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SOUND-LEVEL EVALUATIONS OF MOTOR NOISE FROM PONTOON RAFTS IN THE GRAND CANYON

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Colorado River Research Program Report
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The Colorado River Research Program was initiated by the National Park Service in 1974 to secure scientific data to provide a factual basis for the development and the implementation of a plan for appropriate visitor-use of the Colorado River from Lee's Ferry to Grand Wash Cliffs and for the effective management of the natural and cultural resources within the Inner Canyons. The intensified research program consists of a series of interdisciplinary investigations that deal with the resources of the riparian and the aquatic zones and with the visitor-uses including river-running, camping, hiking, and sight-seeing of these resources, as well as the impact of use and upstream development upon canyon resources and visitor enjoyment.

Final reports that result from these studies will be reproduced in a series of Program Bulletins that will be supplemented by technical articles published as Program Contributions in scientific journals.

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ABSTRACT

The noise problem associated with the use of outboard motors on raft trips through the Grand Canyon was studied in the summer of 1973. Sound-pressure levels of the motors, measured at head level in the boat operator's station, ranged from 83 to 89 dbA, compared with background levels of 35 to 45 dbA. Noise exposures of the boatmen border on, but do not clearly exceed, present health standards, although they can cause significant temporary shifts in the hearing threshold. Vital (i.e., safety-related) communication from the boatman to passengers is not prevented because of masking by motor noise, but no verbal communication, vital or not, is possible from the passengers to the boatman. All other verbal communication, except within small contiguous groups, is hampered by the noise. Motor noise also masks natural sounds in the Canyon and, in contrast, its almost unnatural quiet. Although no effects on the boatman's ability to function can be demonstrated, the noise levels border on those which have been shown to adversely affect performance of tasks of this type. For these reasons, it is recommended that the use of outboard motors in the Canyon be either discontinued or substantially curtailed.

INTRODUCTION

Running all or part of the Colorado River through its Grand Canyon has become, in the words of Newsweek (June 18, 1973), "one of America's ultimate vacation trips." (p. 62) The tremendous growth in the number of people making such trips is in large part attributable to increased use of large, rubberized, pontoon rafts powered by outboard motors. Although such craft make this memorable experience accessible to many more people than could otherwise enjoy it, the motorized boats are objected to by many conservationists and other outdoor enthusiasts on several grounds. Arguments against the large, motorized craft include possible damage to ecological communities along the river from the pressure of large camping groups, as well as direct pollution of the river itself by oil and gasoline. However, the one factor most widely and vigorously objected to is the noise made by the motors.

Nonetheless, despite widespread anti-motor sentiment, there has been virtually no information available on the actual sound-pressure levels of motor noise, other sounds in the Canyon, or background noise. Therefore, in conjunction with a recent study of the number and carrying capacity of camping beaches along the Colorado through the Canyon, a number of sound-pressure levels were measured. Because assessment of noise levels was a secondary objective of the project and of an initial survey nature, measurements were not obtained in any pre-designed, systematic way. Representative sound-pressure levels were, nonetheless, observed for boat-motor noise under various conditions, the noise of several rapids, and background noise at different times and places. Though less comprehensive than might be desired, the observations seem adequate to support some tentative conclusions, as well as point the way for more detailed measurements in the future.

PROCEDURE

All measurements were made with a Type 1565-A General Radio Company sound-level meter, which meets or exceeds specifications in ASA S1.4-1961 (American National Standard Specifications for General Purpose Sound Level Meters, 1961). In accordance with these specifications, the meter has three different weighting networks (A, B, and C), which adjust its frequency response, primarily by attenuating the lower frequencies. Nominal weighting curves and allowable tolerances for the three networks can be found in ASA S1.4-1961 (American National Standard Specification for General Purpose Sound Level Meters, 1961) or such publications as Beranek (1960) or Michael (1972). The purpose of the different weightings is to make instrument response more nearly approximate equal-loudness contours for the human ear at various sound-pressure levels (Michael, 1972). Suggested practice is to use the A-weighting for sounds below 55 db, B for the range 55 to 85 db, and C for above 85 db (Scott, 1957). However, the A-weighted scale is used throughout in governmental specifications of permissable noise levels (National Institute for Occupational Safety and Health, 1971) and has a better-established empirical relationship to effects on man; the A-scale is, therefore, sometimes used at all sound levels. The meter provides for either fast or slow response, giving measurements of, respectively, instantaneous or time-averaged sound levels. The meter reads directly in decibels relative to a reference sound-pressure level of 0.0002 μbar.

All readings were made at the slow-response setting, giving some time-averaging of the sound levels. Whenever feasible, readings on all three weighting scales were obtained; otherwise, only the A-weighted scale was used. The choice of A-weighting was purely for convenience, although it later turned out to have the aforementioned advantage of wider use. In addition, the A-network has the maximum attenuation of the three scales, and consequently gives conservatively low readings for high-intensity sounds, especially those, such as boat-motor noise, which have strong low-frequency components. Unless otherwise noted, the quoted decibel levels are A-weighted readings in decibels relative to the 0.0002 μbar reference.

RESULTS

All sound-pressure levels measured during the trip are listed in Table 1 by date and mile number from Lee's Ferry, Arizona, the embarkation point. Background noise levels varied from 35 to 53 dbA. The lowest level, 35 db, was recorded twice, once during the day in an unusually quiet, calm section of the Canyon and once in the evening. The highest background value, 53 db, occurred on a windy day. Other background sound-level measurements ranged from 40 to 45 dbA.

Boat-motor noise ranged from 52 dbA for an approaching 20-hp raft through 61 dbA on the front of our 20-hp raft and 66 dbA on the front of the 40-hp National Park Service raft to 86 dbA at the boatman's ear level on the 20-hp raft and 89 dbA at a similar location on the 40-hp raft traveling at high speed. At cruising speed, the more-powerful motor was actually somewhat quieter than the smaller one, measuring 83 dbA, although a difference that small may not be significant. Kryter (1970) cites a maximum noise of 85 dbA at the operator's ear for an outboard motor of unspecified size. For power boats he gives a range (for the seat nearest the motor) of 83 to 104 dbA at cruising speed. Thus our observations appear to be fairly typical of noise levels for outboard motors.

