only. An extended analysis showed that the answering scale used had no statistically significant impact on the percentage highly annoyed.

The Community Tolerance Level principle is based on the idea that noise annoyance should increase at the same rate as the duration-adjusted loudness of exposure. The CTL is the day-night average sound level at which half of the people of the community describes themselves as highly annoyed, and it can be used to calculate whether the community is above or below average annoyed, and by how many dB. The community specific fit on the effective loudness function (or 'CTL fit') was calculated by the method described in (14) for both airports, using the centre points of the 5 dB L_{DN} intervals together with the corresponding values for $\%\mathrm{HA}_{11\text{-pt}}$, which where weighted according to the number of respondents in each interval.

By analysis of the TNO/Miedema dataset for all types of transport noise, annoyance score for aircraft noise has been found to be approximately linearly related to L_{DEN} data within the interval $45 < L_{\mathrm{DEN}} < 75$:

$$\mathrm{AS} = 1.58(L_{\mathrm{DEN}} - 33.7) \tag{2}$$

Differences between L_{DEN} and L_{DN} are negligible for the studied airports, so the equation was found to also hold for L_{DN}. Similarly to the CTL concept, this average AS function can be shifted by a community specific value (ΔAS) along the L_{DN} axis to obtain a better fit for the response data at a specific location. The value of ΔAS was determined for both locations using a least squares method and weighted averages.

Furthermore, Generalized Linear Model (GLM) analysis was used to determine the impact of different noise variables on the responses. Instead of using a 'logit' link function (logistic regression), a 'log log' link was chosen. Both links are suitable for a binomial distribution of the HA outcome variable (respondents are either highly annoyed, or not), but 'log log' makes the GLM an analogous, but more general variant of the CTL model, with a slope that is variable instead of fixed. The log log GLM model is defined by the following formula:

$$\mathbf{X\beta} = \ln(-\ln p) \tag{3}$$

where $\mathbf{X}$ is a matrix of independent variables, $\boldsymbol{\beta}$ a vector of unknown parameters, and p the probability that someone is highly annoyed. This probability defines the percentage highly annoyed: $p = \%\mathrm{HA}$.

The impact of noise variables was tested by constructing a GLM for each variable, using only that specific variable to construct $\mathbf{X}$. The Akaike information criterion (AIC) values of the obtained models were then compared to each other, to determine which model provided the best fit (had the lowest AIC). The units were tested again, to see if a model based on this particular unit alone, was of higher or lower quality than an extended model based on this unit and L_{DN} together

Generated dose response curves were also compared to the relationship between L_{DN} and percentage highly annoyed as found by Miedema et al. in (2).

$$\%\mathrm{HA}_{\mathrm{Miedema}} = -1.395\times10^{-4}(L_{\mathrm{DN}}-42)^3 + 4.081\times10^{-2}(L_{\mathrm{DN}}-42)^2 + 0.342(L_{\mathrm{DN}}-42) \tag{4}$$

2.5.2 Specifically annoying flight activities, time of day and season questions

The respondents were asked which airport activities they considered the most annoying, and during which season and period of the day they were most annoyed by aircraft noise.

Most of the respondents' answers to the open question concerning flight activities mentioned an aircraft type (e.g. F-16) or aircraft type category (e.g. jet aircraft). Therefore, it was determined which aircraft type category (helicopters, jet aircraft, small planes, turboprop planes, and fighter aircraft) produced the greatest contribution to the total L_{DN}. The calculated results were then compared side-by-side with the answers from the respondents.

To avoid asking for a higher level of detail than people are conscious of, people were asked to identify one out of five periods for which there are commonly used and unambiguous Norwegian words. These periods were 06:00 to 09:00 ('morning'), 09:00 to 12:00 ('forenoon'), 12:00 to 18:00 ('afternoon'), 18:00 to 23:00 ('evening'), and 23:00 to 06:00 ('night'). For analysis of this data, a summary was made of how frequently a period was named.

