Helicopter Noise in Rural Communities: Assessment of Existing Knowledge

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Existing knowledge on helicopter noise focused on the effects of distance and altitude on ground-level noise, the annoyance caused by helicopter noise expressed by people, and the consequences of findings for helicopter operations in rural areas are presented. A nonlinear association between ground-level noise, altitude, and slant distance was identified. A combination of altitude, standoff distance, and cruise speed for each helicopter type at which ground level noise is minimum appears to exist. Also there is a considerable difference between desired and actual noise levels for rural areas even if penalties are not assessed on the measured helicopter noise. A gap in the connection between actual helicopter noise measurements and community annoyance was also revealed. Specific guidelines or regulations that define paths (separation), the frequency of helicopter flights per path, and the minimum standoff distance and altitude may be necessary for semirural and recreational areas.

There are several studies on helicopter noise measurements for certification, design, and modeling purposes as well as an immense amount of acoustical literature on noise measurements, human response and annoyance, and methodologies for the quantification of human response to aviation noise. However much less is known about helicopter-induced annoyance. In addition there are concerns about the applicability of existing methodologies for the assessment of annoyance and community reaction to noise in situations of infrequent helicopter flights over rural communities and recreational areas.

Specifically concerns have been expressed about whether current methods (i.e., those applied to small, propeller-driven aircraft) of measuring and predicting community response to helicopter noise are adequate. These methods are partly based on the A-weighted day-night average sound level (L_{dn}). Several researchers have strong objections to using L_{dn} under certain circumstances. Schultz (*1*) reports, "Just as the statement that the average depth of a river is 2 ft. may conceal the existence of a pool deep enough to drown in, the restriction of noise exposure in a neighborhood to an average noise level may still permit quite loud and annoying noises, if they are short enough in duration." Dunholter (*2*) observes that noise problems have been located in areas that, on the basis of the L_{dn} criterion alone, would not be expected to have a severe problem. Firle (*3*) goes further by reporting that L_{dn} is not only inadequate to give a realistic picture of the impact of aircraft noise but also may lead to erroneous abatement programs. Igarashi (*4*), a proponent of the L_{dn}, admits that in the case of small number of flights, L_{dn} values are extremely small, thus they may not represent annoyance properly. Such occurrence is predominant in the National Park system, in which otherwise quiet areas are intermittently disturbed by low-level sounds from aircraft flights (*5*).

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Given that L_{dn} may not be an adequate descriptor of noise intrusion and annoyance from infrequent flights, the Environmental Protection Agency (EPA) noise levels (*6*) based on L_{dn} may be inappropriate for evaluating effects of noise from infrequent helicopter flights over rural communities. Consequently discrete noise measurements for each event may be a better way of describing the noise intrusion and annoyance felt (as discussed later).

The issue of helicopter noise is of particular significance to Hawaii because of the large number of tour helicopter flights over rural communities (e.g., Hawaii is only second to the Grand Canyon in terms of tour helicopter operations). Although it was reported (*7*) that L_{dn} levels in rural communities are acceptable, a considerable number of complaints are filed regularly (e.g., 591 and 317 complaints in 1990 and 1991, respectively). The consultants (*7*) performed a number of field measurements. A sample from two locations on Kauai is shown below.

Location	*No. of Daily Helicopter Flights*	*No. of Helicopter Flights Measured*	*Helicopter L_{max}*	*Helicopter L_{dn}*	*Ambient L_{dn}*
1	29	18	68	47	30
2	133	28	72	53	50

Obviously the EPA standard of L_{dn} = 55 dBA is fulfilled when the helicopter flights are included, but the L_{max} is considerably higher than the ambient noise level. The number of daily flights is also considerable. The issue has reached a point at which representatives in the U.S. Congress and university researchers have been called to address the issue.

