HARRIS MILLER MILLER & HANSON INC.
77 South Bedford Street
Burlington, MA 01803
T 781.229.0707
F 781.229.7939
www.hmmh.com

TECHNICAL MEMORANDUM

Subject:	Review of Studies that Address Effects of Helicopter Noise
Prepared by:	Nick Miller
Date:	February, 32015
Reference:	HTO Phase 3, Noise Study, HMMH Project 307161.000 Task 1

From the early 1970's to today, researchers have struggled to understand why helicopters generate so many more complaints than do other aircraft at similar levels of noise exposure. This result applies when the sounds are characterized by cumulative noise exposure metrics based on the sound exposure level, SEL, of single aircraft flyovers[1]. SEL is constructed to account for both the level of a noise event and its duration. Figure 1 illustrates how this is accomplished, using a plot of the A-weighted sound level for a representative aircraft overflight. The shaded area represents the sound energy from the single overflight. In simple terms, the SEL of such an event is the steady-state level with a one-second duration that would include the same amount of noise energy as the actual overflight, as shown.

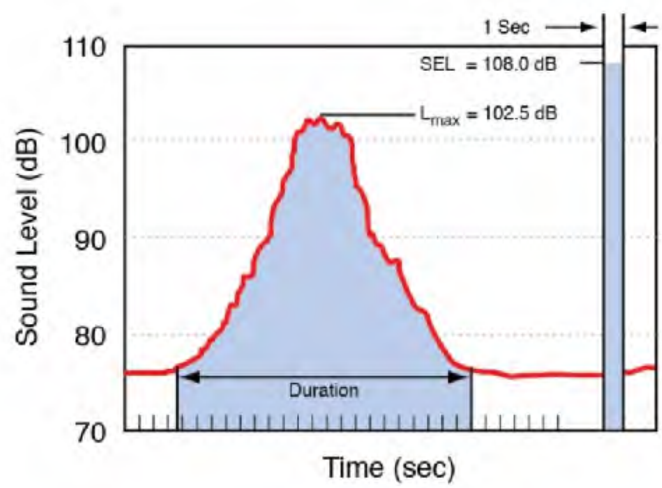


Figure 1 Typical Time History of an Aircraft Overflight, Showing Calculation of SEL

This memorandum reviews may of the studies in the literature that have attempted to understand whether use of this metric for helicopters should include an "adjustment" for helicopters, and whether there are reasons why alternative metrics may be more appropriate.

1. LABORATORY VERSUS FIELD STUDIES

Many of the studies cited here are based on laboratory, rather than field or *in situ* studies. Laboratory studies are generally designed to duplicate specific aspects of a more complex situation. They attempt to "control" a number of factors so that other specific factors of interest can be isolated and examined. However, laboratory studies of human behaviors can also control or eliminate important relevant aspects of the actual *in situ* or field situation and incorrectly assess the human behaviors under consideration.

[1] These cumulative exposure metrics are the day-night average sound level, DNL, and equivalent level, Leq.

One clear example of incorrect laboratory assessments was the early studies of the effects of aircraft noise on sleep. Some reviews of these studies [1] and *in situ* studies conducted in people's homes [2][2] demonstrated significant differences between awakening in the laboratory versus awakening in one's own bedroom. These differences were made evident by a review of sleep studies provided by the Federal Interagency Committee on Aircraft Noise (FICAN) [3]. Figure 2 is taken from Reference [3] and clearly shows how much more easily awakened laboratory test subjects were at a given noise level using the relationship that was recommended by FICON [4] which included considerable laboratory data [5]. The curve labeled FICAN 1997 however was based solely on data acquired from field studies.

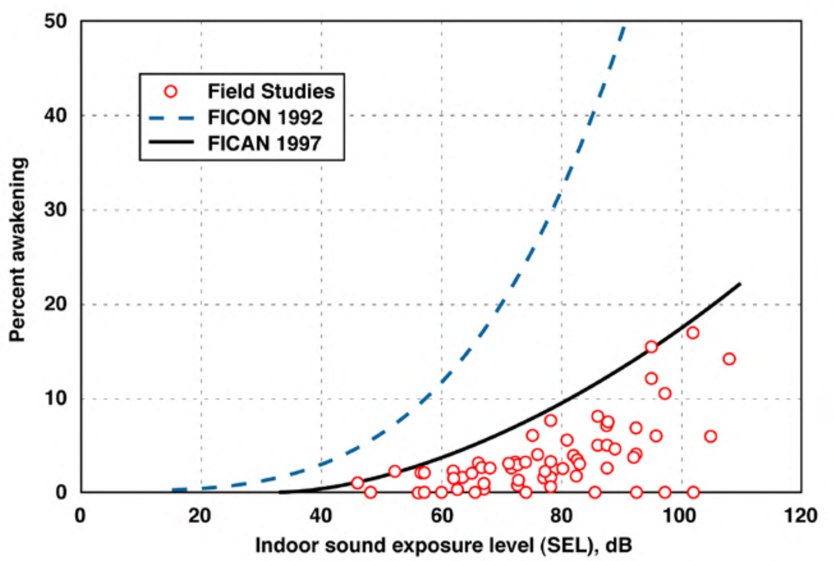


Figure 2 Relationship of Awakening to SEL, Laboratory (FICON 1992), Field (FICAN 1997)

