Psychological Reactions to Aircraft Noise

Possible methods of evaluating the acceptability of the noise from aircraft are presented.

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The subjective reactions of people to noise (here defined as unwanted sound) have for the most part been studied with two somewhat different questions in mind: (i) What is the precise quantitative relation between the physical characteristics of sound and the subjective attributes of pitch, loudness, and noisiness? (ii) Does noise cause physiological or psychological reactions that tend to affect general behavior and to interfere with the performance of physical or mental work?

In certain respects the first set of problems takes precedence over the second, more "practical," set. For one thing, problems in the first set appear to be simpler and more amenable to quantitative research; second and more important, an understanding of these basic relationships may provide considerable insight into the effects of noise on general behavior—that is, on the problems of the second set. Here I discuss the basic psychological attributes of sound; behavioral reactions and auditory fatigue from exposure to noise; and, finally, community reaction to the noise from jet aircraft.

Attributes of Sound

A subjective attribute of sound can be defined only in operational terms. An experimenter asks subjects to make judgments about sounds according to certain prescribed instructions. For example, he asks them to adjust the frequency of a pure tone until it appears twice as high in pitch as it did before, or to adjust the intensity of a sound until it appears to be half as loud, or to adjust the intensity of a sound until it appears to be as noisy, or as acceptable if heard periodically in the home, as a reference sound.

From the results of such experiments, graphs and tables showing the relation between the spectrum of a sound and its pitch, loudness, and noisiness, as judged subjectively, have been derived. Although the effects upon these judgments of some physical parameters, such as the duration and the complexity of a sound, have not been fully studied, there is general agreement about the functional relationship between the general spectrum and intensity level of sound and the apparent pitch, loudness, and noisiness of the sounds to the average observer.

Needless to say, in these investigations the judgments of the different observers differ, but the variation is surprisingly small. For example, about 50 percent of a group of people will usually agree, within ±2 decibels, upon the intensity required to make the sound of one aircraft appear as noisy as the sound of some other aircraft (Figs. 1 and 2).

In the field of noise control, information about the subjective attribute of pitch is of little relevance per se. As for "loudness" and "noisiness," there has been and there continues to be considerable debate as to which of these subjective aspects of sound is of most significance in reactions to the sound from aircraft. Two things may be said: (i) by definition, it is the "noisiness" rather than the "loudness" that is of most importance in the context of estimating people's aversive reaction to sound; (ii) it is an experimentally established fact that the loudness of a sound as established by physical measurements does not usually correspond with its loudness and noisiness as judged subjectively. These functional relationships between the physical nature of a sound and the subjective attributes of noisiness and loudness are determined with sounds having little or no semantic or emotional meaning to the listeners. In brief, it has been found that there apparently is a basic "unwantedness" or "noisiness" to sound beyond that due solely to its measurable loudness. This "noisiness" increases at a somewhat greater rate than the loudness does as (i) the pitch of a sound is raised (Fig. 3); (ii) the complexity of the spectrum is increased (Fig. 4); and (iii) the duration is increased beyond 200 milliseconds (Fig. 5) (loudness is judged to be constant for sounds that continue at a steady level for longer than 200 milliseconds).

It seems reasonable to assume that these basic reactions underlie, if they do not strongly determine, average reactions of people to sounds and noises in everyday life. If one accepts this assumption it follows that choice of the physical parameters that correlate or give promise of correlating most highly with subjective judgments of noisiness is fundamental to the definition and physical measurement of noise in general.

Reasonably high correlations have been found between (i) judgments of the noisiness of sounds in general and of the sounds from piston-driven and jet aircraft and (ii) the so-called "perceived noise level" obtained by summing, in a certain manner, sound pressure levels of octave or one-third octave spectral bands. This perceived noise level of a sound is calculated by weighting the sound pressure levels of the bands in a prescribed manner (*1–3*) and summing the results in accordance with procedures developed by S. S. Stevens (*4*) for estimating the loudness of sounds of different bandwidths. The commonly used unit of loudness is the phon; the unit for perceived noise level (in decibels) is called the "PNdb." As a practical matter, the loudness level, in phons, and the perceived noise level, in PNdb's, of a sound are usually calculated from acoustical measures of the sound rather than found by subjective judgment tests.

Other, more complex methods (*5*) and less complex methods (*6*) of mak-

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ing and manipulating physical measurements of sound pressure level may also provide high correlations with subjective judgments of the noisiness of a given set of sounds, but PNdb's seem to consistently give predictions of judged noisiness that are as good or better than the results obtained with these other methods (see Tables 1–3).

It should be emphasized that octave band measurements do not define or "analyze" the complex spectrum of an aircraft noise in as detailed a way as the human auditory system does. In particular, it appears that in some cases the presence of strong, pure-tone components (which often occur in jet aircraft noise) increases the subjective noisiness of the sound above the level predicted by the octave band measurements and therefore by the calculations, based on these measurements, for perceived noise level in PNdb's (*2, 7, 8*). Some data have been collected which suggest that one-third-octave band measurements may be required for identification of pure-tone or "line" spectrum components in a complex sound and for appropriate correction of the calculated value for perceived noise level to take account of the effect on perceived noisiness of this "pure-tone factor" (see Fig. 6). However, some recent data (*9*) raise questions about how best to incorporate this pure-tone factor into the physical measurement and calculation procedure to obtain results that have the most meaning in terms of human judgments. Additional research on this problem is required before these "pure-tone correction factors" can be used with confidence.

Another variable that has been studied relative to judged noisiness of sounds is the duration of the sound. It was found that, over the range from about 2 to 12 seconds (the only time intervals so far studied), increasing the duration of a sound increased its judged noisiness. Doubling the duration of a sound while keeping the peak sound pressure level constant was found to be equivalent in its effects on judged noisiness or judged acceptability to increasing the sound pressure level by 4.5 decibels (or the perceived noise level by 4.5 PNdb) but keeping the duration constant (see Fig. 5). It is interesting to note that in British (*10*) and Dutch (*11*) sociological surveys, doubling the number of jet flyovers per day produced the same degree of annoyance in the community as keeping the number of flyovers constant but increasing the perceived noise level of each flyover by 4.5 PNdb. While this similarity between the effects on noisiness, as judged by individual subjects, of increasing the duration of a sound and the effects on overall annoyance in a community of increasing the number of daily occurrences of a sound may be purely fortuitous, it would seem to suggest that the impact of aircraft noise on a community could perhaps be rather simply calculated from spectral and temporal measurements of aircraft noise.

More laboratory tests should be con-

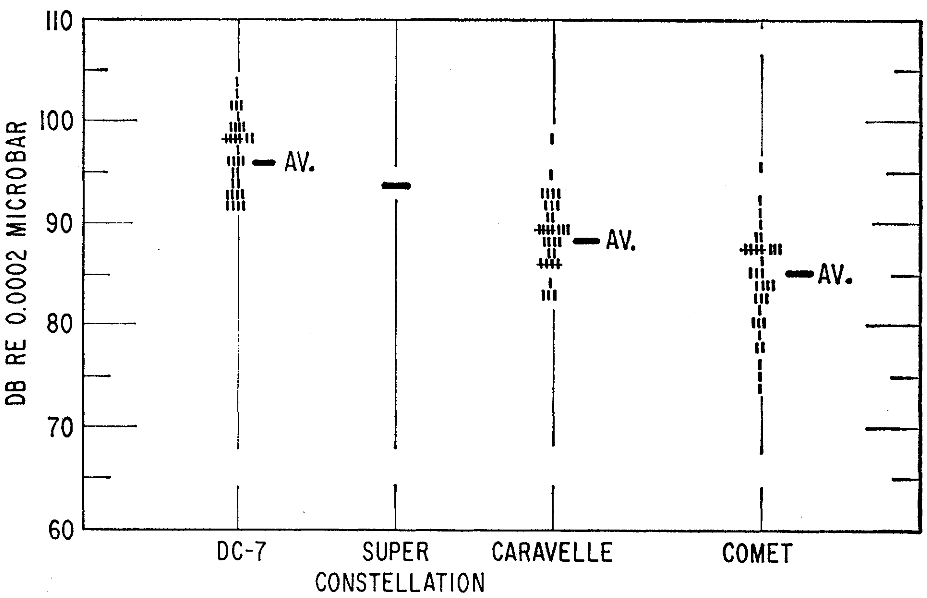

Fig. 1. Results of judgment tests made according to the method of individual adjustment. Each of 36 subjects adjusted the level of recorded sounds until they appeared to be equal to the standard sound (94 decibels, from a Super-Constellation) in noisiness or acceptability. [From Kryter (*1*)]