Sound-pressure levels produced by rapids were found to average about 60 dbA along shore for the two smaller rapids at which measurements were made. A noise level of 69 dbA was recorded from shore at Lava Falls Rapid, the most violent on the river, Readings at the most violent, and therefore loudest, part of this or any other rapid were not taken because

Table 1. Decibel readings.

Mile Number	Date	Scale A	Scale B	Scale C	Remarks
7.8	7/7	54	58	60	Badger Creek Rapid. 300 feet downstream. 9:15 p.m. High water.
	7/7	61	64	65	Shoreline. 200 feet from rapids.
	7/8	51	53	56	300 feet downstream. 6:30 a.m. Low flow.
18	7/8	52	54	58	18 Mile Wash. High flow. 300 feet back from water.
	7/8	58	61	63	At water's edge.
	7/8	48			Low water. 300 feet back.
26	7/10	35	37	40	Quiet section. Background reading.
28.5 to 28.7	7/10	61			Front of boat underway.
	7/10	86			Head level at operator's station.
	7/10	41			Background. Marble Canyon Walls.
37.1	7/10	40	43	45	
40 to 41	7/11	83	86	89	Readings taken from NPS boat (Mercury 4400). Cruising speed at operator's head level.
	7/11	89	91	93	High speed at operator's head level.
	7/11	66			Forward end at cruising speed.
95.7	7/13	35			Evening. Background.
175.7	7/19	52			Passing 20 hp raft. Upstream approach.
	7/19	54			Abreast.
	7/19	59	60	62	Downstream 300 feet.
	7/19	53			Background (windy).

Table 1.--Continued.

Mile Number	Date	Scale A	Scale B	Scale C	Remarks
178.5	7/19	45			Background. Upstream of Lava Falls.
179	7/19	57			Just upstream from Lava Falls.
179.2	7/19	65	67	69	Abreast of Lava Falls. 50 feet above u on rocks
	7/19	69			Water level just below Lava Falls.
204.7	7/19	80	77	76	Noise of Cicada in willows at adjacent shoreline.

of the difficulty and danger of using the meter during transit of the rapids.

The loudest natural sound observed was the strumming of cicadas, which reached 80 db on the A scale. This noise level may be somewhat misleading since the measurement was made with the meter thrust into the foliage of a willow thicket which was swarming with the insects. From a few feet away the sound was much less intense.

For comparative purposes, Figure 1 shows selected Canyon sounds plotted on a decibel scale opposite similarly plotted more-familiar sounds. The lowest background readings can be seen to be no louder than a soft whisper. Lava Falls Rapid on the other hand produces a sound level comparable to that 100 feet from a moving freight train. The noise level at the boatman's ear on the 20-hp raft compares to that just 50 feet from a diesel truck moving at 40 mph. The 40-hp raft moving at high speed subjects the boatman to the noise-equivalent of standing only 20 feet from a moving subway train.

SOUND LEVELS MEASURED IN GRAND CANYON		SOUND LEVELS OF COMMON ENVIRONMENTS OR NOISE SOURCES
	130	
		Jet takeoff (200')
	120	
	110	Riveting machine
	100	
		Textile weaving plant
40-hp motor at boatman station		
	90	Subway train (20')
20-hp motor at boatman station		Diesel truck at 40 mph (50') Pneumatic drill (50')
	80	
Cicada noise		
Lava Falls (at water level just below falls)		Freight train (100')
	70	
Front of boat with 40-hp motor		Speech (1')
Badger Creek Rapid (200')		
Front of boat with 20-hp motor		Near freeway (auto traffic)
	60	
Passing boat with 20-hp motor		
Lava Falls (0.2 mile upstream)		
Background - windy day	50	Light traffic (300') Average residence
Background - Marble Canyon	40	Minimum levels - residential area in Chicago at night
Background - day (quiet section) Background - evening		Soft whisper (5')
	30	
	20	Studio for sound pictures
	10	
	0	Threshold of hearing

Figure 1. Comparisons of Canyon sounds with other familiar sounds.

DISCUSSION

The problem of noise pollution is rarely a simple one in any context and certainly not in this instance. The complexity of the issue arises partly from the variety of effects noise may have, partly from our inability to measur most of these effects in any really precise way, and partly from differences among individuals in the way such effects are perceived. While there is reasonable unanimity about the definition of noise as "unwanted sound" (Harris, 1957), the question--unwanted by whom and how vehemently--remains moot. It isn't difficult to think of sounds which are nois to a 40-year-old but music to a teenager (or perhaps vice versa).

Despite this basic ambiguity, however, few would conte that the sound of an outboard motor is not noise. Whether it constitutes noise <u>pollution</u> is a function primarily of its effects on people. Three different groups may be affec by the noise: (1) the boatmen and helpers who actually ru the motors; (2) passengers on the motor-driven craft; and (3) passengers on unpowered rafts and boats on the river a the time, plus any hikers who may be near enough to hear the motors.

Noise may affect man in three different ways: (1) impairment of hearing, possibly permanent; (2) masking of wanted or incidental sounds, including, but not limited tc speech; and (3) physiological or psychological changes whi affect attitude, behavior, or ability to function. Each of these possible effects will be discussed as it relates to the different people affected.