FUNDAMENTALS OF HELICOPTER NOISE

The character of the noise produced by helicopters is diverse. Each of the primary noise sources—main rotor, tail rotor, and engine—produces distinctive noises. The combination of the sound from the tail rotor and the main rotor (the sound of which varies from mid to high frequencies) results in a unique sound signature for each helicopter type (*8*). According to Hilton and Pegg (*9*), the main sources of noise of four helicopters are the following:

Helicopter	*Main Source of Noise*
Bell 204	Main rotor
Bell 206	Tail rotor
Bell 47	Engine
Hughes 269	Engine and tail rotor

The noises of these individual sources may vary under different operating conditions. At low airspeeds or during hover, the helicopter needs a higher power setting than at intermediate airspeeds. Likewise at high airspeeds increased power is needed. Thus helicopters generally produce a minimum sound level at some intermediate airspeed, with higher sound levels at lower and higher airspeeds (*10*). For example the Hughes 500C helicopter produces lowest ground level noise when flown at about 185 km/hr, whereas the Bell 206L helicopter is quietest at 222 km/hr (*11*).

A primary characteristic of helicopter noise is the blade slap that occurs when one of the rotors passes through the wake created by another blade, especially on descent. A different acoustic mechanism generates blade slap in high-speed forward flight: the advancing side of the rotor combined with the flight speed causes the blade to become transonic (*12*).

During takeoff the interaction that creates blade slap does not occur, and takeoff noise is similar to level-flight noise (*10*). However the total (engine, gearbox, rotors, and interactions) sound level is much louder during take off: the sample of 153 observations analyzed and described below (all of the data are from turbine-powered helicopters) resulted in noise levels of 79 dBA for landing and 85 dBA for takeoff; the difference between the two is significant at the 97 percent level of statistical confidence. Both maneuvers tend to be considerably noisier than most flyovers at 100 m above ground level or higher.

This is significant when the locations of helicopters are considered. Obviously heliports should be sufficiently far away from residential areas, particularly in suburban and rural communities, where low ambient levels of noise are the norm. Noise complaints from takeoff and landing operations are nearly nonexistent in Hawaii, largely because most helicopter flights originate at airports with considerable aviation traffic.

GROUND-LEVEL NOISE, ALTITUDE, AND DISTANCE

Although at a close range helicopter noise violates community noise standards, at a proper combination of altitude and standoff distance the noise impacts at ground level are reduced to acceptable levels. This section presents existing flight regulations or recommendations as well as the results of analysis of correlations among ground-level noise, altitude, and distance.

FAA Advisory Circular 150/5020-2 (*13*) recommends that the flyover altitude should be chosen to be the highest practicable on the basis of the fact that doubling of the flyover height decreases the peak sound level heard on the ground by more than 6 dBA. FAA Advisory Circular 91-36B recommends a 600-m (2,000-ft) minimum altitude over populated areas. The FAA supports both the designation of visual flight rule corridors specifically for helicopters and the helicopter industry's Fly Neighborly Program (FNP).

A large number of helicopter noise measurements (L_{max}) taken at airports and heliports of large U.S. cities have been presented previously (*14*). The altitude, distance, and the executed maneuver during the sound measurement are specified. The data were computer coded and analyzed. The original data contain more than 500 observations. Of those, only 153 were selected and coded because (a) altitude and distance were missing from several observations, and (b) multiple measurements were taken during a given maneuver by the same helicopter. In the latter case, inclusion of measurement other than one of those listed would violate the assumption of independence of observations, which is required for statistical analysis.

Slant or euclidian distances (i.e., straight-line distance between receptor and helicopter) were computed because initial investigation showed that horizontal distance alone and altitude alone did not correlate well with measured sound pressure levels. A nonlinear relationship between measured dBA and slant distance was revealed. The following best-fit model was estimated by regression analysis:

$$L_{max}\text{ (dBA)} = \underset{[99\%]}{95.3} - \underset{[99\%]}{0.915}\text{ (slant distance; ft)}^{1/2} + \underset{[90\%]}{2.2}\text{ (L or TO)} \qquad (1)$$

where L or TO indicates landing or takeoff (1 if L_{max} is estimated for a landing or take off, and 0 otherwise) (N = 153 observations, R^2 = 0.69, the significance of the coefficients is given in brackets).

