STUDIES OF THE RESPONSE OF FISH TO LOW FREQUENCY VIBRATIONS

by

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INTRODUCTION

Studies of the response of salmonids to sound have been conducted by Moore and Newman (1956), and Burner and Moore (1953). Those studies did not describe any response that could be used to attract or repel any particular species.

The most positive results have been obtained by the California Department of Fish and Game (Painter1/), using a sound generator invented by Mr. Ernie Murphey. Using this type of generator at the Granlee Canal in the Sacramento Valley, they were able to obtain guiding efficiencies of 74 to 100 percent with downstream migrating salmon.

This paper reports the results of field studies on the responses of salmonids to random noise in the low frequency range using a generator similar to the California type. Also reported are preliminary results of laboratory studies on the response of fish to discreet vibration frequencies.

FIELD TESTS

Equipment and Procedure

Carson Flume Tests

The first tests were conducted in the Carson behavioral flume located at the Carson National Fish Hatchery, Carson, Washington. The tests were conducted in a wooden flume 50 feet long, 6 feet wide, and 4 feet deep. The sound, or vibration barrier (fig. 1) was located at the downstream end of the flume. The barrier consisted of five vibrating plates 3 feet by 4 feet, of sixteen-gauge steel sheets installed in a vertical position parallel to flow. Plate no. 1 was mounted 10 inches away from the flume wall. Each succeeding plate was mounted 10 inches away from the preceeding plate and staggered 12 inches downstream.

The first, third, and fifth plates had a 3/4-inch Cleveland Air Vibrator2/ (a device similar to the Murphey generator) attached to the lower front corner of the plate

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1/ Painter, Richard. Personal communication describing tests of sound studies conducted in the Cosumnes River area.

2/ Trade names referred to in this publication do not imply endorsement of commercial products.