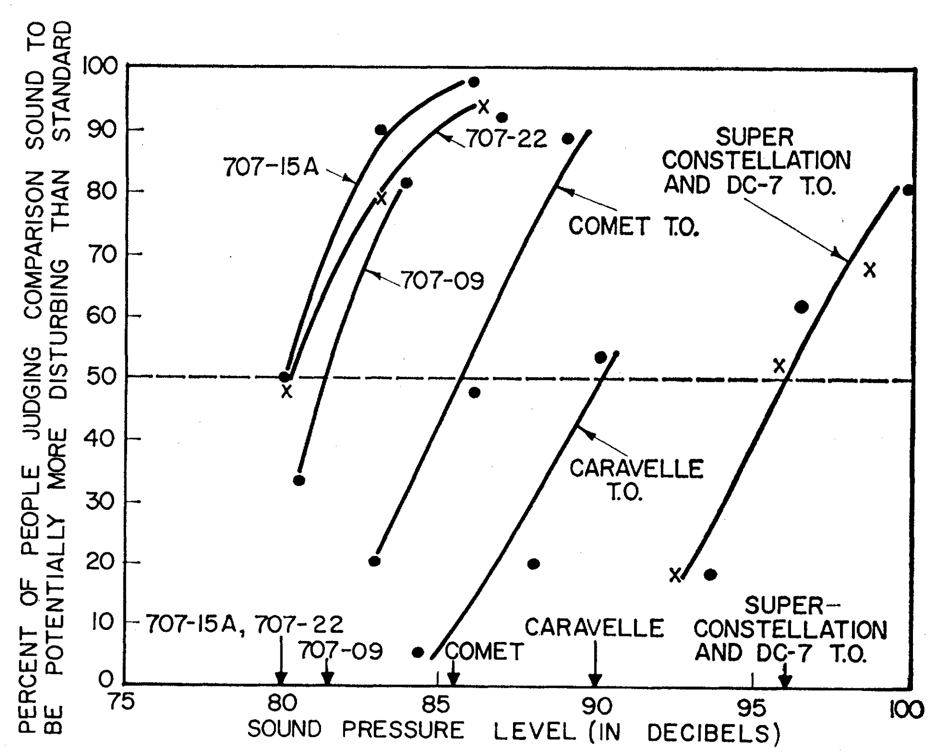

Fig. 2. Results of tests in which 100 listeners judged the noisiness of the recorded sounds, of various aircraft, relative to a standard—the sound of the Boeing 707. The level of the comparison sounds was varied but that of the standard was kept constant at 81.5 decibels (*T.O.*, takeoff). [From Kryter (*1*)].

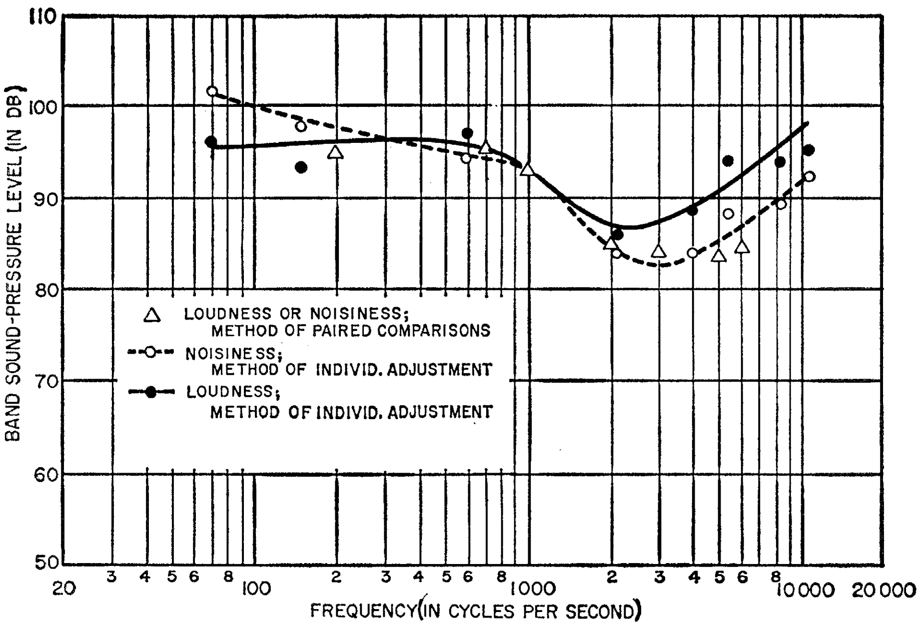

Fig. 3. Sound pressure levels of narrow bands of noises of various center frequencies required to make the bands equal in judged loudness or noisiness to a reference band centered at 1000 cycles per second. [From Kryter and Pearsons (*2*)]

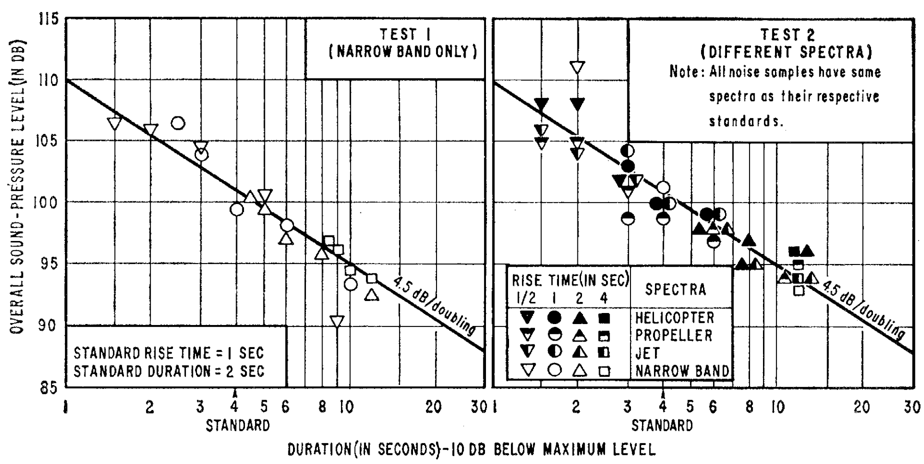

Fig. 4. Sound pressure levels and durations of various sounds judged to be equal in noisiness or acceptibility to the standard or reference sound set at 100 decibels, in tests made according to the method of paired comparisons. [From Kryter and Pearsons (*2*)]

ducted to determine the relation between duration and perceived noise level at both longer and shorter durations than those studied to date. Of particular importance to the evaluation of aircraft noise would be studies of these relations for acoustic signals as short as sonic booms.