A number of studies (*11,15*) analyzed the noise characteristics of several helicopters. The data indicate that the ground-level noise produced by light-duty helicopters, which are typically chosen for sightseeing and inspection operations, often exceeds 75 dBA in flyovers at a 450-m distance from the observer (i.e., at the minimum altitude or standoff distance of 1,500 ft specified in the Hawaii FNP).

ANNOYANCE FROM HELICOPTER NOISE

The connection between noise and annoyance is of significant interest largely because annoyance is a key determinant of how acceptable a noise is. Noise is an objective measure of sound levels, whereas annoyance is a complex index of the perception and reaction of people to a given sound. This section reports on the connections (or the lack of connections) between helicopter noise and annoyance.

Fidell et al. (*16*) offer the following model for estimating the percentage of people in a community who are likely to be highly annoyed (HA) by transportation noise sources:

$$\text{HA (percent)} = 78.9181 + 0.0360\, L_{dn}^2 - 3.2645\, L_{dn} \qquad (2)$$

This model incorporates about 40,000 surveys from 32 studies. None of the data used in the estimation of this model is from helicopter operations. Green and Fidell (*17*) also found statistically significant evidence that people are on average more willing to report annoyance caused by aircraft noise exposure than street and rail traffic.

Tolerance to helicopter flyovers diminishes after a certain number of flights is exceeded. At frequencies exceeding eight helicopter flyovers per day the following concerns increase dramatically (*18*):

1. Large numbers of helicopter flights over residences,
2. Low-flying helicopters,
3. Noise, and
4. Inability of the government to regulate or control helicopters.

Fields and Powell (*19*) reported similar results, plus

1. Fear of helicopter crashes,
2. Belief that the helicopter noise could be prevented (increased annoyance if people believe that pilots or regulations could reduce the noise), and
3. Willingness to tolerate helicopter flights if the missions are of high importance.

Qualitative assessments must be connected to quantitative information and to specific recommendations or regulations to reduce the degree of annoyance. FAA Advisory Circular 150/5020-2 (*13*) includes recommendations on the maximum number of helicopter flights per hour when the community sound level is exceeded by a given level. The FAA uses the sound exposure level (SEL). If the ambient noise level of a rural community is approximately 50 dBA (as in Location 2 in the first in-text table) and the helicopter's SEL is 76 dBA, then a maximum of about nine flyovers per hour is recommended on the basis of the corresponding difference of 26 dBA. [This estimate corresponds to that for the popular Bell 206L-1 helicopter during level flight at 183 km/hr at a 330-m altitude and 330-m distance. This combination of altitude and distance results in a slant distance of 425 m, which is close to the 450-m standoff distance recommended in the Hawaii FNP. The SEL was calculated from data presented previously (*15*, p. F-469).] This translates into one flyover every 6.5 min, which may not be acceptable to rural residents. Even if this estimate is acceptable, FAA recommendations apply to heliport planning only. There is no recommendation that SEL should be the preferred noise measurement methodology in rural areas. Such use of the SEL offers an upper bound for the number of operations in rural areas, whereas L_{dn} does not.

A large part of the literature on helicopter noise (and more generally on impulsive noise) focuses on the need for penalties that may need to be added to measured sound levels so that they reflect the degree of annoyance felt by people more accurately. The results of several major studies follow.

A review and evaluation of 34 studies based on psychoacoustic experiments assessed the need for penalties on loudness from helicopter noise (*10*). The main conclusion was that there is no need to measure helicopter noise differently from other aircraft noise, although it was acknowledged that the results of the reviewed studies were often conflicting. A more recent study by Schomer et al. (*20*) involving real-world experiments has found that helicopter noise measured on either the A or the C scale must be corrected to better correspond to human perceptions. They used the A-weighted SEL and found that a 10-dB penalty should be added to the measured SEL of the sound from two-bladed helicopters and an 8-dB penalty should be added to the SEL from multibladed helicopters.