LINE A

FORMULA: $T = 16 \div 2^{(L-80)/5}$

RANGE: 80 to 115 dbA-slow

LINE B

FORMULA: $T = 16 \div 2^{(L-85)/5}$

RANGE: 85 to 115 bdA-slow

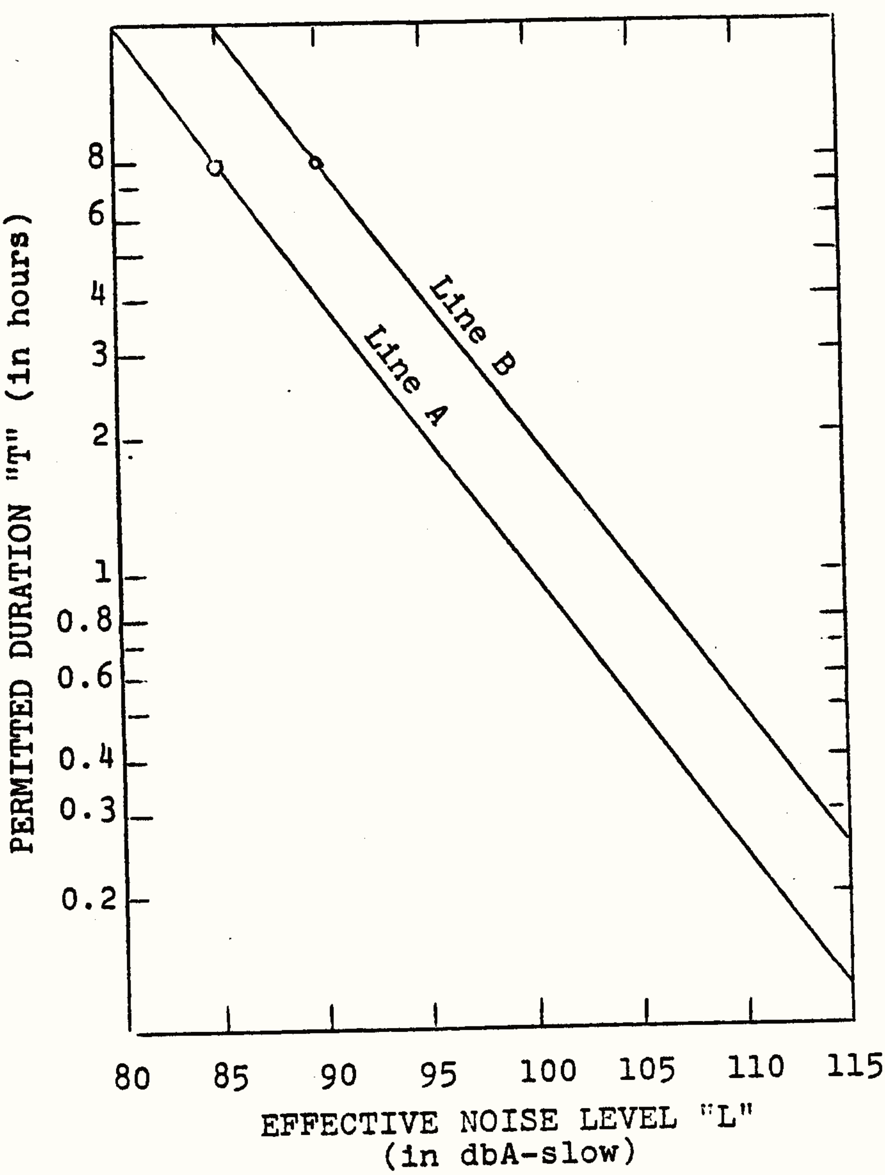

Figure 2. Permitted duration vs. noise level.[1]

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[1]The indicated duration limits which exceed 8 hours are to be used only for purposes of computing daily noise dose and are not to be regarded as defining noise exposure limits for work days which exceed 8 hours.

Impairment of Hearing

That high-intensity noise can cause both temporary and permanent hearing loss is an established fact. Damage-risk criteria for permanent hearing loss as established by the American Conference of Governmental Industrial Hygienists (ACGIH) are shown as line B in Figure 2. Line A shows the somewhat more stringent critical limits proposed for the future by the National Institute for Occupational Safety and Health (N.I.O.S.H.). Comparison of these lines with the data of Table 1 indicates that only the boatmen are exposed to noise of sufficient intensity to cause danger of permanent hearing loss. Reading from line B, the time of exposure to such levels (approximately 90 dbA) necessary to incur risk is about 8 hours daily, continuing throughout a normal schedule of work days (N.I.O.S.H., 1971). The corresponding period under the proposed new criteria (line A) is 4 hours. The nature of most river trips is such that the motors are not normally run continuously for more than 2 or 3 hours at a time. Total running time in any given day seldom exceeds 6 or 7 hours. Each individual boatman is likely to have from several days to a week layoff between the end of one trip and the beginning of the next. In addition, the job is seasonal with about a five-month duration at most. In view of the measured noise levels, and bas on present standards, corrective or protective procedures ar not mandatory for boatmen. However, even under current standards, their noise environment is marginal. Therefore any increase in motor noise should be avoided and persons with sensitive hearing should not be encouraged to be motor boatmen. There is essentially no possibility that either passengers or bystanders can incur permanent hearing loss as a result of exposure to outboard motor noise under the condi tions extant on most raft trips.