Additionally, the categories 'morning', 'forenoon' and 'afternoon' were merged into a 'day' category to allow some form of comparison with L_{DEN}. To check how weighting used for L_{DEN} calculations (+5 dB for evening and +10 dB during for night) compares to the given responses, the relative contributions to L_{DEN} of noise during the day (C_d), evening (C_e) and night (C_n) were calculated from yearly averages of $L_{eq\text{-}day}$, $L_{eq\text{-}evening}$ and $L_{eq\text{-}night}$, where:

$$10^{L_{den}/10} = C_d + C_e + C_n \tag{5}$$

so that

$$C_d = \frac{12}{24} 10^{L_{eq-day}/10} \qquad C_e = \frac{4}{24} 10^{(L_{eq-evening}+5)/10} \qquad C_n = \frac{8}{24} 10^{(L_{eq-night}+10)/10} \tag{6}$$

For each address, it was determined which of these contributions was greatest, and therefore during which period each respondent was expected to experience the most noise annoyance. These were then compared to the answers given by the respondents.

Answers to the question regarding seasons were directly compared to data indicating the relative noise exposure during each month.

3. Results

3.1 Dose-response

Figure 1 and Figure 2 show the mean annoyance scores for each 5-dB bin of L_{DN}, together with box-and-whisker plots for the 11-pt scale annoyance scores, the average and location fitted AS functions, and the number of respondents belonging to each bin. The ends of the drawn whiskers indicate minima and maxima. According to the AS fitting, respondents from the airport with mixed traffic tolerate an 8.1 dB higher L_{DN}, before being equally annoyed as predicted by the average values. This value was 1.6 dB lower than the ΔAS obtained for the civil airport. In other words, people living near BOO are a little less annoyed than those living near TRD are.

Figure 3 and Figure 4 show $\%HA_{11\text{-}pt}$ for each 5 dB bin of L_{DN} together with error bars showing the expanded uncertainty of each data point. At both airports, the $\%HA_{11\text{-}pt}$ was found to be significantly below the Miedema average (solid red line). The largest difference between locations was the presence of highly annoyed respondents near the mixed traffic airport for lower values of L_{DN}.

The CTL method produced an excellent fit (grey dashed line) for the civil airport, but underestimated the annoyance for $L_{DN} < 60$ dB at the mixed traffic airport. Obtained CTL scores (81.3 dB for the airport with mixed traffic and 82.3 dB for the civil airport) were significantly above 73.3 dB, the average found by Fidell et al. (14).

A log log GLM fit for the whole dataset with L_{DN} and location as the only variables (green dotted line) predicted higher percentages at low levels of noise for the airport with mixed traffic. For both locations, the regression coefficient of the GLM fit was much smaller than the coefficient of the CTL model, which assumes that annoyance will increase at the same rate as the duration-adjusted loudness of exposure.

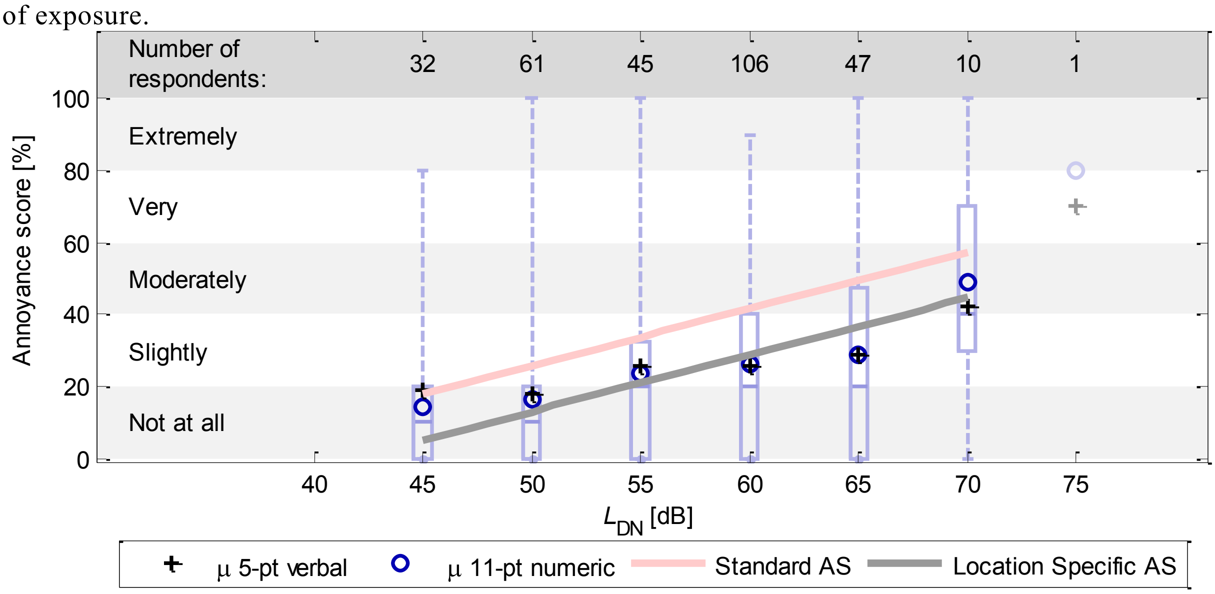

Figure 1 – Annoyance score vs LDN for the airport with mixed traffic (BOO)