This example suggests only that human reactions to sound are likely to be very complex, and that results from any particular study or type of study need to be interpreted and applied with caution. Laboratory studies can reveal effects of noise on people that cannot be efficiently determined in any other way, but what is of most concern when considering the effects on communities is how people in the communities react to the sounds they hear where they live.

2. STUDIES SUGGESTING AN ADJUSTMENT TO STANDARD NOISE METRICS IS APPROPRIATE

2.1 *In Situ* Surveys in the UK in 1993 and Before

Ollerhead [6] reports on several surveys conducted of residents in communities exposed to different types of aircraft noise. Figure 3 summarizes the results.[3] The plotted results are from: [7], [8], [9], [10] and [6][4]. (Logistic curves are fit to the air transport and general aviation survey data.)

[2] These references are examples only; many other studies are available.

[3] At the time of these studies, the UK had chosen to use the 16-hour (0700-2300) equivalent sound level as the primary metric of aircraft noise.

[4] The results from the most recent helicopter noise survey were still under analysis at the time of the Ollerhead Noise Con 93 presentation.

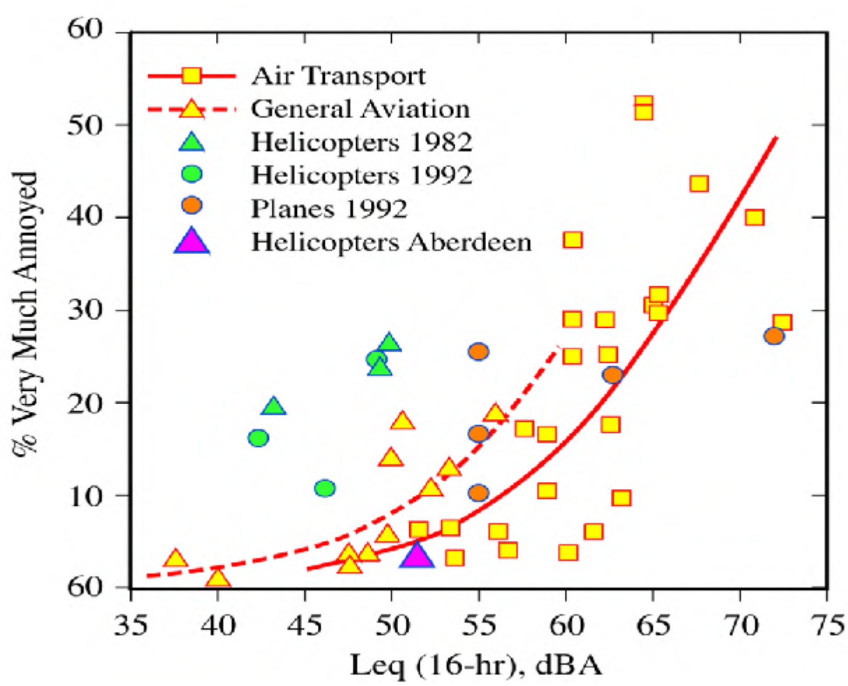


Figure 3 Annoyance Reactions from Various Surveys in UK [6]

Ollerhead offers no final explanation for either the differences between the helicopter noise survey results and the other types of aircraft produced annoyance or for the difference between the results of the 1982, 1992 surveys and the survey conducted at Aberdeen. He does suggest that non-acoustic, attitudinal factors may be at work, including public perceptions of:

- Importance of the flying
- Adherence to routes, noise abatement practices
- Attitudes of the aircraft operators
- Safety of the flying operations

2.2 Controlled Annoyance Studies of Military Helicopter Flyovers

Two studies, [11] and [12] examined reactions of subjects outside in a tent structure, in a trailer and in two different houses to controlled helicopter overflights. Annoyance judgments of various types of helicopters were compared with judgments of constructed A-weighted "ramped" sound levels. The ramping up and down of the sound level was adjusted to have similar level and duration of the helicopter flyover, Figure 4. To adjust the helicopter and ramped annoyance reactions to be equal, at a given SEL, the indoor ramped results needed to be offset upward 5 to 12 dB, the greater adjustment needed when audible rattle occurred. In fact, in one situation when the rattle was considerable, an adjustment of 20 dB was required to equate the annoyance reactions. Outdoors the upward adjustment of the ramped signal was 1 to 5 dB. The differences between the indoor and outdoor adjustments are not surprising. There can be no rattle outdoors, and houses tend to decrease the higher frequency components and emphasize the lower frequency components of sounds. Helicopters have significant low frequency sound energy.