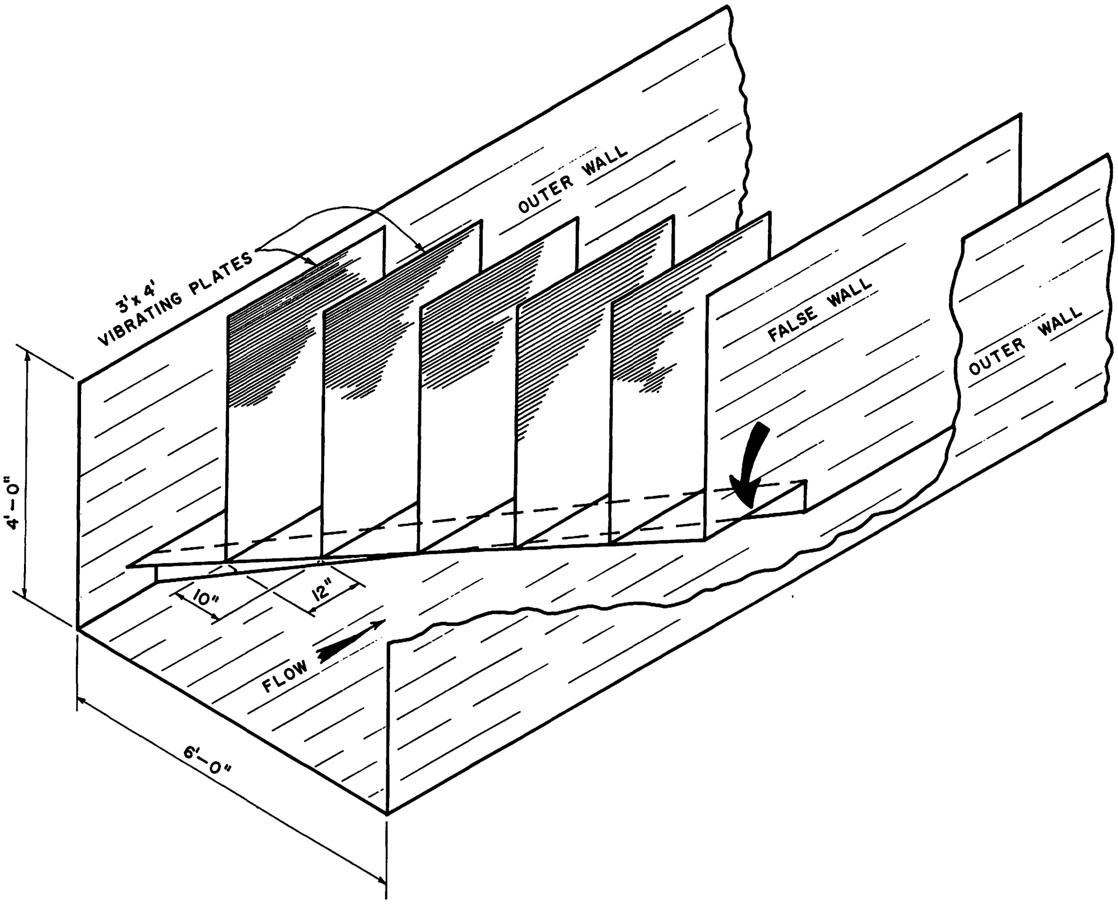

Figure 1.--Diagrammatic view of sound barrier showing vibrating plates. Note horizontal bypass (arrow) angled across floor and leading into side bypass.

(fig. 2). These vibrators were actuated by 80 pounds of compressed air supplied by a portable air compressor. At this pressure the vibrator had a vibration rate of 270 cycles per second.

Horizontal and vertical bypasses (fig. 1) were installed to allow the fish to migrate through the flume without traveling through the sound barrier.

For testing, the flume was filled with water, the depth and velocity were adjusted, and the vibrators actuated. Juvenile spring chinook (Oncorhynchus tshawytscha) 3 to 5 inches in total length were taken from one of the hatchery raceways and placed in the flume at the upstream end. The response of these fish to the vibration barrier was observed for periods of 1 to 6 hours.

Maxwell Canal Tests

Following the Carson tests the study was transferred to the Maxwell test site near Hermiston, Oregon. These tests were to investigate further the possibility of using the vibration techniques developed at the Carson site. The experimental area was considerably larger than that at the Carson facility and the water was more turbid. Wild migrant steelhead were used in these tests.

Maxwell Canal is an integral part of the irrigation project that diverts water out of the Umatilla River near Hinkle, Oregon, for distribution to farms in the Hermiston, Oregon, area. The canal is of earthen construction, approximately 25 feet wide and 4 feet deep. Downstream migrating steelhead (Salmo gairdneri) from 5 to 10 inches in length enter the canal in May and June. These migrants are diverted back into the river at a facility located about 3 miles downstream from the diversion dam. A plan view of this facility, which was used as the test site, is shown in figure 3.

The facility consists of two channels, one 10 feet wide, the other 5 feet wide. Within each of these channels there is a louver line which guides fish to a bypass and into a trap. At the downstream end of each channel, a recovery net was installed to catch any fish which might go through the louver lines during the testing periods.

The vibration barrier located upstream in front of the 10-foot channel was similar to the one used during the Carson studies. It consisted of ten 3-foot by 4-foot plates, with vibrators driven at 270 c.p.s. attached to alternate plates.