General Behavioral Reactions to Noise

Numerous laboratory and industrial studies have been made in attempts to show that noise has an adverse effect on the performance of physical and mental work (*12*). By and large, the results of these studies show that noise per se probably has little or no adverse effect upon performance provided the work does not require auditory communication of some sort. These results were found even in environments where the noise levels were such that near-daily exposure over several years would cause some permanent deafness. Incidentally, the noise due to aircraft flyovers even in communities immediately adjacent to an airport cannot cause any significant auditory fatigue because the noise occurs for very brief periods followed by long periods of relative quiet (*13, 14*).

These and related experiments have shown, nevertheless, that people exposed to the noise object to it, the specific noise levels found acceptable being a function of the activity the person is engaged in. For example, the judged "threshold of annoyance" is found to vary, for steady-state sound, between about 40 and 90 PNdb, depending upon whether the person was a "conference room" worker, a clerical worker, or a worker in a ma-

Table 1. Comparison of the intensities, as assessed by various methods of physical measurement, of various noises subjectively judged to be equally acceptable. The method of measurement having the smallest "range" and the smallest "average difference from standard" best predicts the results of the subjective judgment. An ideal method would have a range of zero and an average difference from standard of zero. [After Kryter and Pearson (*2*)]

Noise	Overall "flat" (db)	A scale (db)	B scale (db)	C scale (db)	Stevens (phons)		Zwicker * 1/3-octave band (phons)	PNdb	
					1/3-octave band	Octave band		1/3-octave band	Octave band
150–300 cy/sec	92.0	82.0	90.5	92.0	90.5	89.0	92.5	93.0	92.5
600–1200 cy/sec (standard)	90.0	90.0	90.0	90.0	93.5	93.5	97.0	94.0	94.5
2400–4800 cy/sec	80.5	79.0	78.5	79.5	86.5	88.0	87.0	90.5	93.0
4800–10,000 cy/sec	80.0	74.5	75.0	76.5	90.5	90.5	89.0	90.5	88.5
150–4800 cy/sec, "flat"	80.5	79.5	79.5	80.0	90.5	92.5	95.5	92.5	91.5
150–4800 cy/sec +	83.0	81.0	81.0	81.5	94.0	90.5	96.5	96.5	95.0
150–4800 cy/sec–12 db/octave slope	84.5	80.5	83.0	84.5	89.0	87.0	95.5	90.5	90.0
Diesel engine	87.0	79.0	84.5	87.0	89.5	88.0	95.0	91.0	90.0
707–120B Landing Turbofan with "Hushkit"	80.0	80.0	80.0	80.0	91.0	89.0	95.5	93.5	92.5
Range	12.0	15.5	15.5	15.5	7.5	6.5	10.0	6.0	6.5
Average difference from standard	–6.5	–10.4	–8.5	–7.4	–3.3	–4.2	–3.7	–1.8	–2.4

* Values calculated by E. Zwicker.

chine shop (*15*). Somewhat similarly it has been found that, in a community, the threshold of annoyance due to intermittent real-life sounds (from aircraft, automobiles, and so on) varies between about 50 and 90 PNdb (see *10*).

These judgments are undoubtedly a joint function of a general "bothersomeness" level composed, perhaps, of (i) concern (conscious or unconscious) about damage to one's hearing, (ii) the masking of speech or other desired auditory signals, and (iii) interference with sleep. We have data concerning some of these effects. For example, exposure to a noise level of 90 PNdb for 4 hours can cause a temporary rise of as much as 15 to 20 decibels in the threshold of auditory sensitivity (*14*), and a jet flyover following takeoff, with a noise level of 85 PNdb, will mask approximately 25 words of conversational speech (see Table 4). There are no precise quantitative data concerning effect on sleep, but it appears that during evening hours aircraft noise must be about 10 PNdb less than during the day, and 20 PNdb less than during the hours from 1 a.m. to 7 a.m. to cause equal complaint activity per aircraft operation (Fig. 7). These findings are undoubtedly related to interference with sleep or the process of going to sleep and have been partially verified by laboratory experiments.

It should be noted that these several effects of intense sounds are somewhat similarly related to the spectrum of the sound, at least over the important frequency range from about 100 to 2000 cycles per second; progressively higher frequencies in that region tend to produce correspondingly greater auditory fatigue and judgments of greater noisiness, greater masking of speech, and increased arousal from sleep. It is undoubtedly primarily for this reason that community reaction to aircraft can be fairly well estimated on the basis of physical measures of sound, such as the PNdb.

Community Reaction to Jet Aircraft Noise

The problem of community reaction to aircraft noise is, among other things, a statistical question. Some people will be annoyed by sounds that others accept, and this difference in turn is influenced by what these individuals are doing from moment to moment. There is evidence, incidentally, that after an initial adjustment, a person becomes less, rather than more, tolerant of continued exposure to aircraft noise (see *17*).

Second, community reaction is a relative matter. The seriousness and importance of the annoyance due to aircraft noise will undoubtedly be viewed in the light of the noise environment as a whole.

Third, it is a matter of equities. This factor cannot be judged on a scientific basis; it is a matter of opinion concerning the rights of individuals to be protected from nuisances, and the welfare of the community as a whole.

My remaining comments are directed toward (i) the three aspects of the problem that are given above; (ii) criteria of unacceptability of community noise environment; and (iii) a possible future aircraft noise problem, the sonic boom.

Table 2. Coefficients of correlation between physical measurements and subjective ratings of the sound from several vehicles (trains, automobiles, and aircraft). [After Cohen and Scherger (*27*)]

Measurement	Pearson product moment coefficient	Spearman rank order coefficient
Phons (Zwicker)	.96	.98
Phons (Stevens)	.91	.92
PNdb	.90	.92
db(A scale)	.83	.72
db(C scale)	.75	.68

Table 3. Provisional values reported by Copeland *et al.* (*28*) for differences in measured sound pressure level (SPL), calculated loudness (Stevens' phons), and calculated perceived noise levels (PNdb) for pairs of piston-driven (A) and jet (B) aircraft judged subjectively to be equally "loud" and equally "disturbing." A minus value indicates an underestimation of the loudness (as calculated from sound pressure level) of aircraft B relative to aircraft A or of the noisiness (as calculated from sound pressure level) of B relative to A. For example, when the listeners judged the Boeing 707/120 to be as loud as the Super-Constellation, the calculated loudness was 3.1 phons lower for the Boeing 707/120 than for the Super-Constellation. Similarly, a plus value indicates an overestimation for B relative to A. The smaller the values, the greater the agreement between the physical measures (SPL, phons, PNdb) and the subjective judgments.

Aircraft		A vs. B when judged equally loud			A vs. B when judged equally "disturbing"		
A	B	SPL, C scale (db)	Stevens' phons	PNdb	SPL, C scale (db)	Stevens' phons	PNdb
Super-Constellation	Boeing 707/120	−9.0	−3.1	+0.7	−10.8	−5.1	−1.3
Super-Constellation	Vulcan Mk. I (jet)	−4.7	−1.4	+0.7	− 6.0	−2.7	−0.6
Vulcan Mk. I	Boeing 707/120	−5.2	−2.6	−0.9	− 5.5	−2.9	−1.2
Average		−6.3	−2.4	+0.2	− 7.4	−3.6	−1.0