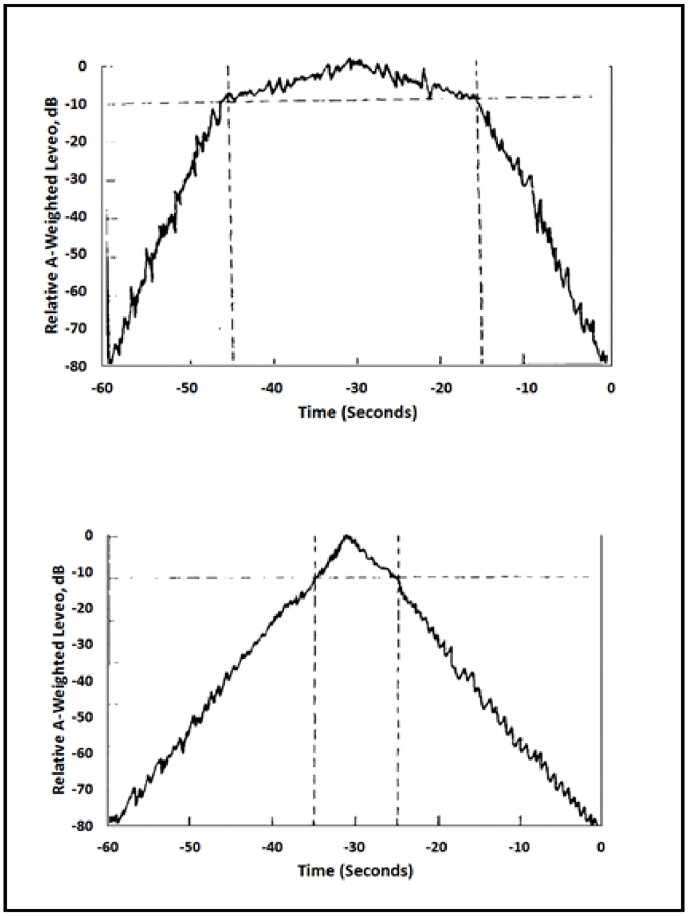


Figure 4 Examples of the Ramped Comparison Signal with Different Durations

2.3 Department of Defense Guidance

For a period from 1977 to 1982, DoD policy for assessing helicopter noise annoyance was based on the concept that the "banging" or "blade slap" that could occur would increase annoyance.

> *"When computing helicopter noise levels using data collected from meters, a correction of +7db shall be added to meter readings obtained under conditions where blade slap was present until and unless meters are developed that more accurately reflect true conditions."[13]*

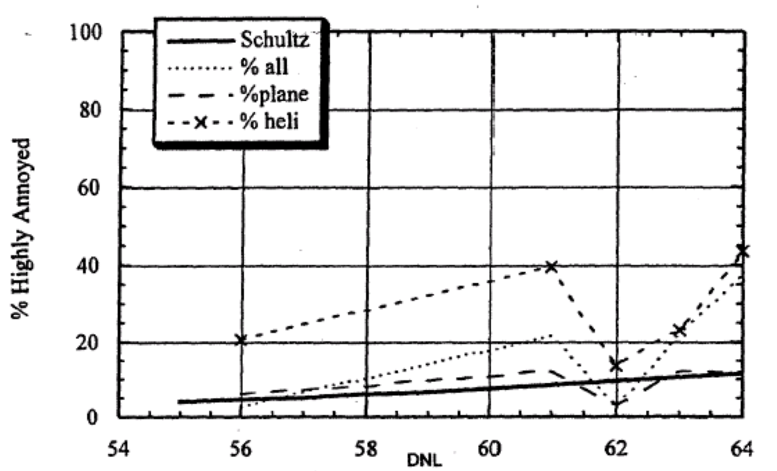
This policy was based on studies like that of Leverton [14] , that used tape recordings of "banging" and "non-banging" helicopters presented at a level of 66 dBA in a background of music at a level of 77 dBA. The study found that the subjects set the level of the non-banging helicopters at 6 dBA above the banging helicopters to achieve equivalent annoyance. However, later studies, described below in Section 4.1, influenced the DoD to reverse policy and subsequent versions of the DoD AICUZ[5] instruction treat the SEL of helicopters without adjustment as the SEL of fixed-wing aircraft are treated.

[5] AICUZ, Air Installations Compatible Use Zone, is an aircraft noise and accident potential study that identifies which areas around a base are compatible with residential use.