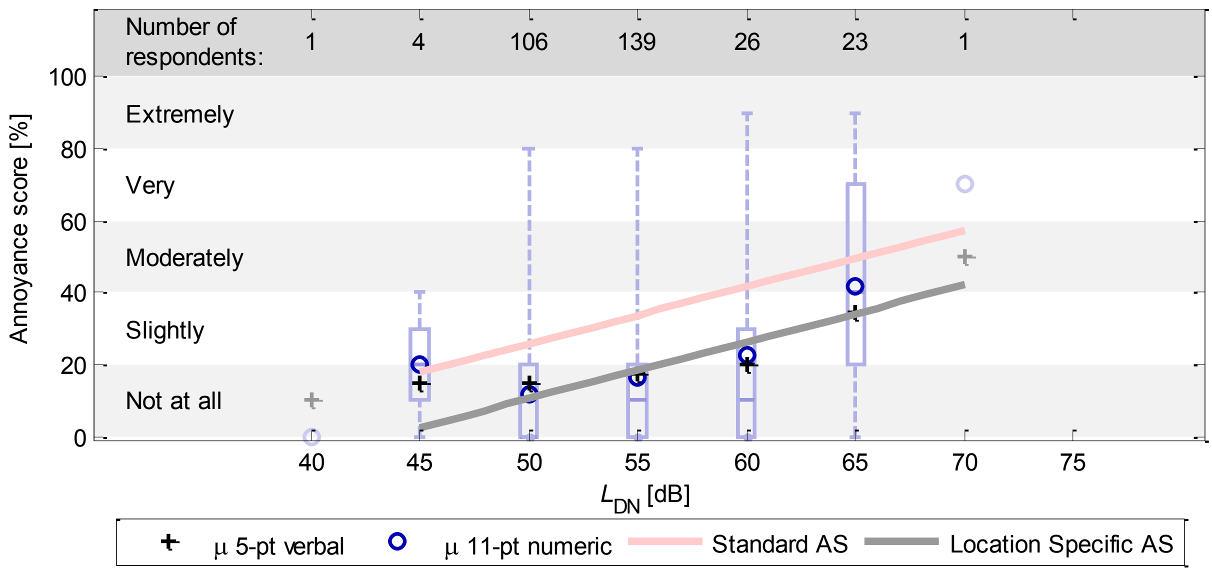

Figure 2 – Annoyance score vs LDN for the airport with civil traffic (TRD)