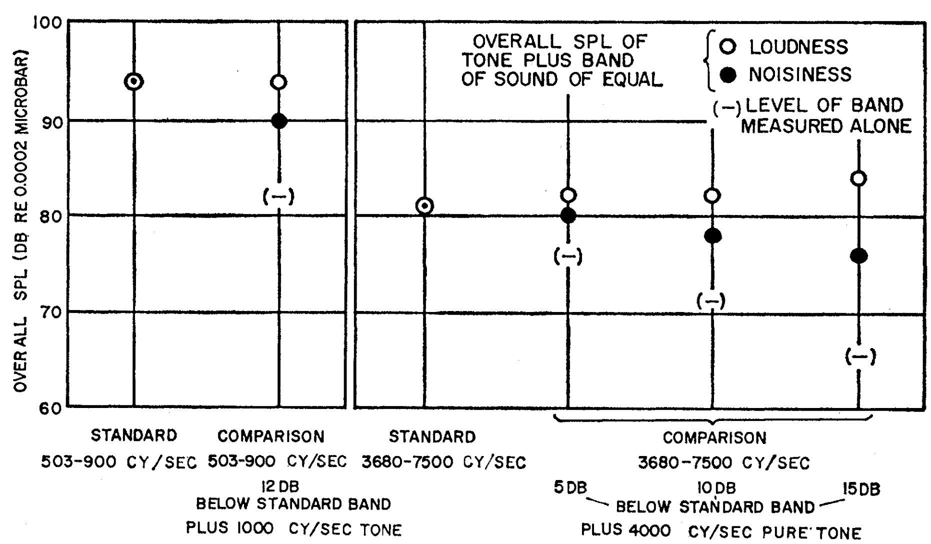

Fig. 5. Results of loudness and noisiness judgment tests (made according to the method of paired comparisons), showing that the presence of a pure tone in a band of random noise resulted in judgments of increased noisiness but did not appreciably influence judgments of loudness. That is, the overall sound pressure level of the comparison sound (tone plus band of noise) had to be less than the sound pressure level of the standard sound (band without tone) for the comparison sound to be judged equal to the standard in noisiness, but the overall sound pressure level of the comparison sound had to be at least equal to the overall sound pressure level of the standard for the comparison sound to be judged equal to the standard in loudness. [From Kryter and Pearsons (*2*)]

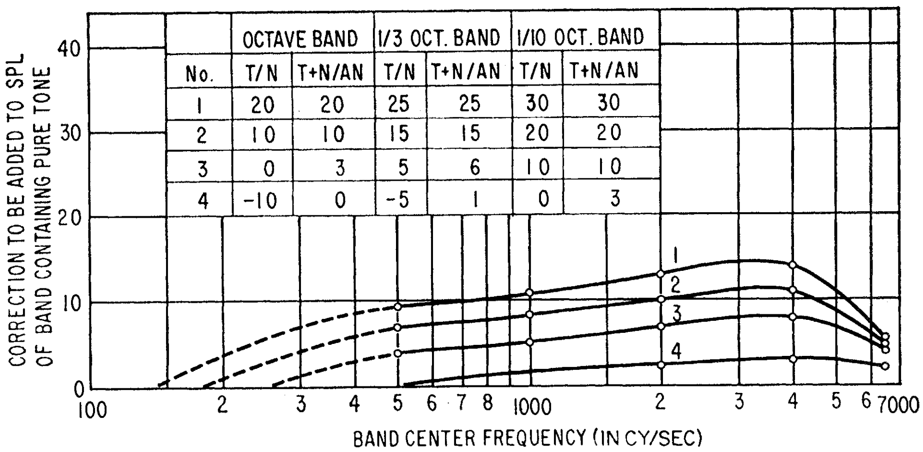

Fig. 6. Graph showing numbers of decibels to be added, prior to calculation of the perceived noise level, to the sound pressure level of the band containing the pure-tone component (see text). The parameter is the ratio, in decibels, between tone and noise measured separately within a band (T/N) or the ratio between the level of the band containing tone and noise together and the level of adjacent bands (T + N/AN) when measured with full octave, one-third octave, or one-tenth octave band filters. [From Kryter and Pearsons (*8*)]

Table 4. Percentage and number of words that would be masked in speech following takeoff flight operations for each of four aircraft. [After Kryter and Williams (*29*)]

Aircraft	Aircraft altitude (ft)	Peak PNdb level*		Time interval between levels 15 PNdb below peak level* (sec)	Words masked during test (%)		Number of words, spoken at a rate of 140 words per min. that would be masked	
		Out-doors	In-doors		In-door 69-db speech†	Out-door 84-db speech†	In-door 69-db speech†	Out-door 84-db speech†
707/120 (jet)	1500	109	91	35	46	48	37.5	39.1
720B (jet)	1980	112	94	23	39	42	20.9	22.5
727 (jet)	1500	105	89	25	19	34	11.1	19.8
Super-Constellation (piston-driven)	1350	101	86	24	9	13	5.0	7.3

* As determined on playback of sound tape. † The loudness of conversational speech under quiet conditions is typically 58 db 3.3 feet from the speaker. The levels of speech used in these tests correspond to very strong conversational effort (69 db) and shouting (84 db), in imitation of speech that might be used in the presence of aircraft noise.

Table 5. Number of people with various "annoyance" scores, classified by calculated noise level and number of aircraft per day. [After Wilson (*10*)]

Noise level in PNdb	Average number of aircraft per day	Annoyance score 0	1	2	3	4	5	Average annoyance score	Number of people in stratum
84–90	5.75	230	128	113	5	5	31	1.1	512
84–90	22.5	45	33	26	17	12	22	1.9	155
84–90	81	5	7	2	7	10	7	2.8	38
91–96	5.75	51	41	28	17	11	10	1.5	158
91–96	22.5	90	64	55	45	35	32	1.9	321
91–96	81	18	15	13	23	18	23	2.7	110
97–102	5.75	2	1		3	1		2	7
97–102	22.5	13	9	20	16	11	13	2.5	82
97–102	81	20	22	38	26	30	64	3.1	200
103–108	5.75								
103–108	22.5	1		1	5	2	2	3.2	11
103–108	81	11	7	17	16	19	67	3.6	137

Statistical Nature of Sociological Surveys

The most comprehensive study yet made of the reactions of people to noise in their communities due to the activity of commercial aircraft was conducted by the British Government in 1961 (*10*). This study was concerned primarily, but not exclusively, with the question of reactions to aircraft noise within a 10-mile (16-kilometer) radius of London's Heathrow Airport. Previous studies of this type had been made in the United States in communities near military air bases (*17, 18*).

Table 5, from the British study, shows the statistical nature of individual reactions to aircraft noise; for example, a small percentage of people found the lowest noise levels extremely annoying (annoyance score, 5) and a small percentage found the highest noise levels not at all annoying (annoyance score, 0). In general, however, there is an orderly progression in annoyance as a joint function of the PNdb value and the number of occurrences per day of the noise. Using data of this sort, the British derived what they call the Noise and Number Index, or NNI. Essentially, this index states that an aircraft noise below 80 PNdb contributes little or nothing to annoyance and that the contribution to overall "noisiness" of the number of occurrences of a typical flyover sound can be represented by 15 $\log_{10}N$, where N is the number of events. Specifically, their formula is, NNI= average of peak PNdb levels $+15 \log_{10}N-80$.

The British survey revealed interesting relations between the NNI and the percentage of people reporting various types of disturbances. Some of these results are shown in Figs. 8–12.

The British procedure is essentially that developed earlier in the United States by the staff of Bolt Beranek and Newman Inc. for the U.S. Air Force (*19*) and the Federal Aviation Agency (*20*), except that the U.S. procedure equates the number of occurrences on the basis of an equal-energy concept. According to this concept the effect of repetitions of a noise becomes equal to 10 $\log_{10}N$ rather than to the 15 $\log_{10}N$ used by the British. The difference between these two methods is rather unimportant in view of the rather large variation in the ratings, by members of a community, of annoyance due to noise.