2.4 FAA Study Showed Helicopter Noise More Annoying than Fixed-wing Aircraft Noise

Before and during the 1996 Olympic Games in Atlanta, noise measurements and surveys of residents were conducted to determine whether increased helicopter operations affected attitudes towards the neighborhoods in general, the noise levels in the neighborhoods, and the annoyance with specific sources of noise [15]. Though residents did notice an increase in noise level during the Olympic Games, it appeared that the average levels of annoyance with overall noise, with fixed-wing aircraft noise or with helicopter noise did not increase.

The study results, however, do suggest greater annoyance with helicopters than with fixed-wing aircraft. Figure 5, taken from reference [15] shows percent of surveyed residents reporting that they were highly annoyed (the top two categories of a five point scale) by all noise, by helicopter noise, by fixed-wing noise and, for comparison, the values predicted by the "Schultz Curve" [16].[6]



DNL	55	56	57	58	59	60	61	62	63	64
Schultz		4.57					8.49	9.57	10.77	12.11
# at Location		36					37	38	27	16
% HA Overall		2.78					21.62	2.63	22.22	37.50
% HA Aircraft		5.88					12.12	2.86	12.00	12.50
% HA Heli		20.69					39.39	13.51	23.08	43.75

Figure 5 Annoyance as Expressed by Residents Near Dekalb Peachtree Airport

2.5 Comparisons for Natural Settings

Mace *et al* [17] conducted a laboratory simulation to differentiate between three types of aircraft noise common to national parks. Two-hundred sixty-eight participants rated pictures of 40 natural landscapes while listening to natural sounds or aircraft overflight noise. Helicopter noise was perceived as the most disruptive to the national park experience, followed closely by propeller plane noise, with jet airplanes being the least negative of the three noise conditions. Figure 6 graphs the results.

[6] The data in Figure 5 are grouped in the 1 dB intervals of DNL which included 10 or more households.

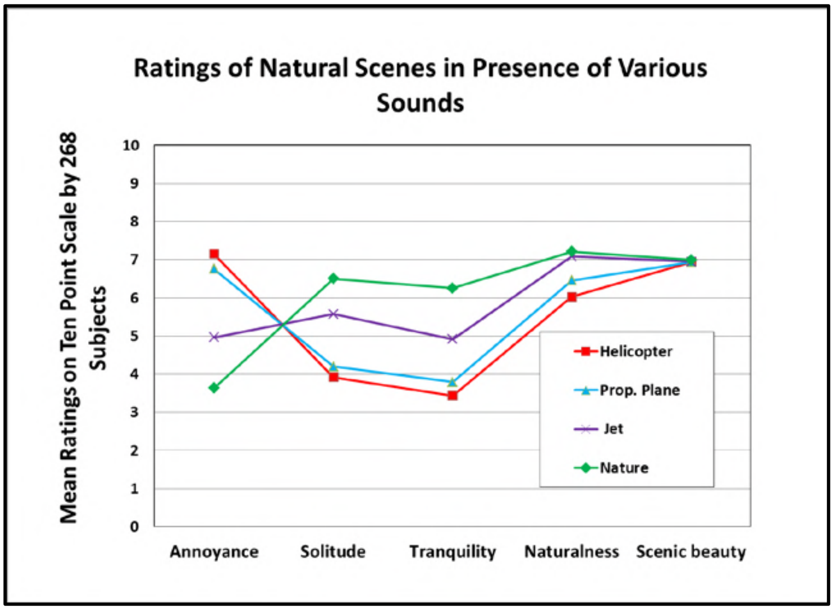


Figure 6 Ratings of Annoyance and Various Affects of Various Sounds on Natural Scenes

2.6 Comparing Helicopters with Fixed-wing Annoyance

Atkins *et al* [18] conducted social surveys in five communities and showed that annoyance responses to helicopters varied community to community. However, in two communities with approximately equal numbers of helicopters and fixed-wing aircraft, though fixed-wing were on average eight decibels louder, annoyance due to helicopter noise was about 2.5 times as large as that due to fixed-wing aircraft.

3. ADJUSTMENT POSSIBLE BUT UNCERTAIN

3.1 NASA *In Situ* Study

A 1987 study of helicopter noise annoyance was conducted through 4880 interviews over 17 days of exposure of 330 respondents living along a military helicopter flight corridor[19]. Unbeknownst to the respondents, the numbers of helicopter flights per day were altered systematically, and telephone interviews were conducted each of the days. The interview consisted of many questions in which annoyance with helicopter noise was buried. For each day, the nine-hour equivalent level was calculated and the results are shown in Figure 7.