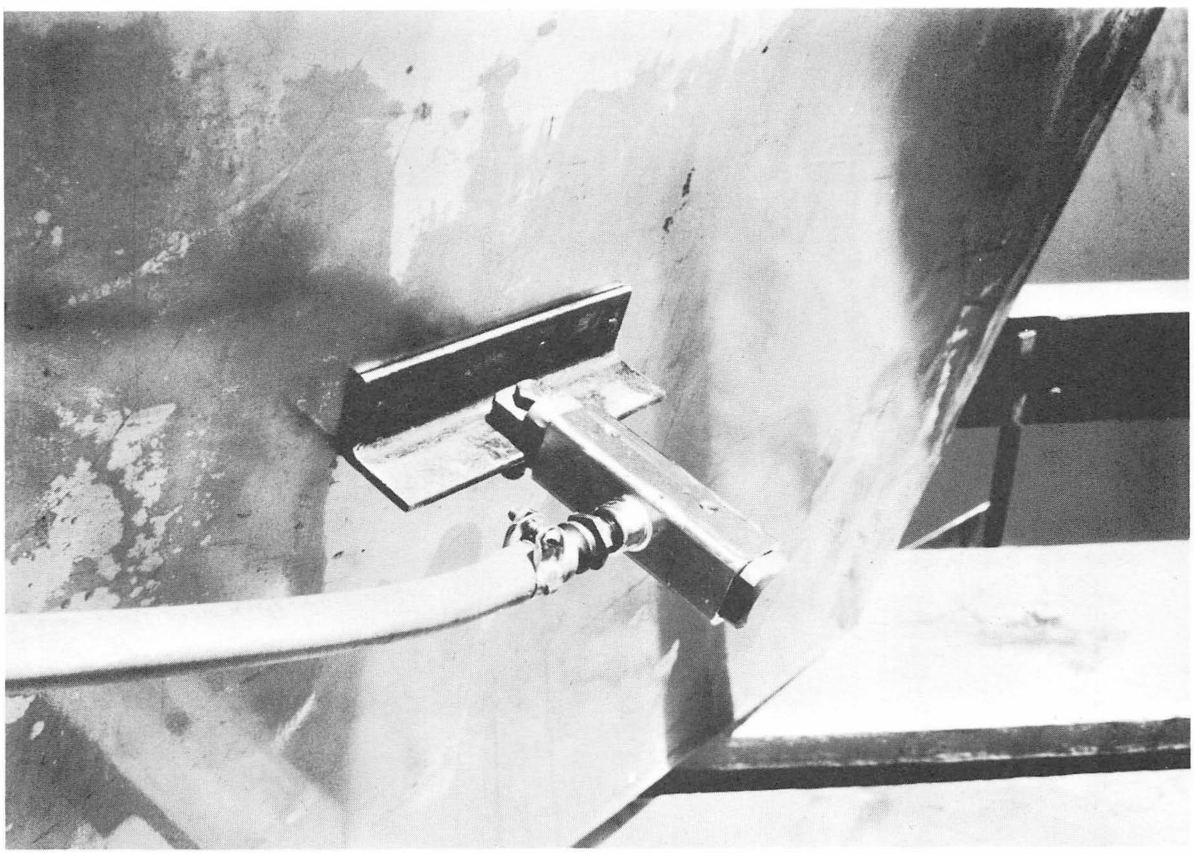

Figure 2.--Portion of vibrating plate with vibrator attached.

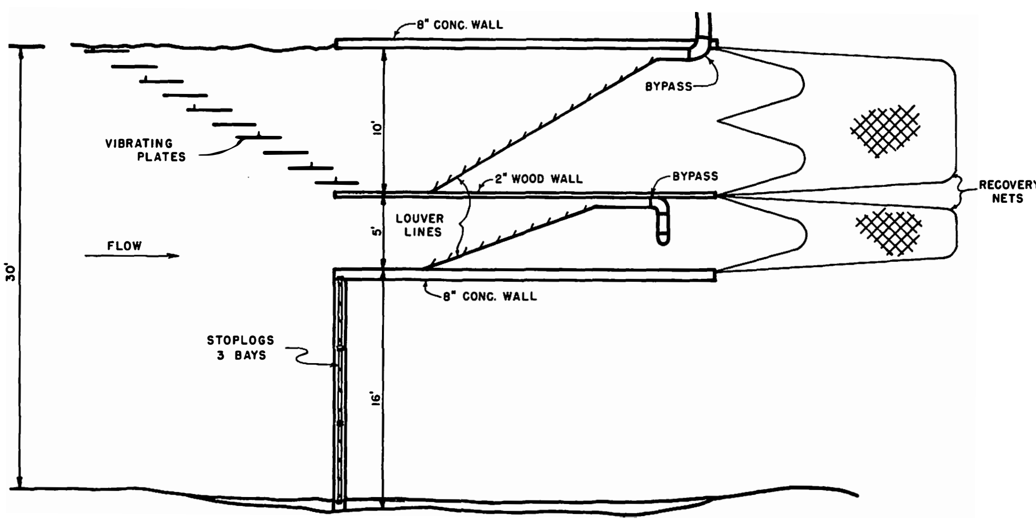

Figure 3.--Plan view of Maxwell Canal test site.

The water approached the vibration barrier at a velocity of 1.3 to 1.7 feet per second. The water depth varied between 30 and 48 inches. Although Secchi disc readings fluctuated over a wide range they were generally around 2 feet.

As fish migrating down the canal approached the test structure, they had the choice of entering the 10-foot channel by passing through the sound barrier, or of going around it and migrating through the 5-foot channel.