It would appear, from both the British and the U.S. studies (see Fig. 11), that an aircraft flyover sound having a noise level of 80 PNdb or less is of no concern to a community as a source of noise. There is, however, possibly some disagreement, as indicated in Fig. 11, between the U.S. and the British studies as to what level of noise from a *single* flyover would be judged unacceptable. Part of the problem here is, of course, the meaning of the descriptive words to the different groups of subjects in the several studies. In any event the data of Fig. 11 are perhaps of somewhat academic interest in that one cannot set a reasonable upper bound for allowable noise levels without considering the number of occurrences of the noise and the duration of each occurrence.

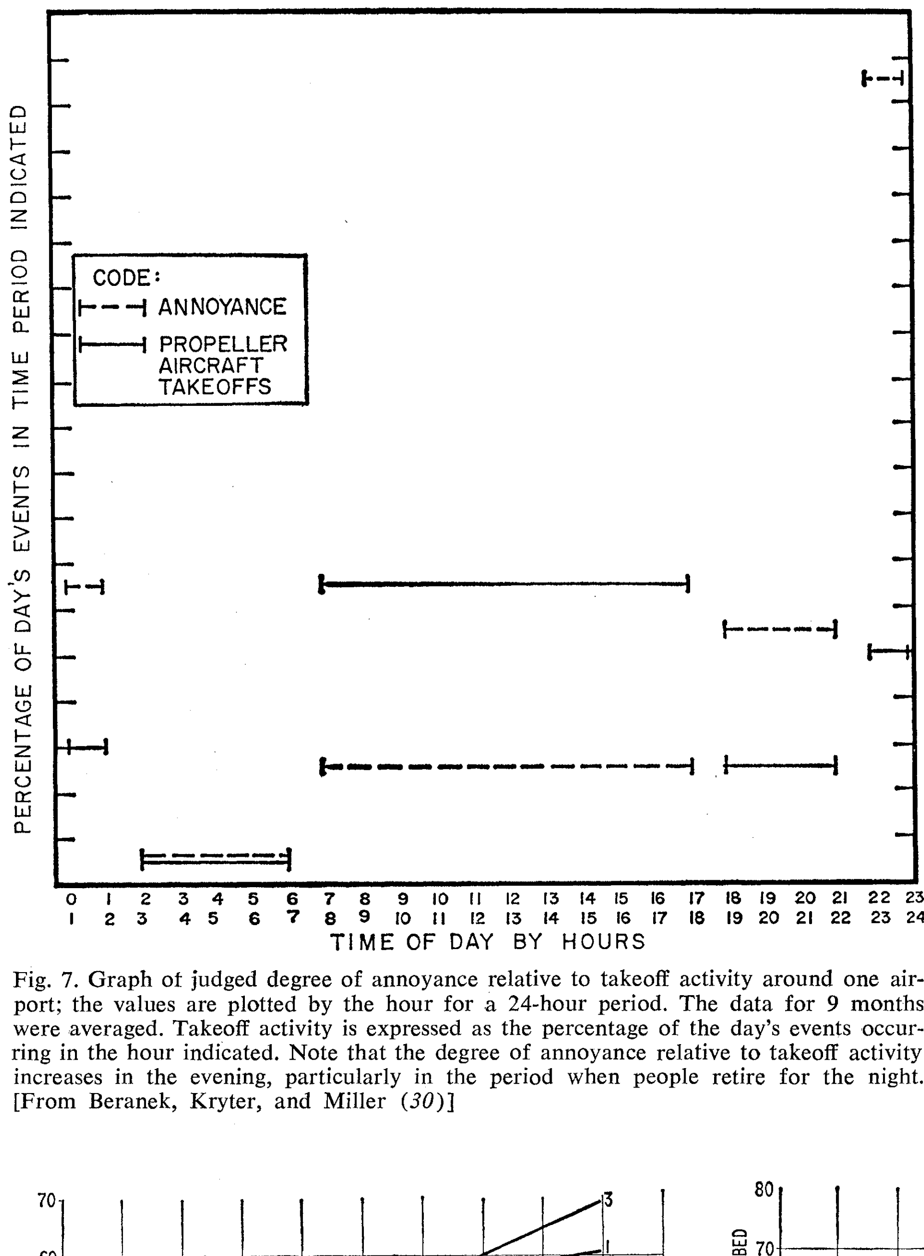

Fig. 7. Graph of judged degree of annoyance relative to takeoff activity around one airport; the values are plotted by the hour for a 24-hour period. The data for 9 months were averaged. Takeoff activity is expressed as the percentage of the day's events occurring in the hour indicated. Note that the degree of annoyance relative to takeoff activity increases in the evening, particularly in the period when people retire for the night. [From Beranek, Kryter, and Miller (*30*)]

Comparison of Different Noise Sources

One way to estimate the impact of aircraft noise upon a community is to compare the perceived noise levels for sounds generated by aircraft with those for other community noises; such a comparison is presented in Fig. 12. It is difficult to draw a single curve to represent the noise from jet aircraft, particularly following takeoff. Different aircraft have somewhat different flight characteristics, and reductions in engine power at various stages after takeoff reduce the noise level. On the other hand, the takeoff noise depicted is for short- and medium-range jet aircraft, but longer range, more powerful jets generate higher noise levels than the takeoff noise levels shown in Fig. 12. As may be seen in Fig. 12, jet aircraft noise is greater by an order of magnitude than other common noises, and it is, therefore, not surprising that communities near airports complain about it.

The Port of New York Authority, on the basis of considerations of the perceived noise level of jet-aircraft flyover sounds and the number of aircraft operations involved, has specified that aircraft shall be operated in such a way that the noise level in neighborhoods adjacent to the airports shall not exceed 112 PNdb. However, the upper limit was based on the view that the upper noise level should be

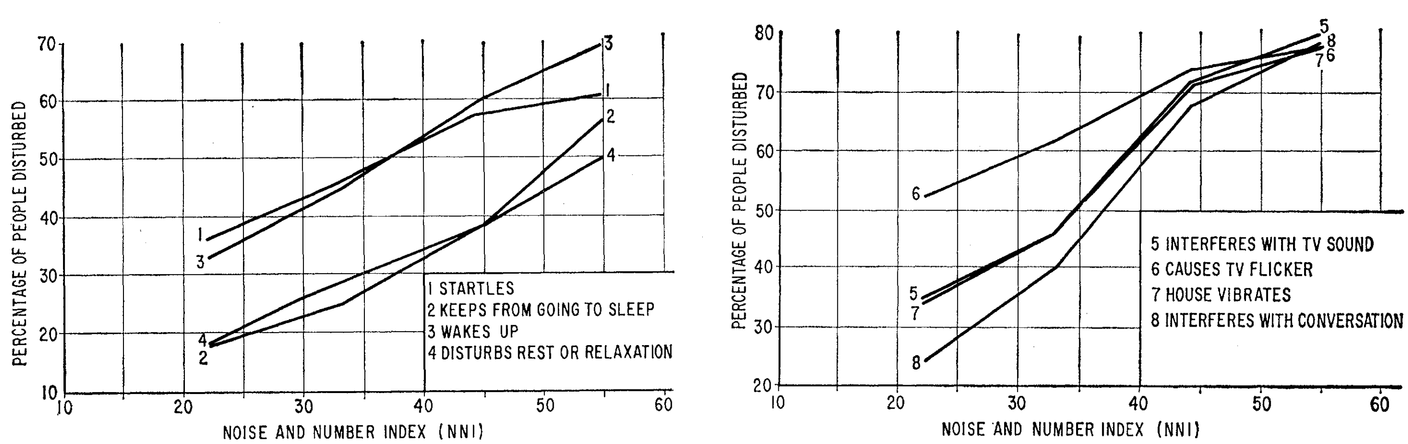

Fig. 8 (Left and right). Results of interviews in communities within a 10-mile radius of Heathrow Airport, London, showing percentages of people disturbed by aircraft noise for various reasons. [From Wilson (*10*)]

comparable to the noise level equaled or exceeded by 25 percent of the piston-driven aircraft 2½ miles from the start of takeoff roll [that is, a mile or so from the airport (*20*)]. The British Ministry of Aviation, using somewhat similar reasoning, has adopted upper limits of 110 PNdb for daytime aircraft operations and 100 PNdb for nighttime operations.