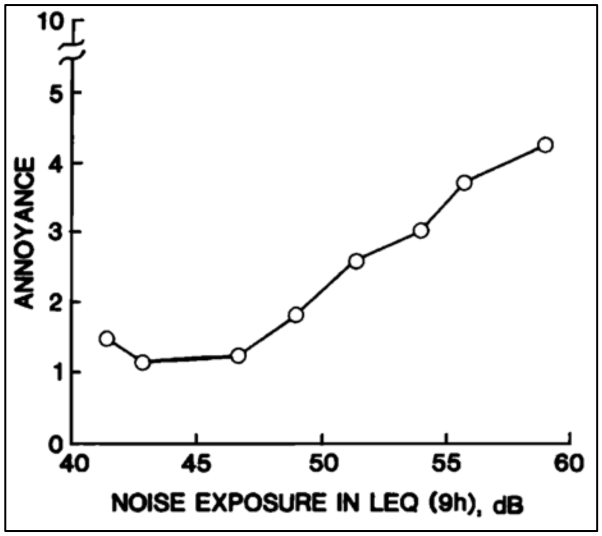


Figure 7 Mean Annoyance Ratings versus Helicopter Produced 9 hour Leq

What is so significant about this study and the result is that respondents were: 1) not aware of the specific nature of the study; 2) not asked to listen for helicopters and judge each one; 3) not comparing helicopter noise with other types of sounds; 3) responding to an entire day's experience; 4) a virtual complete sample of eligible adults; 5) not exposed to any other significant source of environmental noise; and 6) in their homes. These factors and the results argue strongly for SEL as a basic metric of helicopter noise annoyance.

However, the results do not negate the possibility of the need for an adjustment to SEL for helicopters. The study also contained Figure 8. If "highly annoyed" is assumed to include between27% to 29% of the upper part of the annoyance responses [16], then Figure 9 displays where the highly annoyed line would fit.

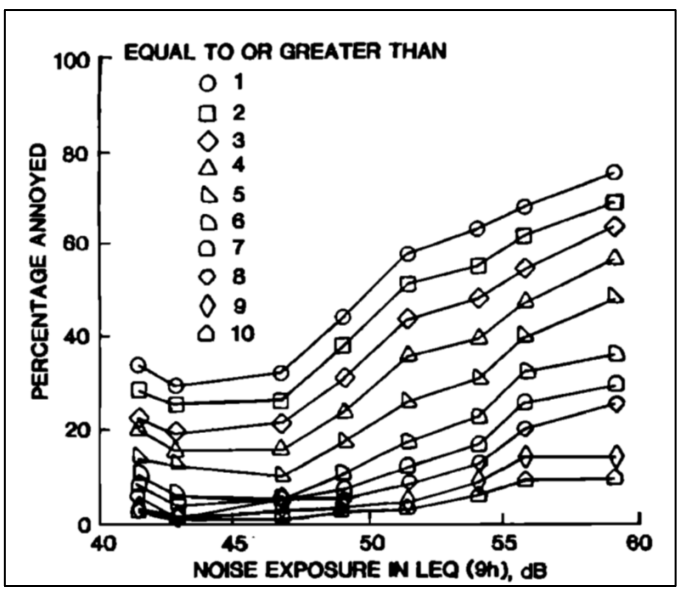


Figure 8 Ten Dichotomizations of the Annoyance Scale

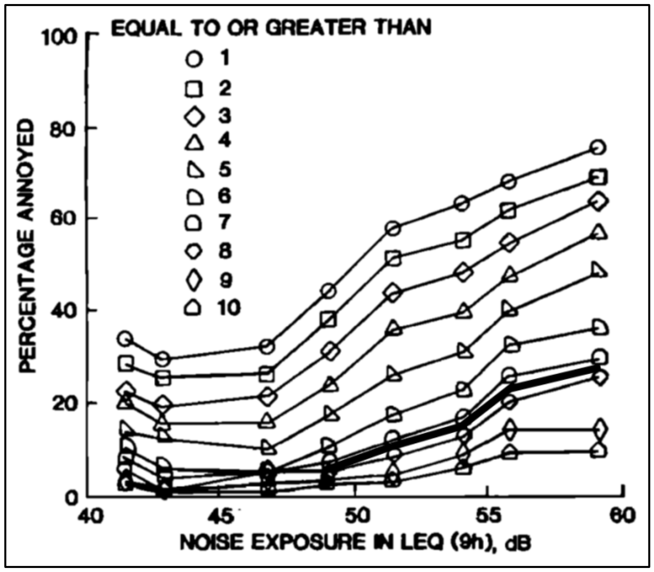


Figure 9 Ten Dichotomizations of Helicopter Annoyance Scale and Estimated percent Highly Annoyed Response

An immediate question is whether this curve can be compared with other published curves of high annoyance. The published curves, though based on the same questions asked in the Fields and Powell survey, are usually asked with only one interview or questionnaire, are intended to reflect the annoyance over an entire year, and are related to annual average day-night sound level, DNL. Fields and Powell recommend not comparing their results with other curves based on annual results [20].