Before the vibration equipment was installed at Maxwell, the percentages of the migrating population entering the 5-foot and 10-foot channels were established with the aid of the louver lines and recovery nets. Approximately 11 percent of the fish entered the 5-foot channel, the balance passing through the 10-foot channel. After the plates were installed but not actuated, approximately 32 percent of the fish entered the 5-foot channel.

Results and Discussion

Carson Flume Tests

Fish used in the Carson tests tended to avoid the vibrating barrier. Of the first groups placed in the channel, several hundred moved directly downstream, dived below the barrier, encountered and followed the angled sill (horizontal bypass), and passed into the vertical bypass. During subsequent tests, this response no longer appeared. Fish that moved downstream while the barrier vibrated did not appear to choose the bypass. Fish placed in the flume when the barrier was not vibrating would migrate through the array without hesitation.

Soon after the first group of test fish had been placed in the flume, it became evident that they could feel the influence of the vibrations throughout the flume. Apparently the vibrations from the plates were transmitted to the floor and walls of the flume which then became a source of vibration the fish could detect. Fish introduced into the upper end of the flume would generally depress and stay within a few inches of the floor. Almost every fish stayed at least 12 inches away from the walls. After long periods of exposure, some fish would drift down the flume and through the plates, or the 1-foot bypass.

While these tests were being conducted, approximately 5,000 of the Carson reared fish which had been released from the hatchery, took up residency in a pool immediately above the flume entrance. During the sound tests small numbers of these fish would enter the flume. When the barrier vibrated, these fish would remain at the upper end of the flume; as soon as the sound was turned off they would migrate through the flume.

If an efficient deflector using high intensity vibration can be developed, the possibility of injuring fish exposed to it must be considered. Preliminary tests in which groups of fish were held within 2 feet of a vibrating plate for 45 minutes showed no visible harm to the fish. These fish were held in a pond for an observation period of 48 hours and no mortality was noted.

Maxwell Canal Tests

The percentage of the fish migrating down the canal which entered the 5-foot channel increased from 32 percent with a non-operating barrier to 77 percent with vibration. A total of 221 fish migrated through the site during the testing period of this group--171 entered the 5-foot channel.

The results of the Carson tests and of those conducted by the California Department of Fish and Game indicated that salmon approaching the barrier tended to deflect downward. The turbidity of the water at Maxwell precluded any observation of the steelhead as they approached the barrier. Assuming they would react in a way similar to the behavior of the migrant salmon, it is possible that a bypass located under the barrier along its entire length would have caused higher deflection efficiencies at the Maxwell site.

No attempt was made to determine if the barrier was discouraging the migrants from moving into the test area. Because of the mud banks of the canal and the greater dimensions of the site, it was assumed that the reverberation experience at Carson was not a problem during the Maxwell study.

Having found that sound of some unknown frequency and force would cause fish to respond, field studies were discontinued in favor of laboratory studies where more precise determination could be made on the nature and effect of sound.

LABORATORY TESTS

Equipment and Procedure

Equipment

After the Maxwell tests, studies were initiated at the Boeing Developmental Center Vibration Laboratory, Seattle, Washington. The purpose of these studies was to define the response of juvenile migrant salmonids to discreet vibration frequencies between 10 and 500 cycles per second. This study, still in progress, will determine the critical frequencies and levels required to accomplish efficient deflection of downstream migrating salmonids.

The experimental apparatus consisted of two main parts: the vibration chamber, and the electromagnetic vibrator with its various electronic controls (fig. 4). The chamber, measuring 18 inches by 18 inches by 6 inches, was constructed of aluminum and plexiglass. Plexiglass was used in the construction of the chamber to allow observation of the fish during the testing period. A 2-inch hole in the top of the tank was used for filling and emptying the chamber. A threaded plug with a stopcock was used to close this hole during the tests.

Pressure sensing transducers, one in a plexiglass side and one in an aluminum end of the chamber, constantly monitored the pressure inside the chamber. The G-level force exerted in the chamber during the testing periods was measured with an accelerometer attached to its base.

The chamber was bolted to a 2-inch-thick magnesium plate that rested on a slippery table. A thin layer of grease was spread on top of the table to allow the plate to slide freely. The magnesium plate, bolted to the vibrator, transmitted the vibrations from the vibrator to the test chamber. The vibrator was a Ling Model 246 electromagnetic exciter. For the purposes of this study it vibrated at frequencies from 10 to 500 cycles per second at a maximum G level of 5.