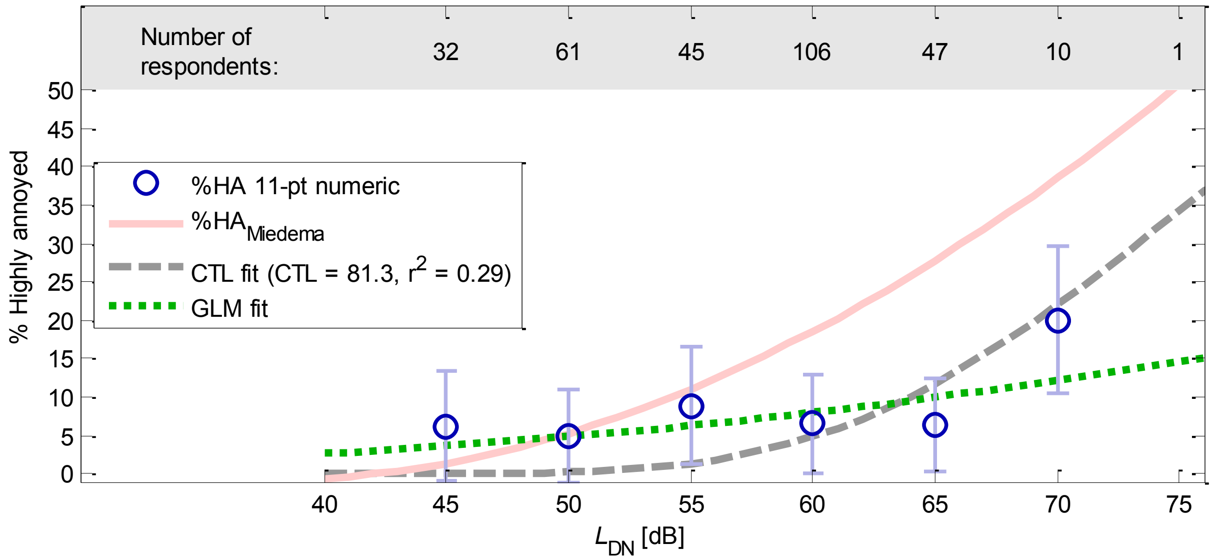

Figure 3 – Percentage highly annoyed vs L_{DN} for the airport with mixed traffic (BOO)

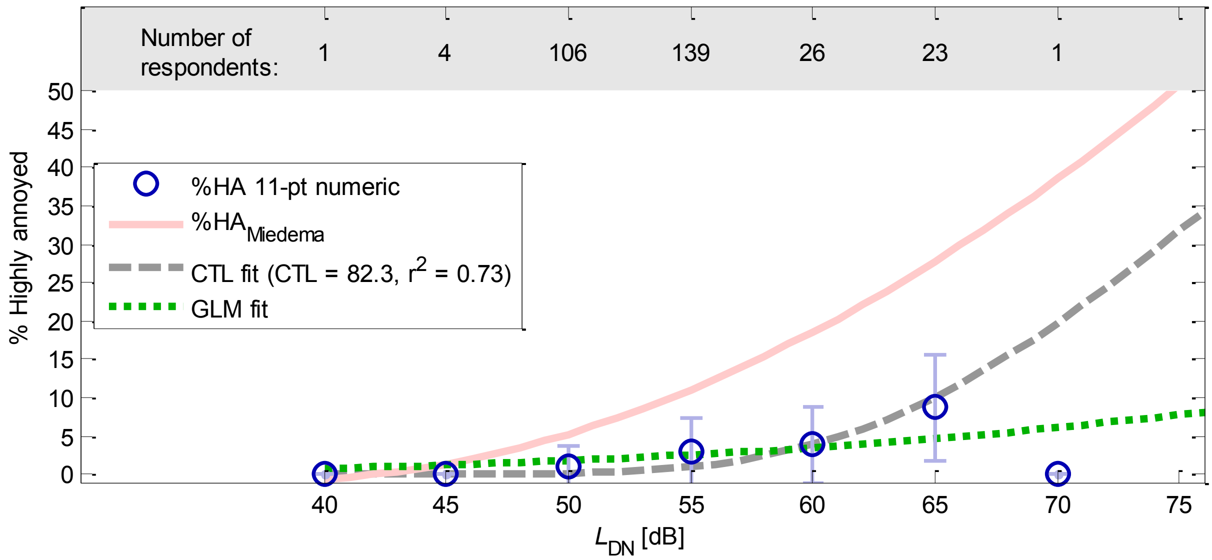

Figure 4 – Percentage highly annoyed vs L_{DN} for the airport with civil traffic (TRD)

Table 2 shows the results obtained from the GLM analyses.

Table 2 – Time of day during which the most annoyance is experienced

Parameter	AIC for GLM with only this parameter	Statistical Significance	AIC for GLM with this parameter and L_{DN}	Statistical Significance
L_{max}	229	<0.01	230	<0.01
L_{5AS}	230	<0.01	232	0.02
$N_{events>100dB}$	231	<0.01	233	0.03
$N_{events>80dB}$	233	<0.01	235	0.1
$N_{events>90dB}$	233	<0.01	235	0.1
$L_{Aeq\text{-}day}$	234	<0.01	235	0.1
$N_{events>40dB}$	234	<0.01	229	<0.01
L_{Aeq24h}	235	<0.01	235	0.1
Location	235	<0.01	233	0.02
L_{DEN}	236	0.02	238	1
L_{DN}	**236**	**0.02**	**-**	**-**
$L_{Aeq\text{-}evening}$	237	0.02	238	0.7
$N_{events>70dB}$	239	0.07	238	0.8
$L_{Aeq\text{-}night}$	241	0.3	236	0.2
$N_{events>50dB}$	242	0.6	234	0.06
$N_{events>60dB}$	242	0.7	234	0.1

The results were controlled for age, gender, length of residency, home ownership and airport related work, with no effect on the results.