This recommendation is based primarily on 6 concerns:

1. The surveys of annoyance are most often collected with one interview, phone call or mailed questionnaire. Their results (Figure 9) are based on a series of interviews over 22 days of exposure and average reported annoyance increased over that period.
2. The long-term helicopter noise exposure of their subjects is not known.
3. Their best estimate of annoyance as a function of DNL is more than would be predicted by the Schultz curve.
4. The study results focus on one specific source (helicopters) and there is some experience that focusing a question on one source results in responses of higher annoyance than asking about the sources in general. For example, Fields and Powell cite a British survey of road traffic noise in which people were more annoyed about motorcycles than about the sum of all traffic noise sources.
5. When asked how annoyed they were overall for the 8 week period during which the series of surveys occurred, their annoyance responses were higher than the daily annoyance responses.
6. Annoyance responses were weekday, daytime only and hence did not include nighttime or weekend annoyance responses.

- Concern 1 suggests that the study results would over-estimate the annoyance response compared to a one-time survey.
- Concern 2 effects are unknown – annoyance could be higher or lower if the rest of the day were included. If the helicopter events about which the subjects were asked were the only noticeable outdoor events in the full 24 hour day, then an inclusion of quiet times might result in lower overall annoyance. If helicopters continue into the late evening or through the night, reported annoyance could be greater.
- Concern 3 has been true for many years in the case of most aircraft noise annoyance surveys. Most exceed the Schultz curve, Figure 10.
- Concern 4, though likely true, does not seem to be a concern for the present situation at HTO where the primary sources of community reactions are helicopter operations.
- Concern 5 suggests that the daily annoyance reports may underestimate the long-term annoyance reactions.
- Concern 6 also suggests that a survey addressing all times of day and times of year might produce higher annoyance responses unless all other days have similar helicopter operations.

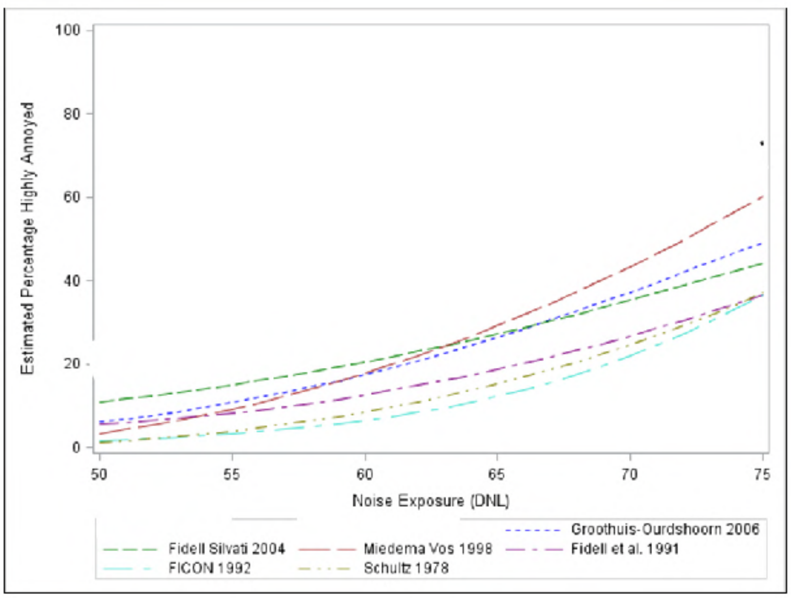


Figure 10 Long-Term High Annoyance Dose-Response Surveys [21][22][23][24][25][26]

Whether or not the comparison is meaningful or valid is, it seems, indeterminate. Figure 11 provides the direct comparison of the highly annoyed relation, Figure 9, with multiple other available long-term highly annoyed relations, plotted against DNL. Differences between the Figure 9 curve and the two curves that are widely used to justify aviation noise and land use compatibility policy are shown [FICON (FAA policy) and Miedema Vos (EU noise assessment)].