Handling Procedure for Test Fish

The fish used in the Boeing vibration studies were juvenile spring chinook, 3 to 5 inches in length, held at the Behavior and Physiology Laboratory in Seattle, Washington. At the beginning of each test day, approximately 50 fish were removed from a holding tank and placed in a plastic bucket containing 3 gallons of water, and 8 cubic centimeters of MS-222 (5 percent solution). At this concentration the fish were in a deep anesthesia in a few seconds. As soon as the fish were anesthetized they were transferred from this bucket to a commercial-type chest containing 20 gallons of water. The water temperature in this chest was maintained at the same level as the water temperature in the holding tank. The dissolved oxygen concentration was 8 p.p.m. or greater.

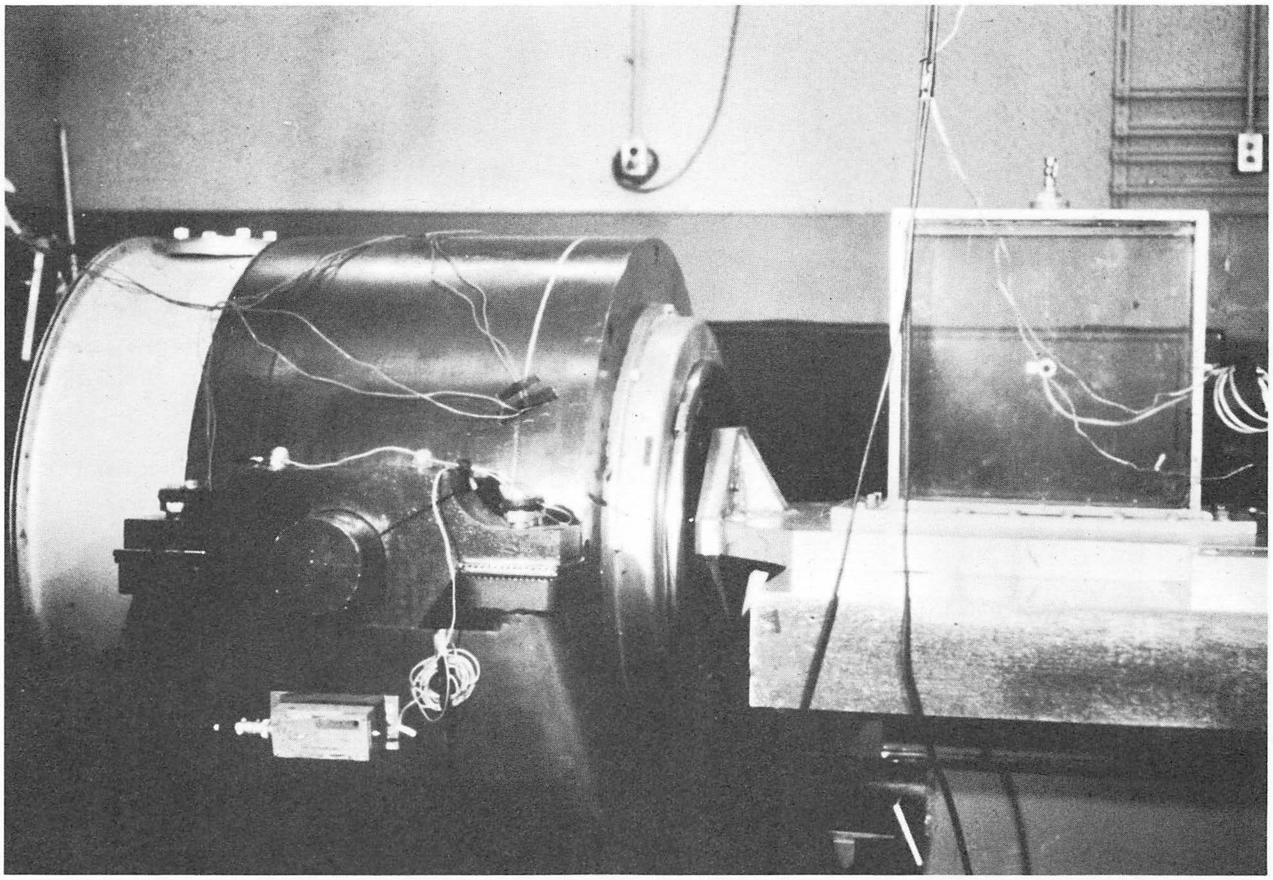

Figure 4.--Sound test chamber mounted on slippery table. Electromagnetic exciter is seen on left hand side.