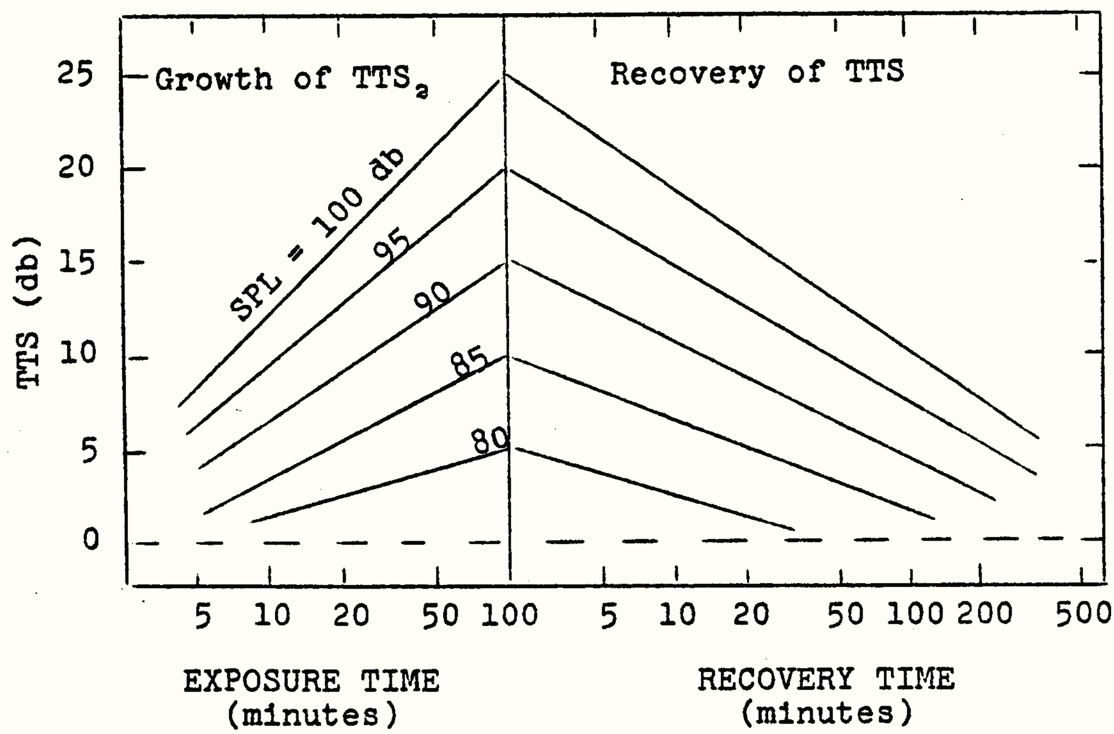

Figure 3. Growth and recovery of temporary threshold shift as a function of time. Adapted from Ward (1970, p. 563).

Temporary hearing loss may be another matter. Exposure to high-intensity sounds for even relatively short periods of time can produce significant temporary shifts in the threshold of hearing; i.e., the lowest sound level which can be detected by an individual. Temporary threshold shift (TTS) is most often measured as the change in the threshold two minutes after cessation of the noise from what it had been prior to exposure. Defined in this way, it is called TTS_2. Figure 3 shows the growth and recovery curves for TTS used by the Committee on Hearing, Bioacoustics, and Biomechanics of the National Academy of Sciences and National Research Council (CHABA) for establishing damage risk criteria.

Boatmen operating typical pontoon rafts at normal cruising speeds are exposed to noise levels of approximately 85 to 90 dbA (see Table 1). Exposure periods may range from a few minutes to several hours. There are normally several such periods in any one day, with similarly varying periods of quiet interspersed. Based on the criteria of Figure 3, such noise levels may produce TTS_2's of 10-15 db in less than 2 hours (100 minutes exposure time in Figure 3). Longer exposures could be expected to produce correspondingly greater shifts. Also significant in this regard is the fact that recovery from TTS is slower than its growth. Thus, even if the periods between exposures are equal in length to exposure periods, complete recovery will not occur. In such cases, the effects of subsequent exposures will be added to the residual effects of prior ones, producing still greater temporary losses. These losses will, in general, be completely recovered overnight (see the 85 and 90 db intercepts with the recovery time axis in Figure 3). However, the important fact is that the typical boatman, throughout the major part of his working day, is handicapped by an inability to hear sounds that he normally could. The consequences would in most instances be insignificant or, at worst, annoying. In some circumstances, however, the consequences would be serious. They include decreased ability to hear warnings or cries for help from passengers or others, approaching boats, falling rocks while on hikes, etc., or aircraft overhead at a time when communication with the "outside" is necessary (as for example when a member of the party is ill or injured). Most of these are closely related to and overshadowed by the consequences of the masking of sounds by the motor noise, to be discussed later.

On the basis of our measurement of sound-pressure levels in other parts of the boat, and of passing boats, it is unlikely that passengers would experience TTS of any significance, unless seated much closer to the motor than is normal practice. There is, further, virtually no likelihood that persons on unpowered boats or on shore would experience even slight temporary hearing loss from the noise of passing motors.

A more detailed, technical discussion of noise-induced threshold shift, both temporary and permanent, can be found in Kryter (1970).

Masking of Wanted Sounds

A second possible effect of motor noise is the masking of speech or other sounds. While speech communication would not at first seem to be of any great consequence during a river-running trip, it may be quite important for two reasons. First, most boatmen, in addition to their strictly manual duties, also serve as interpreters of the river and canyon environment, constantly pointing out features of biological, geological, and historical interest and importance. If passengers are unable to hear such commentary, they are deprived of a significant part of the total experience. Secondly, the dangers inherent in traversing a wild and violent river through wilderness area make it necessary that rapid and effective emergency communication be possible. The boatman may need to convey instructions or warnings to the passengers at a time when he also needs the full power of the motor to control the boat. Similarly, passengers may need to communicate with the boatman in emergency situations, either to call for aid or to warn him of obstacles or other impending dangers he may not see. Such occasions are not common and most, of course, occur during the running of rapids. However, the depth, swiftness, and treacherous currents of the Colorado coupled with the unfamiliarity of many passengers with wild environments make emergency situations possible at any time in the trip.

Such communications would take place in an acoustical environment that our measurements show is dominated by motor noise averaging about 85 db at the boatman's ear. Decibel levels decrease logarithmically with distance from a point source in a free field at the rate of about 6 db for each doubling of the distance (Young, 1957). Figure 4 shows a hypothetical plot of the variation in decibel levels with distance calculated on the assumption that the foregoing conditions are met and that the boatman's ear is 1.5 feet from the noise source. The most forward point likely to be occupied by a passenger is about 25 feet from the motor. The actual noise level measured at that point was 61 db, which differs from the hypothetical value by only 1 db. This suggests that the assumptions on which the curve is based are met well enough for the purposes of the following interpretation.