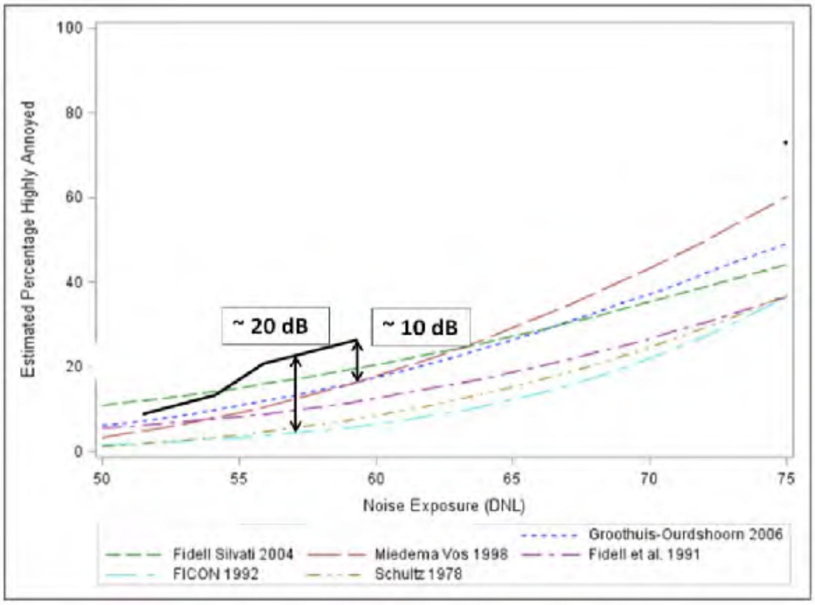


Figure 11 Short-term Helicopter Percent High Annoyance compared with Long-term High Annoyance Dose-Response Surveys [27][28][29][30][31][32]

4. STUDIES SUGESTING NO ADJUSTMENT IS NECESSARY

4.1 Multiple Studies Summarized – NASA Literature Review

Because as amply shown above, there was a concern that helicopter noise was more annoying or bothersome than the noise of fixed-wing aircraft, many laboratory studies were conducted in an attempt to determine whether helicopter noise should be quantified differently from fixed-wing noise. Noise characteristics such as "blade slap," low frequency impulse sound generated by the large rotor, interactions of the tail rotor turbulence with main rotor turbulence, tones or "buzz" generated by the tail rotor, engine whine and differences in operating time sequences as compared with fixed-wing aircraft were all considered as possible reasons for a perceived greater annoyance reaction from communities. Much of the effort was directed at determining whether there should be special metrics or "weightings" used when certifying or quantifying the noise levels of helicopters. Studies such as those reported in [33] and [34] and a review of 34 psychoacoustic experiments reported in [35] explored this question. Molino [35], page 2, summarizes the result of these efforts as follows:

> *"Thus the following conclusion is drawn from the often conflicting results of the 34 studies considered in the present review: There is apparently no need to measure helicopter noise any differently from other aircraft noise."*

4.2 Laboratory Test of Variations of Helicopter Event Duration

A Japanese study [36] used digital technology to preserve the maximum sound level of a recording of a helicopter conducting an overflight and a landing while varying the duration for the events from 4.5 sec to 35 seconds. The conclusion was:

> *"an A-weighted sound exposure level is better than a maximum A-weighted sound pressure level as the index of annoyance, and there is no necessity for the correction of impulsiveness for the evaluation of helicopter noise."*

5. ALTERNATIVE METRICS AND THE SPECIAL NATURE OF HELICOPTER NOISE

5.1 Activity Effects - NASA Double Room Study

In [37] subjects were located in a room surrounded by another room. The interior room was divided into two areas – one a comfortable lounge, the other a library type work area. Audio equipment in the outer room produced the sounds of helicopter flights and a reference jet sound. Subjects spent time in each end of the interior, relaxing at the one end, working at the other and registering their annoyance reaction within 10 seconds of the sound ending.

> *"during leisure activities there were more occasions when the VTOL[7] aircraft sounds were not noticed than during work activities."*

Interestingly:

> *To be judged equal in annoyance to the reference jet sound, the helicopter and tilt wing sounds must be 4 to 5 PNdB lower when lasting 15 seconds in duration.*

5.2 Alternative Metrics - A Diary Assessment of Annoyance

Sixsmith-Titley [38] recruited a two or three residents who lived near each one of 58 noise monitoring sites to keep annoyance episodes in diaries. The goal was to match these episodes with measured noise events. The area is rural with low background noise levels. Helicopter flights were those used in RAF training.

> *"there were statistically significant relationships between the observed activities, and the reasons why diarists found them to be problematic."*

The results showed that most residents were not worried about accidents and felt that training flights should take place locally, but were equivocal over whether they felt that community concerns mattered and whether they could influence decisions made about training operations.

Only 10% of residents reported that they had been "very" or "extremely" annoyed by helicopter noise in the two-week monitoring period, and annoyance ratings did not correlate well with the LAeq, LCeq, LAmax, L10 or LAmax - L90 metrics. Overall there was a poor relationship between objective noise levels and subjective response. Residents were more likely to report being "very" or "extremely" annoyed by an episode of helicopter noise if they were homeowners, "noise-sensitive", held a negative attitude towards the RAF or reported being annoyed by helicopter noise generally in the two-week period.

Overall, the survey demonstrated that the relationship between helicopter noise and reported annoyance is not straightforward, and that annoyance relates partly to individual differences and the impact of helicopter noise on daily living but apparently less to objective measured noise levels.