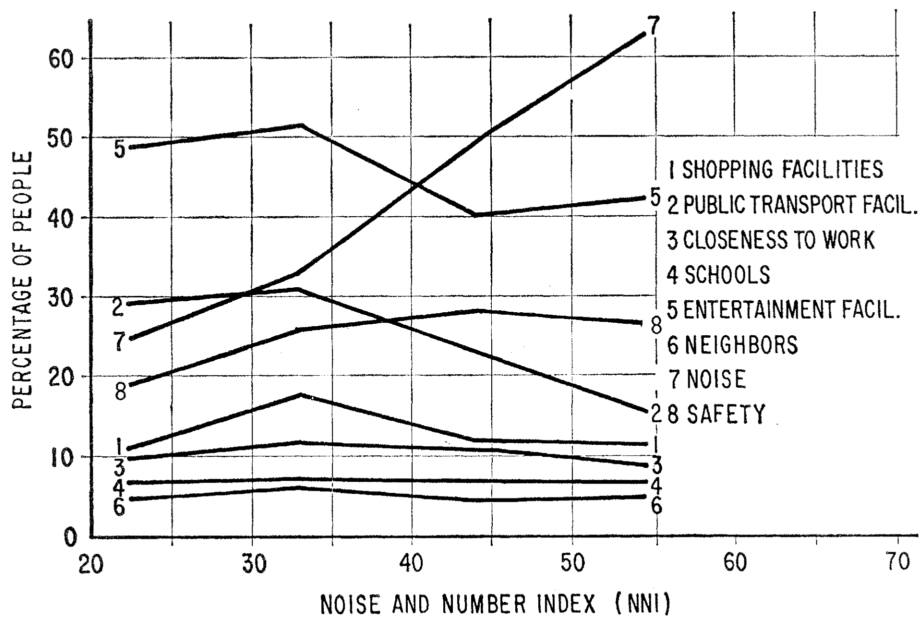

Fig. 9. Results of interviews in communities within a 10-mile radius of Heathrow Airport, London, showing percentages of people rating their area as a poor, or very poor, place to live for various reasons. [From Wilson (*10*)]

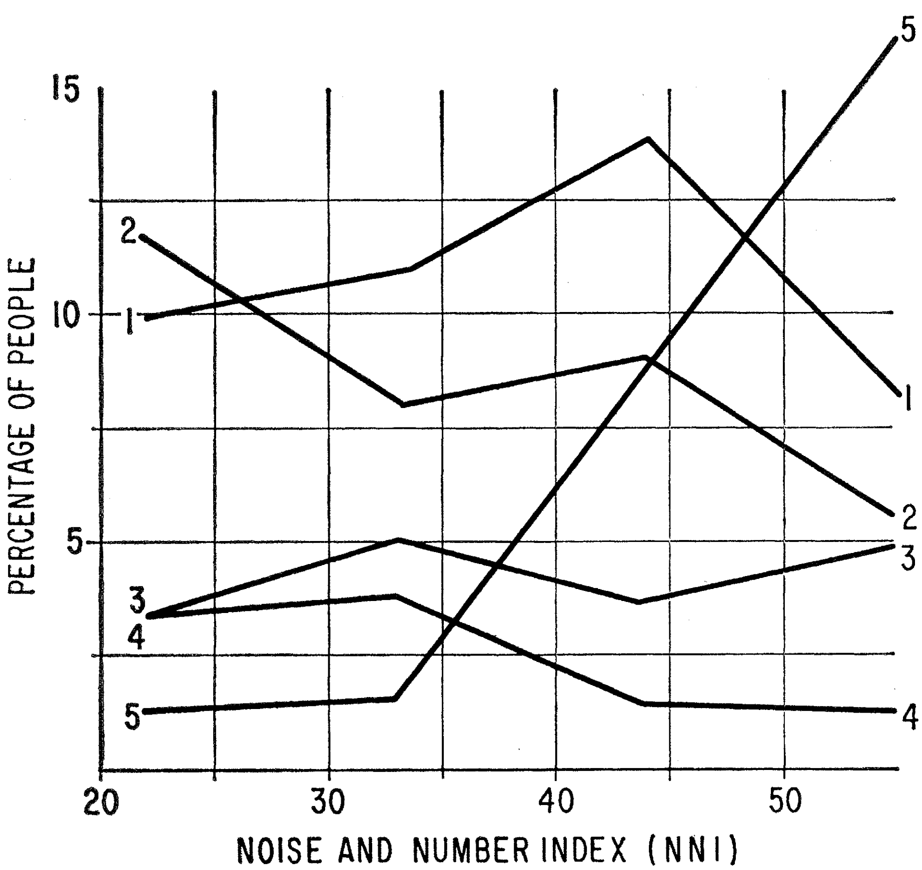

Fig. 10. Results of interviews in communities within a 10-mile radius of Heathrow Airport, London, showing percentages of people giving particular reasons for wanting to move: (1) want to go where the climate is better; (2) want better living accommodations; (3) want to get away from smoke, dirt, smells; (4) want to be nearer work; (5) want to get away from aircraft noise. [Wilson (*10*)]

Adoption of the limit of 112 PNdb by the Port of New York Authority does not mean that this is necessarily a tolerable level, particularly in view of the number of aircraft operations at New York airports. Some communities near New York airports were engaged in legal action concerning the noise from conventional aircraft prior to the introduction of jets, and lawsuits concerning the noise of jet aircraft near New York City are now in progress. These facts seem to indicate that a number of people find a distribution of aircraft noise levels whose upper limit is around 112 PNdb, unacceptable.

It is obvious that air transportation benefits a community and that air transportation is an important part of our economy and way of life. Perhaps the annoyance and disturbance suffered by some people is the price that must be paid. The noise levels can, of course, be reduced by designing or operating the aircraft so that they are somewhat less efficient (that is, are more expensive to operate) than they are now, or by locating the airports farther from communities. How much, if any, the noise must be reduced and how far the airports must be placed from the communities are still, ostensibly, unanswered questions.

Criteria of Unacceptability

People and agencies concerned with the problem of aircraft noise in communities have requested engineers and scientists to (i) quantify and categorize the effects of aircraft noise on people, and (ii) derive from the data some criterion or criteria for specifying what noise environments should be considered unacceptable.

By and large, the first of these tasks seems fairly well in hand, though further work remains to be done. But the second is a more difficult matter that depends upon the exercise of personal value judgments. Three criteria for the evaluation of aircraft noise in a community are suggested below, primarily to illustrate possible methods for using psychological and sociological data in the specification and use of such criteria.

Criterion 1. A new or novel noise environment that is comparable in basic noisiness to a noise environment known and considered by the average person to be significantly unacceptable at a residence will likewise be con-

Table 6. Number of occurrences of aircraft noise and averages for peak PNdb's exceeding 80 required to achieve a Noise and Number Index of 45 or a Composite Noise Rating of 100, for typical civil aircraft operating during the hours from 7 a.m. to 10 p.m.

Number of occurrences	Average peak PNdb	
	NNI = 45	CNR = 100
1	125.0	115
2	120.5	112
4	116.0	109
8	111.5	106
16	107.0	103
32	102.5	100
64	98.0	97
128	93.5	94

sidered significantly unacceptable at a residence. Obviously the expressions "average person" and "significantly unacceptable" render this criterion open to interpretation and adjudication. But the approach may have some merit in that it allows persons to evaluate a noise environment that is relatively unknown to them with another with which they are more familiar. Many of the people making decisions about the possible effects of aircraft noise upon people in communities near airports have not been repeatedly exposed to such a noise environment.