Schomer and Neathammer (*21*) noticed that human reaction is strongly influenced in a negative way when the helicopter noise induces rattle of the objects in the house or vibration of the building in general. [Some complaints in Hawaii include fear and annoyance from rattle caused by helicopter flyovers. Such complaints do not apply to tour operations except when weather confines flights to very low altitudes.] Their results suggest a need for a penalty in the order of 10 dB to assess annoyance from helicopter noise properly when vibration and rattle are produced. Considerable rattle is not likely to occur at slant distances exceeding 300 m, but rattle is nearly certain when slant distance is less than 150 m. The vibration avoidance distance usually varies with the type of helicopter and executed maneuver.

Several sources (*22,23*) indicate that acceptable maximum sound levels to residents are 35 and 40 dBA for bedrooms and living rooms, respectively. They also recommend (with some variance) that these criteria should be increased by about 5 and 10 dBA for suburban and urban residential areas, respectively. A zero increase is recommended for hospitals and recreational and rural areas. In addition a 5-dB penalty should be added to noise measurements in locations in warm climates to account for the more open-air living, including open windows and thinner insulations (*24*).

The desired standards form the one side of the equation (e.g., the maximum desired noise for living rooms in rural areas is 40 dBA). The other side of the equation is the actual noise level: model estimates plus penalties yield a maximum actual helicopter noise of 75 dBA [model estimate of 60 dBA (equation 1 for a helicopter overflight at 450 m) plus the impulsive noise penalty of 10 dBA plus the warm climate location penalty of 5 dBA]. The comparison reveals a large difference between actual and desired noise levels. Even if the penalty for impulsive noise is not assessed, there is still a considerable difference between desired and actual noise levels for warm-climate rural areas (e.g., 60 + 5 − 40 = 25 dBA).

DISCUSSION OF RESULTS

A nonlinear association between ground-level noise, altitude, and slant distance prevails. There is evidence that for each helicopter type an optimum combination of altitude, standoff distance, and cruise speed exists whereby ground level noise is minimized. Thus the ground-level noise for a number of altitude and speed combinations for each helicopter type could be identified with field experiments and noise propagation modeling. Then maps with maximum noise tolerances (depending on the land use) could be created. Using these maps, pilots may choose to adjust either their flight path (i.e., avoid the sensitive area altogether) or the flight characteristics (i.e., change their altitude and speed so that the helicopter's ground-level noise will not exceed the specified limit). The feasibility and necessity of such actions should be evaluated, and FAA must decide whether such guidelines should be recommended or mandated.

Tolerance to helicopter flyovers tends to diminish quickly with an increasing frequency of flights and an increasing difference between helicopter noise and ambient sound level. Alternative, separate corridors may need to be established, and traffic may need to be appropriately distributed among them to minimize the impact on the public. Also given the unique characteristics of and the manifested annoyance from helicopter noise, various studies propose penalties on helicopter noise measurements. The imposition of penalties may be appropriate. Penalties that are helicopter type specific should be considered for analysis and evaluation.

Self-regulation of the helicopter operators' industry through FNPs is promising, but a large number of flights are excluded from such programs. [For example, the Hawaii Helicopter Operators Association's FNP specifies, "If it isn't a tour flight, it is not covered (by the FNP)."] FNPs may need to be expanded to cover most types of missions and exclude mainly emergency, security, and court-warranted operations. In addition the public should be given ample opportunity to challenge local FNPs and easy access to state or federal agencies for reporting aviation noise complaints.

This review has revealed a clear gap in the connection between actual helicopter noise measurements and human reaction. Existing studies can be grouped into three categories: (a) studies of helicopter noise measurements that, although many exist, primarily use measurements from airports or heliports taken for certification purposes or for other technical inquiry; (b) studies on community reactions that are of rather limited applicability to rural residential areas because they were conducted in communities adjacent to military bases, focusing primarily on military helicopters; and (c) studies commissioned by the National Park Service, which generally are market opinion oriented and focus exclusively on the reactions of visitors and naturalists.

Not only is existing knowledge of the connection between actual helicopter noise measurements and rural, residential community annoyance limited, but also the derivations of estimates of acceptable noise levels and community reaction, based on inferences from knowledge gathered in other settings, may be erroneous. Thus study of this topic focusing exclusively on rural and recreational lands where opposition to helicopter flights is strong and growing seems necessary.

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