Passengers normally occupy that part of the boat from about 5 feet to about 25 feet forward of the motor. Figure 4 then indicates that they would be subject to noise levels in the range from about 60 to 75 db. Although noise levels vary with many factors, the boat and motor on which our

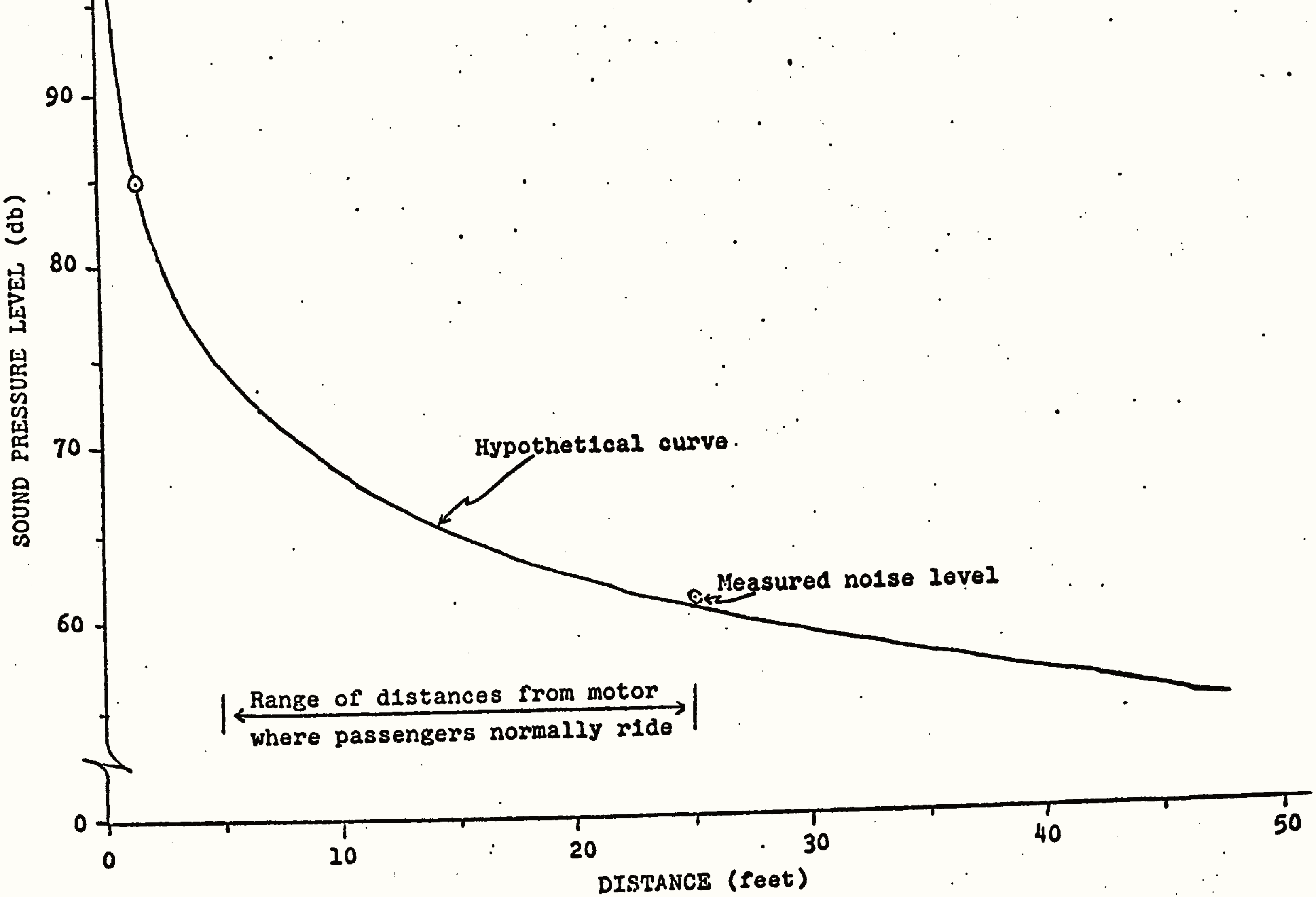

Figure 4. Hypothetical variation with distance in sound-pressure level of noise with 85 db SPL at 1.5 feet (Young, 1957, pp. 2-12).

observations were made are fairly typical and the measurements are representative of the situation on almost any large pontoon raft.

The effects of noise on speech communication are summarized in Figure 5, adapted from a paper by Webster (1969) which also forms the basis for much of the following discussion. The parallel, solid, diagonal lines represent combinations of noise level and distance which permit satisfactory face-to-face communication at the indicated voice levels. At noise levels below about 47 dbA, satisfactory speech communication in a normal voice is possible at distances up to about 32 feet. When exposed to noise levels higher than about 57 dbA, speakers begin to increase their voice levels. For normal communication this increase is about 3 db for each 10 db increase in noise level and is represented on the graph by the lower of the two dashed, diagonal lines. When communication is considered vital, the increase is about 5 db for each 10 db increase in noise level, represented by the upper, dashed, diagonal line on the graph. As an example, consider the expected voice levels for a speaker surrounded by noise of 75 dbA. In Figure 5, the vertical, dotted line through 75 dbA on the sound-pressure level (SPL) axis intersects the lower expected voice level line at the "raised voice" level. This indicates that a person exposed to noise of 75 dbA will speak in a raised voice for normal communications. Projection of this point to the distance axis shows that he could be heard satisfactorily only up to about 2 to 3 feet away. A similar consideration of the line representing expected voice level for vital communications indicates that a very loud voice would be used and that communication would be satisfactory up to about 6 feet away.

The effect of noise on communication among people on the boat is complicated by the fact that the noise level is different from one part of the boat to another. Thus a speaker may be in noise at one level while the listener is subjected to noise of either higher or lower intensity. It can be assumed that the amount of vocal effort exerted by a speaker is determined by the noise level at his location, since he probably has no means of assessing the noise level where the listener is. The basic graph of Figure 5 is reproduced in Figure 6. Noise levels at several locations on the boat are shown along the SPL axis by circled numbers indicating distance, in feet, forward of the motor.