3.2 Specifically annoying flight activities

Approximately 31 % of respondents (124 for the airport with mixed traffic (BOO), and 62 for the airport with civil traffic (TRD)) named at least one flight activity that they considered specifically annoying. Despite the open form of the question, all but eight answers could be categorized into one or more of the following categories: helicopters, jet aircraft, small planes, turboprop planes, and fighter aircraft. Only 39 respondents specifically said they did not find certain flight activities more annoying than others. The remaining 377 respondents did not answer the question.

Where possible, answers were placed into one or more of the earlier mentioned aircraft type categories. When these answers were compared to the aircraft category that had been identified as contributing most to L_{DN} for each particular respondent, 65 % matched.

At BOO, 76% percent of respondents provided an answer that corresponded to the expected category. All the others named fighter jets as being specifically annoying, even though at their home address noise from either jet aircraft or turboprops dominated.

The fraction of matched answers was significantly lower at TRD (41 %). Surprisingly, 51 % of them also named fighter jets as being most annoying; even though there were in total only 18 fighter aircraft operations at TRD executed within the past 12 months. The rest identified turboprops, helicopters or small aircraft as being the most annoying.

3.3 Effect of time of day

As much as 63 % of respondents did not provide an answer to the question regarding time of day, and 17 % of respondents did not feel that their annoyance due to aircraft noise was more pronounced during a certain period of the day. Table 3 shows a summary of how the remaining respondents answered the question.

Table 3 – Time of day during which the most annoyance is experienced

Answer	BOO (n = 116)	TRD (n = 77)
06:00 to 09:00	6 %	29 %
09:00 to 12:00	30 %	4 %
12:00 to 18:00	41 %	44 %
18:00 to 23:00	17 %	16 %
23:00 to 06:00	5 %	8 %

At the location with mixed traffic, BOO, daytime noise was calculated to be predominant for all but four addresses. For these residences night-time noise was found to contribute most to the calculated L_{DEN}. Of their four respective respondents, only two answered the question, and both chose daytime. The great majority (78 % percent) of the 116 respondents that provided an answer chose the period that had been calculated to contribute most.

At the civil airport, TRD, despite the low levels of traffic during the night, night-time noise was calculated to contribute most to the calculated L_{DEN} for all addresses. However, as Table 3 shows, only 8 % of those who answered the question agreed.

3.4 Effect of season

Most respondents did not provide an answer (63 %), or did not specify a preference (14 %), when asked during which of the seasons they were most annoyed by aircraft noise. The majority of those who did answer chose the summer season. The other responses were approximately equally spread over the remaining seasons. See Table 4.

Table 4 – Season during which the most annoyance is experienced

Answer	BOO (n = 81)	TRD (n = 58)
Winter	16 %	1 %
Spring	14 %	5 %
Summer	57 %	90 %
Autumn	14 %	3 %

4. Discussion

4.1 Dose-response

At both locations, annoyance due to aircraft noise was significantly lower than predicted by the Miedema curve. This was also confirmed by high CTL scores and ΔAS values for each community.

The percentage highly annoyed at a certain L_{DN} was found to be significantly different for the different types of airports, but comparison of annoyance scores did not support this conclusion. The clearest difference between locations was an increased percentage of highly annoyed at lower levels of L_{DN} for the airport with mixed traffic. This may be explained by the presence of fighter jets in this area. These aircraft are responsible for relatively high noise levels per event in areas where L_{DN} was low in comparison.

The observed importance of L_{max}, L_{5AS} and the number of noise events above a relatively high threshold supports this reasoning. The fact that combining these units and L_{DN} actually lead to worse performance of the models indicates that the effects of these factors do not add up. Instead, one could expect overall annoyance of residents to depend on whichever dominates at their home: a general build-up of noise, or the occurrence of especially disturbing loud events. Further research is required to determine if the predictive power of each unit changes with the difference between them, or if there is a noise level threshold above which the noisiest events always becomes the main cause of annoyance. Evidence for the suitability of such a segmented noise predictor has been provided before, when it was found that the number of events is more significant than maximum or energy weighted levels for small airports with less than 70 flights per day (11).

Overall, the difference between the annoyance levels found at the two airports was however unexpectedly low, especially considering the difference in the type of noise respondents were exposed to. At both locations, respondents tolerated approximately 8 to 10 dB more noise, before being equally annoyed as predicted by the Miedema curve. This is opposite to the findings of a recent study in Frankfurt, where respondents were 10 dB above average sensitive to noise (14,15). A difference of almost 20 dB between studies is enormous, and clearly undermines the use of standard curves to predict noise annoyance.