5.3 Airport / Community Relations - Reactions before and after Modification of Helicopter Schedules

Haugg and Vogt [39] tested reactions before and after scheduling of helicopter operations. Before implementation of scheduling helicopter flights, helicopters using Augsburg Regional Airport would fly until 10 p.m. and more than one could be in the air at a time. After scheduling, none would fly after 7 p.m. or after 30 minutes after sunset if before 7 p.m., and only one would be in the air at a time. Before and after surveys of annoyance were conducted in three areas surrounding the airport

[7] Vertical takeoff and land – helicopters.

and in all three average reported annoyance was reduced. However, opinions about residents' satisfaction with airport management did not change despite reduction in annoyance. An important conclusion offered by the authors was that when undertaking noise control measures, airports should publicize their actions and interact with the citizens to attempt to get credit for their efforts.

5.4 Helicopters May be More Noticeable

5.4.1 Logging "Important" Events in a Diary

Schomer and Wagner [40] asked subjects under the approach to a National Guard airfield and along a frequently used rail line to log in diaries any noise events that they deemed important to note. Simultaneous continuous monitoring was conducted. Subjects more often logged helicopter noise events than they did fixed-wing or railroad noise events, even when measured SEL values were similar. The conclusion offered is that helicopter noise events are more readily "noticed." Interestingly, in this study, once an aircraft event is noticed, the annoyance is fairly constant regardless of measured SEL. This phenomenon may be one reason that helicopters generate more complaints than do fixed-wing aircraft at any given level of noise exposure; suggesting that it is noticing that triggers annoyance, not sound level.

5.4.2 Unusual Sound Characteristics

Yansunori [41] studied the relationship of loudness perceptions to repetition of single events. Loudness increases from single events when the repetition rate exceeds about 20 times per second, the sound changes from a whooshing sound to "motorboating." A four-bladed helicopter (EC135) produces the pulsating sound at about 20 times per second which may make it easily detected.

Hiramatsu et al [42] explored the effect of sound event duration on annoyance. They found that SEL as a predictor of annoyance may not respond to very long duration events – longer than about 90 sec. This suggests that, if annoyance is increased from long events, the SEL increase will not correlate with the increase in annoyance.

Rosinger et al [43] had 24 subjects listen to sounds that were ramped up in level and sounds ramped down. Most annoying were those that were ramped up, least annoying were those that were ramped down or constant. This phenomenon is reported elsewhere and the term "looming" has been used to characterize this effect.

Two studies Neuhoff [44] and Bach *et al* [45] examined objective metrics of fear related to "looming" sounds. Neuhoff found that through examination of brain waves he verified that the "fear" area of the brain was activated by looming sounds. Bach verified this increase of anxiety through changes in skin conductivity.

In analyzing community complaints, Luz *et al* [46] suggests that looming may explain why 87% of the aircraft noise complaints stated that the aircraft was too close but only 24% complained about objectionable sound.

Sixsmith-Titley [38] (see also Section 5.2, above) from the diaries, found a similar disconnect between perception of loudness and perception of proximity. Diary reports were as follows:

Table 1 Comparison of Judgments of Proximity and Loudness

Judgment of Flight Type	*Percent Judged Too Close*	*Percent Judged Too Loud*
Low altitude	46.%	27.9%
Direct Overflight	23.6%	15.8%
Circling	20.7%	0%

6. CURRENT NOISE ANNOYANCE THEORY

Several researchers [47] built a theoretical model of perception of sounds starting with fundamentals of the human hearing system. They were able to show that their model could mimic the differences between the annoyance caused by road traffic noise exposure and railway traffic noise exposure that are also observed empirically in other studies and thus could provide an explanation for these differences. Their basic model is:

- People are only annoyed by sounds which they notice,
- The long-term perception is determined by short "notice events", and
- Habituation decreases the noticeability of auditory objects

7. SUMMARY

Taken together, these various studies suggest several common observations. However, in considering the studies, the distinction between *complaints* and *annoyance* should be kept in mind. Complaints are reactions to annoyance, while annoyance, as defined by legislation for the FAA, is a *surveyed* reaction to noise. Surveyed reaction is a formal measure that is collected through mail, telephone or in-person surveys which are carefully designed to produce unbiased responses.

- Except for Luz [46] all studies reviewed were focused on annoyance reactions and associated variables that could affect annoyance.
- Annoyance may be correlated with Leq, DNL
- Some adjustment to SEL based metrics may be appropriate if surveyed helicopter noise annoyance is to be predicted in terms and with metrics used to estimate the annoyance of fixed-wing aircraft noise
- Annoyance reactions (e.g. complaints) though not the degree of annoyance may be triggered by noticing the event rather than by the loudness of an event
- Helicopter noise may contain aspects that increase probability of noticing:
    - Low frequency modulation of broad-band noise
    - Slow travel speed and relatively low and constant altitudes that may lend to long audibility of approaches
    - Fear reactions to approaching sounds may be endemic to humans
- SEL or SEL based metrics are not likely the entire answer as far as complaints are concerned; they may depend upon noticeability as well

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