The dotted, vertical line through 85 dbA represents the noise environment at the boatman's station. It intersects the expected-voice-level curve for normal communication about midway between the lines representing "raised" voice and "very loud" voice. The dotted line, marked 1-1, through this intersection parallel to the voice-level lines indicates the voice level which a boatman would be likely to employ for non-vital communications, such as the interpretive commentary referred to earlier. People in any combination of noise level and distance from the boatman which falls below and to the left of this line could hear him satisfactorily. Some actual combinations of noise level and distance on the boat are indicated by the circled letters A, B, C, and D on the graph, representing, respectively, locations 25, 15, 10, and 5 feet forward of the motor. All of them are somewhat above and to the right of the expected-voice-level line, indicating that clear communication would not be possible. However, these points are near enough to the expected-voice-level line so that remarks might be at least partly understood. If the boatman speaks more loudly than he perceives to be necessary, communication from boatman to passengers is possible. For interpretive commentary, either speaking or listening or both will be strained and certainly not relaxed. This interpretation

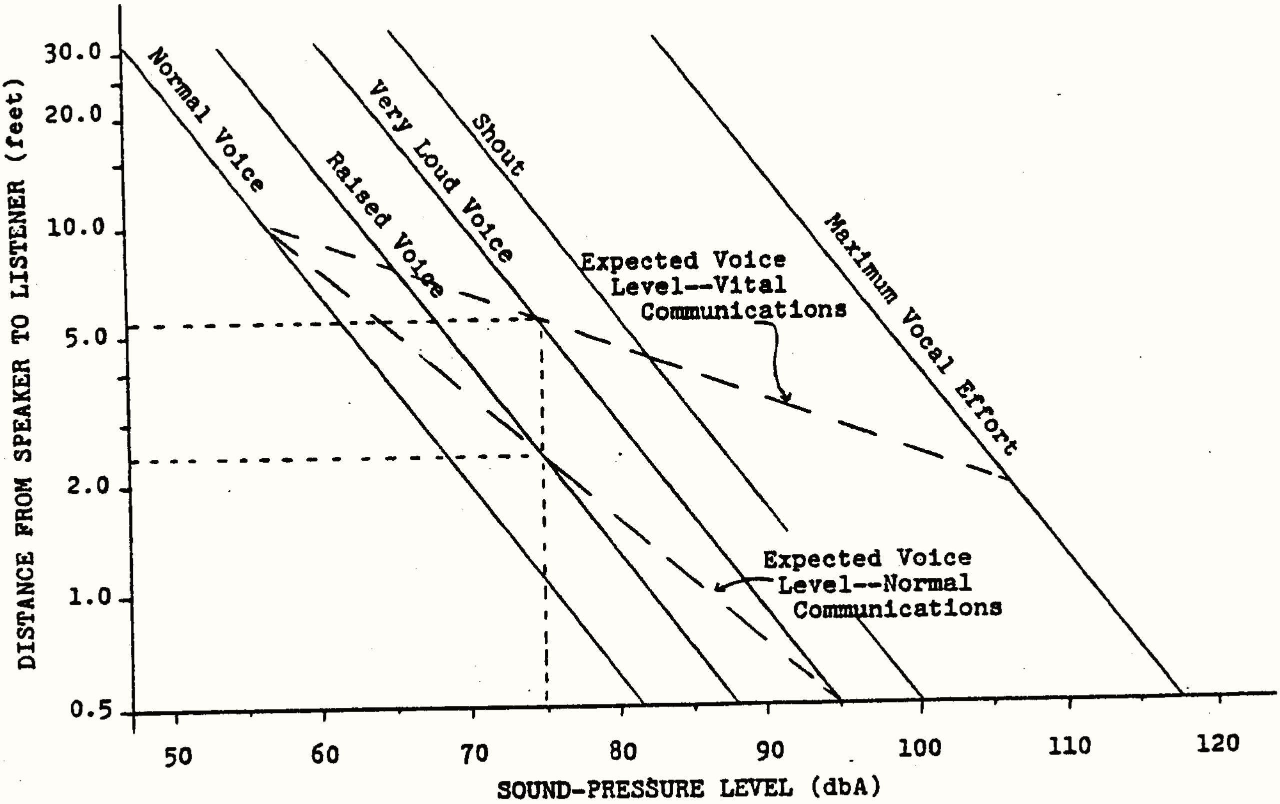

Figure 5. Relationships among ambient noise, voice level and distance from speaker for satisfactory face-to-face communication. (Adapted from Webster, 1969, p. 69.)