The authors behind the CTL method concluded that CTL values appear to be little influenced by airport size per se, but could be related to airport type (14). This study has shown that the presence or lack of military noise is not enough to discriminate between types of airports. Classifying both Frankfurt and TRD equally as 'civil airports' would clearly not be sufficient from an annoyance point of view. Of course, with Frankfurt being Europe's third largest airport and TRD being a medium sized regional airport, there are plenty of operational and acoustical differences between the two locations that may have caused the difference in annoyance. Examples of such differences are the number of events, time between events, and night-time activity. More research is required to see if airports can be classified by such acoustical factors.

By observing very low levels of annoyance, this study provides counter evidence for a general rise in annoyance over time. While some have observed such a trend, there is no conclusive evidence that people's tolerance for noise is waning (16–18).

4.2 Specifically annoying flight activities

Respondents, when given the choice, tend to separate airport activities by the type of aircraft involved. Clearly, the aircraft that contributes most to the locally present $L_{DN,}$ is not necessarily considered the most annoying. Very loud events like fighter aircraft operations will be remembered as specifically annoying, even if they occur extremely infrequently. This result indicates again that the impact of maximum levels is not properly accounted for in energy weighted dose units.

4.3 Effect of time of day

The two periods that most respondents at the airport with mixed traffic chose, are also by far the noisiest periods of the day, as this is when fighter aircraft activity is highest.

However, the significantly higher annoyance during morning hours at the civil airport cannot be explained by aircraft activity alone. The number of events is actually 35 % lower between 06:00 and 9:00 than between 09:00 and 12:00. Neither L_{DN}, nor L_{DEN}, differentiates between these periods.

Results of the comparison between the chosen period and the period that contributes most in the calculation of L_{DEN} suggests that for the civil airport L_{DEN} overestimates the impact of night traffic. Even if all respondents that pointed out the morning period are added to the night-time category to compensate for the one-hour difference between both definitions for 'night', the majority still felt more annoyed during the remainder of the day.

As evening noise never dominated at either location, results are very similar if this analysis is done for L_{DN} instead of L_{DEN}.

There is a firm foundation for the 10 dB night-time penalty used in the calculation of L_{DN} and L_{DEN} (19). However, at the civil airport of this particular study, almost half of the night flights occur between 23:00 and midnight. Overall results indicate that separating 24-hours into day, evening and night periods might not provide sufficient resolution for a noise annoyance indicator. However, it may not be feasible to obtain weighting factors for each hour in an international context, as daily activity patterns differ widely for different cultures.

4.4 Effect of season

Aircraft noise annoyance is known to be higher in warmer seasons (20). This is most likely because during this time of the year, people have their windows open and spend more time outdoors. In case of the studied Norwegian locations here, factors like extreme changes in length of day and the presence of sound insulating snow during winter, may be expected to have an additional effect.

While aircraft noise exposure was relatively constant during the year for the civil airport, fighter aircraft activity at the mixed traffic location was three times higher in September than in other months. In the Norwegian language all of September is generally considered to be an autumn month and yet, very few respondents rated autumn as the season during which they experienced most annoyance.

Short-term increases in traffic contribute to calculated L_{DN} values, especially when noise policy procedures require calculations to be done for the period during which activity is highest. Former research has already shown that short periods of significantly increased noise, have surprisingly little impact on noise annoyance (21). This study shows that the effect of season on annoyance is possibly more significant than short-term noise increases. L_{DN} calculations can therefore be expected to underestimate the effect of policies that lead to reduced air traffic during summer.

5. Conclusion

Two annoyance surveys were carried out to assess long-term annoyance induced by aircraft noise near an airport with civil traffic only, and near an airport with mixed military and civil traffic. The annoyance response at a given L_{DN} was below average and relatively similar for both locations.

Descriptors of the noisiest events, like L_{max}, L_{5AS} and the number of loud noise events, were more strongly related to the observed noise annoyance than the energy-weighted units L_{Aeq24h}, L_{DN} and L_{DEN} are.

Answers to indirect annoyance questions indicate that L_{DN} and L_{DEN} do not adequately take into account:

- the effect of season on annoyance
- the annoyance difference between early night flight activities and flights during the small hours
- the annoyance caused by a relatively low number of loud events

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