Figure 12 suggests that aircraft noise in excess of 100 PNdb might be considered by a significant number of people to be unacceptable in their homes, inasmuch as that is the approximate noise level 50 feet (15 meters) from trucks or motorcycles at maximum highway speed or in the course of acceleration, or 200 feet from a diesel train going 30 to 50 miles per hour. These comparisons, to be most meaningful, should include not only peak PNdb levels but also the number and duration of occurrences. In these respects the exposures to aircraft, truck, motorcycle, and train noise differ greatly, not always in favor of the aircraft noise.

Criterion 2. A noise environment having a Composite Noise Rating (CNR) (see *21*) which indicates that vigorous complaints and concerted group action against the noise may possibly be made is considered unacceptable. These are the expected responses for a CNR of 100 to 115 (see *21*). Table 6, column 3, shows the average peak PNdb levels for various numbers of occurrences of aircraft noise (column 1) which, if they occurred between the hours of 7 a.m. and 10 p.m., would provide a rating of 100.

Criterion 3. A noise environment having a Noise and Number Index which indicates that about 50 percent of the people will report that they are disturbed by the noise in various ways is considered unacceptable. Figures 8–11 indicate that such an environment would have an NNI of 45. Table 6, column 2, shows the average peak PNdb levels per occurrence which would provide an NNI of 45.

In short, it is deduced that a noise, repeated fairly often during each day, having a peak level of 100 PNdb (criterion 1) or a CNR of 100 (criterion 2) or an NNI of 45 (criterion 3) would probably be rated unacceptable by about 50 percent of the people in a residential community. It is deduced on the basis of all three criteria that 30 to 40 daily repetitions of an aircraft noise at 100 PNdb would probably be rated unacceptable by many people.

Some persons may feel that the proposed criteria and the specifications of noise environments that meet these criteria would lead to undue restriction on the generation of noise; others, on the other hand, may feel that they are not sufficiently restrictive. Although one may argue about criteria of unacceptability, the physical data that have been obtained to describe noise environments and the psychological and sociological data describing individual and public reactions to the noise environments appear to be valid and reliable.

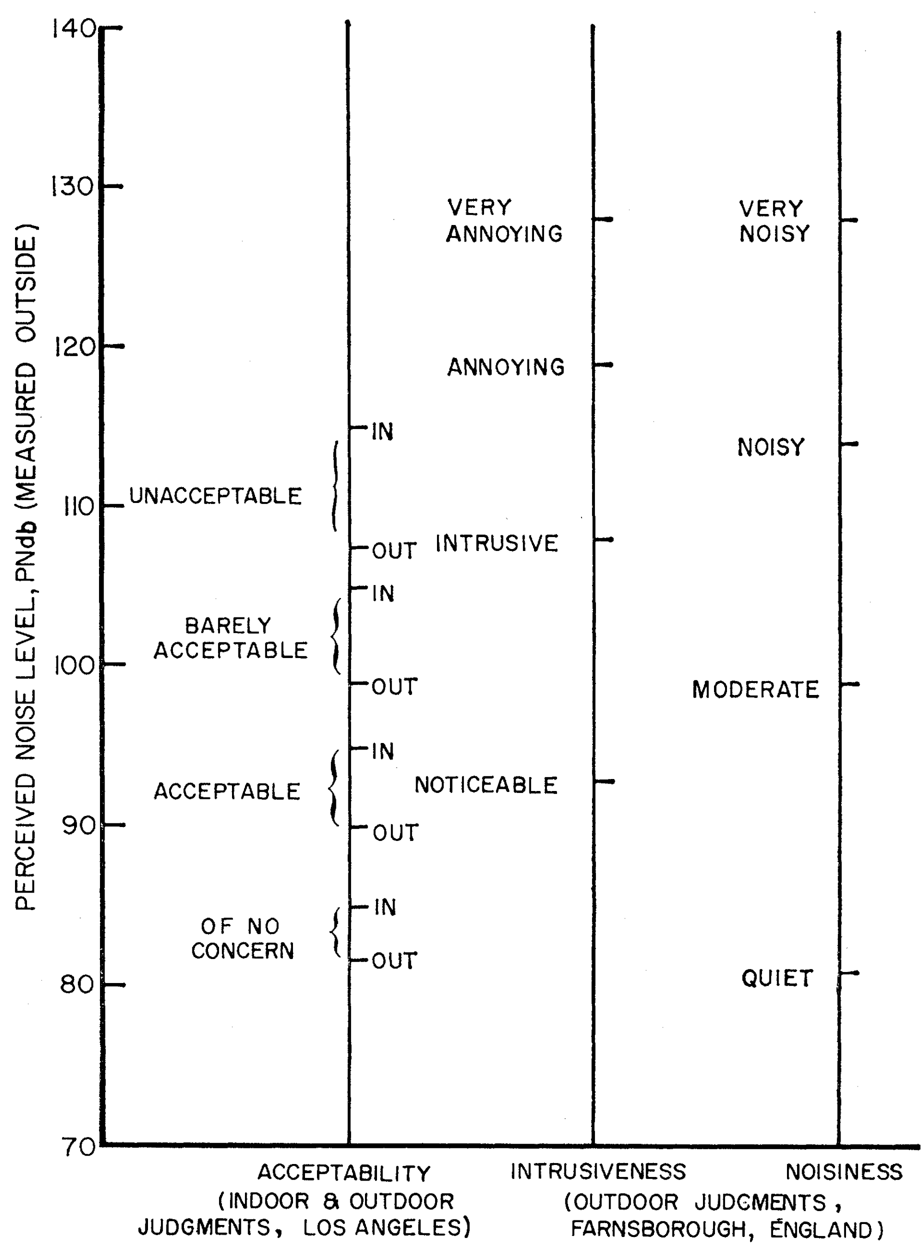

Fig. 11. Calculated perceived noise level of aircraft flyovers and corresponding scales of judged acceptability, intrusiveness, and noisiness. [From *31*]

Subjective Noisiness of Sonic Booms

Aircraft that fly at supersonic speeds are being developed in both Europe and the United States for commercial aviation. In addition to the typical jet noise made during takeoff and approach to landing, when the aircraft is traveling at subsonic speeds [a detailed analysis of this problem has been made by Greatrex (*22*)], these aircraft will generate a shock wave, the so-called sonic boom, when their speed is supersonic. The shock wave on the ground, from commercial aircraft reportedly will be of the order of 2 pounds per square foot (950 dynes per square centimeter) when the aircraft is in supersonic climb, and 1.5 pounds per square foot (720 dynes per square centimeter) at cruising altitude.

Considerable concern has been expressed over the possible adverse effects of this sonic boom upon people in their homes, and, indeed, the design, development, and operational use of the supersonic air transport are and will be strongly influenced by estimates of these effects. No definitive answers can yet be given about the possible effects, but some useful information is available (summarized in *23*) from two psychological studies of reaction to the sonic boom, by Broadbent and Robinson (*24*) and by Pearsons and Kryter (*25*).

Broadbent and Robinson conducted a laboratory study in which listeners compared the annoyance of the sound made by subsonic jet and conventional aircraft with the annoyance of sonic booms (or "bangs," as they are called in England) as heard in a house. The sonic booms were recorded on magnetic tape in a house under the flight path of the supersonic aircraft. This recording was played back over a loudspeaker system in a soundproof and semianechoic chamber. The noises from subsonic jet and conventional aircraft were recorded outdoors when these aircraft were flying overhead. The subject was asked to listen to pairs of recorded sounds—the sound of conventional aircraft and the sound of sonic boom—and to assign a numerical value for the annoyance caused by the boom relative to a value of 10 "units of annoyance" assigned the sound of the conventional aircraft.