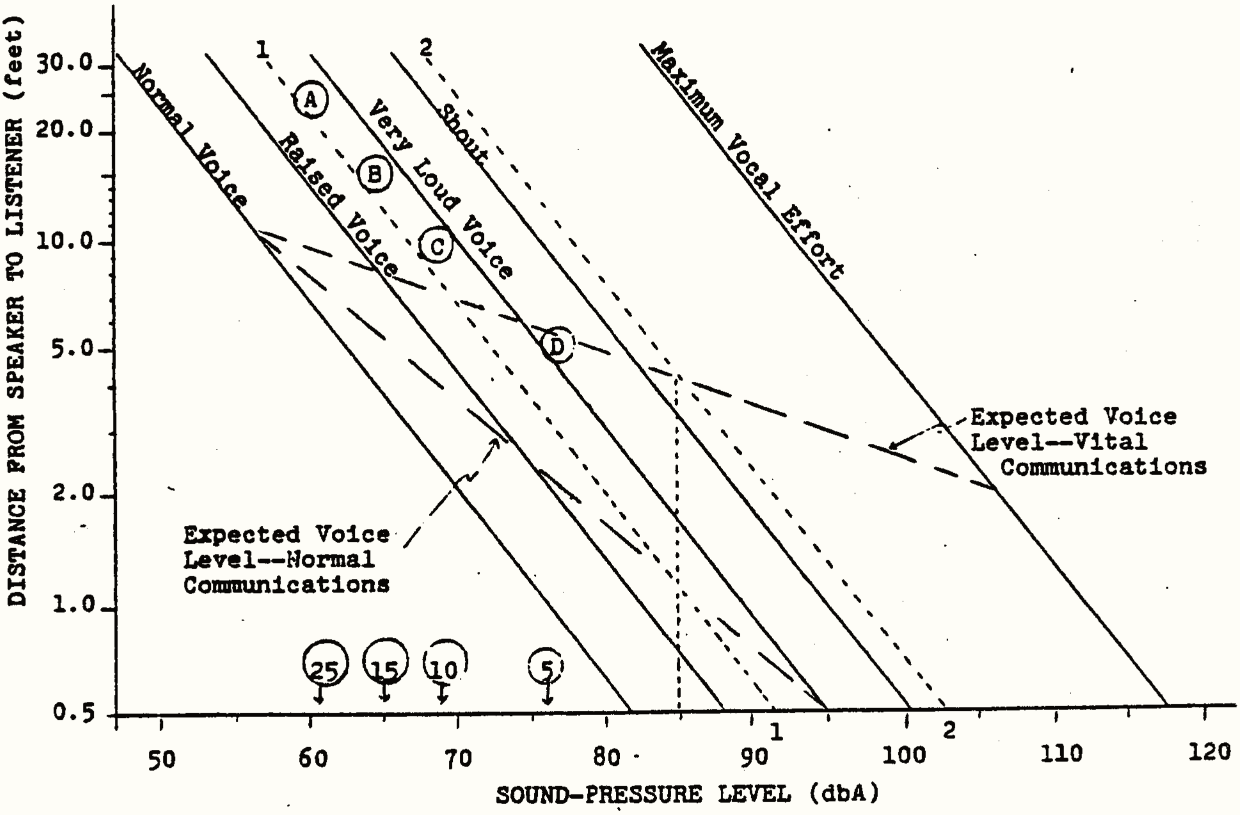

Figure 6. Relationships among noise, voice level, and distance as they affect boatman's ability to communicate with passengers.

conforms with our actual experience on the trip. Most of us could understand the interpretive commentary of our boatman only with the motor off. With the motor running, we could hear well enough to know he was speaking, but could understand only fragments of what was said, a situation which most of us found quite frustrating.

The dotted voice-level line marked 2-2 is the expected voice level the boatman would employ for communications which he considers vital, such as safety instructions, warnings, etc. It can be readily seen that all combinations of noise level and distance possible on the boat are well below and to the left of this curve. Motor noise would not, therefore, seriously interfere with vital communications from the boatman to the passengers. This conclusion is also supported by our experience. In no case did we have difficulty in hearing safety instructions or other vital messages from the boatman, even with the motor running. The foregoing, of course, ignores the possibility of additive effects of the motor noise in conjunction with other sounds, such as the roar of rapids, which may be significant but which would require much more elaborate studies for evaluation.

When communication in the other direction (i.e., from passenger to boatman) is considered, the situation changes. Further inspection of Figure 6 shows that in no case would the passenger's expected voice level, even for vital communications, be loud enough for the boatman to hear. Even a shout could not be heard by the boatman from beyond about 3 feet, and from 25 feet maximum vocal effort would not be enough. The same would be true for people on other boats or on shore who might want to communicate verbally with the boatman. Again, the interpretation drawn from the data is confirmed by our actual experience. On at least two occasions during our trip, beaches on which we wanted to make observations were missed because the boatman did not hear shouted requests to land. It can be concluded, therefore, that before any meaningful sound communications with a boatman from beyond his immediate proximity is possible, his attention must first be gained by some visual means, so that he can quiet the motor. If this cannot be done for some reason, such as the need for power to control the boat in hazardous waters, then the communication must be entirely visual. This, of course, places a tremendous burden of alertness and vigilance on the boatman. While most boatmen bear their responsibility admirably, the potential for accidents that might otherwise be avoided persists as long as verbal communication to the boatman is prevented by motor noise.

The general effects of motor noise on ease of communication among the passengers can also be deduced from Figure 6. Passengers near the front of the boat (indicated by the circled 25 on the graph) would find no difficulty in communication at normal voice levels. Those near the back of the boat (5 feet forward of the motor) on the other hand would find it necessary to speak in a raised voice in order to be heard by someone only 2 feet away. Near the center of the raft (10 to 15 feet forward) conversation in a normal voice would be possible up to 2 to 4 feet, with the natural increase in voice level in response to noise increasing that distance to 4 or 5 feet. Since most of the passengers are likely to be in the area from 10 to 25 feet forward of the motor, conversations within small contiguous groups would not be seriously hampered. It would, however, be difficult for someone near the front of the boat to communicate effectively with someone near the rear. Once again, this interpretation is consistent with our recollections of our experience on the river.

Sounds other than speech may also be masked. The previously mentioned profound quietude of most of the Grand

Canyon makes every natural sound--the ripple of currents, braying of wild burros, roar of rapids, squawking of ravens, even the music of songbirds--stand out in dramatic contrast, if they can be heard. Outboard motor noise partially or wholly masks these and other natural sounds as well as obliterating the quietude of the environment. Thus, while the motor is running, the sound dimension of the wilderness experience is denied and detracts from the enjoyment of those passengers to whom such aspects of nature are important.

Effects on Attitude, Behavior, or Ability to Function

Of the possible effects of noise, those on attitude, behavior, and ability to function are the most difficult to assess objectively. Two basic questions are involved: (1) Does motor noise adversely affect the boatman's ability to do his job with maximum safety and effectiveness? and (2) Does motor noise seriously detract from the quality of the wilderness experience for either the passengers on the motorized rigs or other people in the Canyon?

Sounds or noises are known to affect the physiological state of the body. Jansen (1969) found that noise of 90 db caused reduced pulse amplitude and reduced blood volume in the skin due to vasoconstriction. Dilation of the pupils of the eyes also resulted from noise of that intensity. Other studies (Cohen, 1969) have shown adverse effects of high-intensity noise on balance or equilibrium with the effect most evident for unequal stimulation of the two ears. Visual accommodation can also be affected with the speed of eye movement through certain angles reduced and focusing on near and distant objects slowed. These are examples from among the many kinds of physiological responses which have been observed and which have been reviewed comprehensively by Kryter (1970). All such effects are small and have been observed only at relatively high (ca. 90-130 dbA) noise levels. Their importance stems not from the magnitude of any single response, but from the possibility that they are part of an array of physical effects which in toto can influence the individual's ability to function.

Whether noise does in fact adversely affect the ability of a person to function is in dispute. Some authorities, notably Kryter (1970), contend that, except for the obvious case where the task requires voice communication, no such effect has been conclusively demonstrated. Rodda (1967) says that "for every study showing impairment of efficiency there is at least one other showing that there is no impairment of efficiency." (p. 52) Broadbent (1957), Cohen (1968, 1969), and others, on the other hand present evidence of definite decrements in the performance of certain kinds of tasks while finding no effect on others.

According to Cohen (1969), studies with noise levels below 90 db rarely show adverse effects. With respect to higher-intensity noises, he makes the following generalizations:

1. There is no effect on simple repetitive tasks, and the effect on more complex tasks is transitory.
2. Noise affects the quality rather than quantity of work.
3. Performance in noise fluctuates more widely than in quiet, but the overall level changes very little.
4. Noise is most likely to impair performance of tasks which place great demands on the worker.

In particular, Cohen (1968) has pointed out that the ". . . most consistent laboratory evidence for noise-performance losses have been found in vigilance-type tasks." (p. 914) These are described as tasks in which the individual must maintain constant alertness for faint or inconspicuous signals which occur infrequently and at random over long time periods. Both this description and generalization number 4 above seem unquestionably to apply to the boatman's job. His is a physically demanding job, performed over long hours, with substantial periods of relatively routine cruising during which he must maintain constant vigilance for proper raft operation as well as for passenger safety. The demand for vigilance is compounded by the fact that he cannot hear verbal communications. Furthermore, the running of rapids, at least the more violent ones, may tax his dexterity to capacity while he still must maintain vigilance for signs of danger or distress to the boat or passengers.

Thus, while it is unlikely that adverse effects on a boatman's performance can ever be shown conclusively, it is apparent that the boatman's job is of the type which is most likely to be affected by exposure to noise. Furthermore, the noise levels to which we have shown the boatman is exposed border on the levels (ca. 90 dbA) for which adverse effects have been demonstrated. Therefore, the possibility that such adverse effects do occur is quite real, although it does not seem possible to assess their magnitude or importance.

The other important aspect of the effects of noise is how it affects the overall experience of visitors to the Grand Canyon. Noise can be annoying, as anyone who has tried to sleep within hearing of a dripping faucet or a snoring spouse must know. In a similar way, the sound of an outboard motor seems to many people to be an anachronism or even an intrusion in the abnormal hush which seems to so strongly impress every author who has written about or artist who has tried to portray the Grand Canyon. On the other hand, many people who have been equally impressed and awed by the Canyon would have been denied that experience were it not for the intrusion of the motors. Although our measurements put some dimensions on the problem, the basic question in this regard cannot be answered on the basis of these data alone.

CONCLUSIONS

With regard to permanent impairment of boatmen's hearing, the noise levels generated by outboard motors do not clearly exceed present health standards, but are high enough to be considered marginal. Temporary hearing loss to boatmen during motor operation is virtually certain, but recovery would be complete overnight. For passengers and others, neither permanent nor significant temporary hearing loss is likely.

No problem exists for vital (i.e., primarily safety-related) communication from the boatman to passengers. However, both vital communication from passengers or others to the boatman and two-way communication between the boatman and passengers are precluded by the masking effect of motor noise.

Non-vital communications, such as conversations among party members, interpretative commentary by the boatman, and questions to the boatman by passengers, are all degraded to some extent by motor noise. None of this communication can take place at normal, relaxed voice levels except within small contiguous groups. Interpretive commentary by the boatman cannot be clearly understood, except at a very loud voice level. Inquiries to the boatman are essentially not possible.

In the presence of motor noise, natural environmental sounds or the lack of sound can never be sensed by party members.

Although it cannot be concluded that motor noise affects the performance of the boatman, the job is of the type most likely to be affected and the noise levels are such that they are known to affect performance.

In summary, outboard motor noise is a deterrent to normal, relaxed conversation that one would expect in such an environment, a safety hazard in raft operation, and a health hazard to the motor boatmen.

RECOMMENDATIONS

It is recognized that noise is not the only factor affecting decisions with respect to outboard motor use in the Grand Canyon. Party size, trip duration, impact on the Canyon environment, operational safety, and scheduling flexibility are other factors which merit consideration along with outboard motor noise. The data upon which these recommendations have been made are not comprehensive in coverage of the variety of rafts and motors commonly used in river-running. However, the data and subsequent analysis were exceedingly consistent with theory and human experience. It is recommended that comprehensive data be collected and analyzed according to the methodology used in this study to augment the findings of this study and thereby reinforce or modify the following recommendations.

The evidence of adverse effects of motor noise contained in this report compels the recommendation that the use of outboard motors be substantially reduced or eliminated.

There do not appear to be any reasonable alternatives which would allow unlimited use of outboard motors. Quieter motors are not available with the necessary power; ear protection for boatmen solves only part of the problem while compounding the communications problem; and no other alternatives seem to exist. The only complete solution to the noise problem appears to be a complete ban on outboard motors. A partial solution to the overall problem would be to regulate the use of motors to certain parts of the river and under certain conditions. For example, motors might be permitted in the section of the river affected by Lake Mead for propulsion in those sluggish waters or in emergencies to gain more rapid transit to a lift-out point. In these cases, the problems associated with motor noise would be eliminated for most of the river and for most of the time, in contrast to present usage.

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