In the studies of Pearsons and Kryter the subjects adjusted the level of recorded sound of a subsonic jet aircraft until it was equal in noisiness or acceptability to simulated sonic booms as heard indoors and outdoors. The subjects were seated in a small, airtight cubicle, and the booms and other sounds were presented by means of a loudspeaker system.

Table 7 summarizes the findings of these two investigations; when similar conditions were investigated, the results of the two studies are in close agreement. The data of Table 7 suggest several conclusions.

1) As heard by a subject outdoors

Table 7. Results of test of subjective "acceptability" of simulated sonic boom and of noise from subsonic jet aircraft. [After Pearsons and Kryter (*25*)]

	Anticipated typical sonic boom (lb/ft^2)		PNdb values for subsonic jet aircraft that would be judged of equally acceptable noisiness				Typical PNdb values for noise 1.5 miles from airport after takeoff of subsonic jet aircraft	
				Indoors*				
	Outdoors	Indoors	Outdoors	No rattle	Rattle†	Rattle‡	Outdoors	Indoors
Under flight path	1.5	0.34	92.5	81.5	95	95	112	95
± 4 miles to side of flight path	1.3	.29	91.5	82.5	94	94	70	55
± 8 miles to side of flight path	1.0	.23	90.5	79.5	92	92		

* For the indoors "no rattle" tests, a heavy metal door was used for the test chamber; for the indoors "rattle" tests, a plywood door with a glass window was used. † Pearsons and Kryter (*25*). ‡ Broadbent and Robinson (*24*).

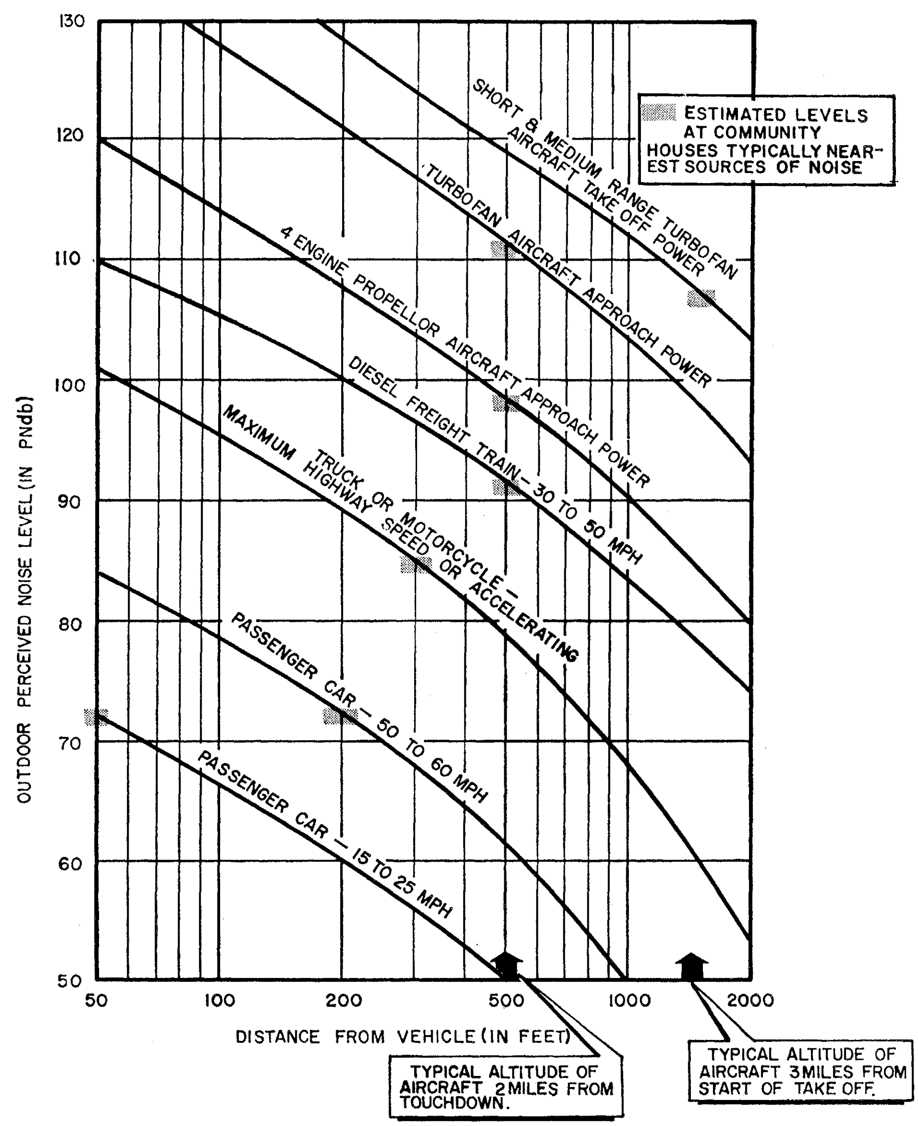

Fig. 12. Typical levels of intermittent noise produced by vehicles. An increase of 10 PNdb is usually equivalent to a 100-percent increase in subjectively judged noisiness. [After *20, 21, 32*]

and under the flight path of the aircraft, the sonic boom would be appreciably less bothersome than the sound of a subsonic jet about 1½ miles from an airport after takeoff.

2) As heard indoors by a subject under the flight path of the aircraft, the sonic boom would be about as bothersome as the sound of the subsonic jet about 1½ miles from an airport after takeoff.

3) Persons indoors not directly under the flight path of a supersonic jet but within 8 miles to either side would be bothered by the sonic boom to about the same degree as persons indoors directly under the flight path of a subsonic jet about 1½ miles from the airport would be bothered by the noise of the aircraft.

In general, one might conclude from these two studies that with the advent of the supersonic transport many more people, of the order of tens of millions (*25a*) will be exposed to a sound that is as noisy or as objectionable as that now experienced under the flight path of jet aircraft within about 1½ miles from an airport (*26*).

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Architectural Acoustics

Persisting uncertainties in the acoustical design of concert halls show the need for more basic research.

M. R. Schroeder

Several modern concert halls, among them La Grande Salle in Montreal, Canada, completed in 1963, and the Music Pavilion in Los Angeles, inaugurated early in 1965, have been acclaimed for their outstanding acoustical quality. Other new concert halls have been criticized for one or several acoustical deficiencies. London's Royal Festival Hall (1951), New York's Philharmonic Hall (1962), and Berlin's new Philharmonie (1963) are in this category. This inconsistency in the acoustical quality of concert halls, especially large halls of modern design, attests to an insufficient understanding of the important factors that make for good concert hall acoustics. This lack of understanding is manifest, to varying degrees, in all three problem areas affecting concert hall acoustics: the physical, the psychoacoustic, and the esthetic.

The physical side of the problem is characterized by the question, "Given an enclosure with known shape and wall materials, how do sound waves travel in it?" Much uncertainty exists about important details of the reverberation process, both as a function of time (sound decay) and as a function of location and direction (sound diffusion). In fact, even the measurement of some of the physical parameters presents formidable obstacles.

Turning to the psychoacoustic side of the problem ("Given a known sound field, what do we *hear*?"), we find that areas of uncertainty tend to dominate. Many basic questions relating, for example, to the subjectively perceptible differences of sound diffusion have not been tackled, let alone answered. More complex problems, such as the identification of the physical correlates of "reverberance" ("liveness"), "intimacy", "warmth," "immersion," and many

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