After the fish were placed in the chest, it was sealed and transported to the Boeing Development Center. Upon arrival the chest was opened and an air stone was placed in the tank to provide oxygen during the test day. The water was maintained at the initial temperature by the addition of ice when needed. In order to keep the fish quiet and allow handling without an undue amount of stress, a low concentration of MS-222 was used in the chest. The lid of the chest remained open during the testing period to allow the test fish to acclimate to the light present in the laboratory. At the completion of the test, all fish were returned to the ice chest which was then sealed and transported back to the Behavior Laboratory. There, the fish were held in separate tanks for an observation period of at least 3 weeks.

Test Procedure

To conduct a test, the chamber was filled with water of the same temperature as the water in the fish holding tank. The air bubbles which were trapped against the top of the chamber were removed by a vacuum tube and the stopper was placed in the top of the tank. The chamber was then filled to the top and the stopcock turned to the "off" position. The fish were allowed to remain in the test chamber for approximately 15 minutes before the beginning of vibration to provide time for them to recover from prior use of the anesthetic. After this recovery period, the test was started and the fish responses to the various vibrations were noted. At the completion of a test, the chamber was opened and the fish were anesthetized. This made it possible to remove the fish from the tank with a minimum amount of disturbance and injury. As soon as the fish were removed, the tank was drained, and refilled with fresh water and the next test was started.

RESULTS

Two types of response were noted during the study period. The first was a loss of equilibrium, interrupted by short periods of erratic swimming. The second response was an escape action in which the fish swam very rapidly around the chamber. Fish exhibiting this response often ran head first into the walls, or into other fish.

The loss of equilibrium occurred at a frequency of 60 cycles per second at the 3-G level. This response was also evident at the 30 and 180 c.p.s. frequency at the 3-G level. The escape response was noted at several frequencies and G levels. However, the most violent reaction was obtained in the 80 and 180 c.p.s. range at a G level of 3 or greater.

DISCUSSION

The responses at the 60-, 80-, and 180-c.p.s. range were all obtained at a 3-G level exerted on the tank. This is not necessarily the force that was experienced by the fish. The resonant frequency of the chamber may have amplified the force two or three times. Another factor that varied independently of the frequency was the pressure within the tank. Figure 5 shows the pressure within the tank at the various frequencies between 15 and 500 c.p.s. The pressure fluctuations occurring at 60 cycles, and to a lesser degree at 30 and 180 cycles, may account for the loss of equilibrium exhibited by the fish at these frequencies. The pressure fluctuated over a 1.5 pounds per square inch range approximately 100 times per minute at 60 cycles, smaller fluctuations occurring at 30 and 180 cycles. These fluctuations also occurred to a lesser degree at 80, 120, and 240 cycles, but no loss of equilibrium was exhibited by the fish at these particular frequencies.

The escape response was noted at several of the vibration frequencies. The frequency at which the fish gave the most positive and consistent response was in the 70- and 88-cycle range at an acceleration level of 3 G's. At this frequency the fish would frantically swim around the tank, seeking an escape from it. This reaction would continue as long as the chamber was vibrated at this frequency. As soon as the vibration ceased the fish would settle to the bottom of the tank and remain nearly motionless. If the vibration was resumed, the fish would again begin searching for a way out.

No loss of equilibrium was observed during tests at 70 to 88 cycles. As can be noted on figure 5 there was no appreciable amount of pressure fluctuation over this frequency range. No significant mortality of test fish occurred in the 3-week observation period following the tests.

The results of the preceding tests demonstrate the need for eliminating the pressure fluctuations to prevent them from affecting the response of the fish to the vibration. This will be accomplished by modifying the present test chamber to maintain a 0.25 pound per square inch of pressure in the chamber at all frequencies. Following this modification, tests similar to those already completed will be conducted to single out those frequencies resulting in the most positive escape response. Using this information, a sound transducer will be designed and built for use in the Carson flume.

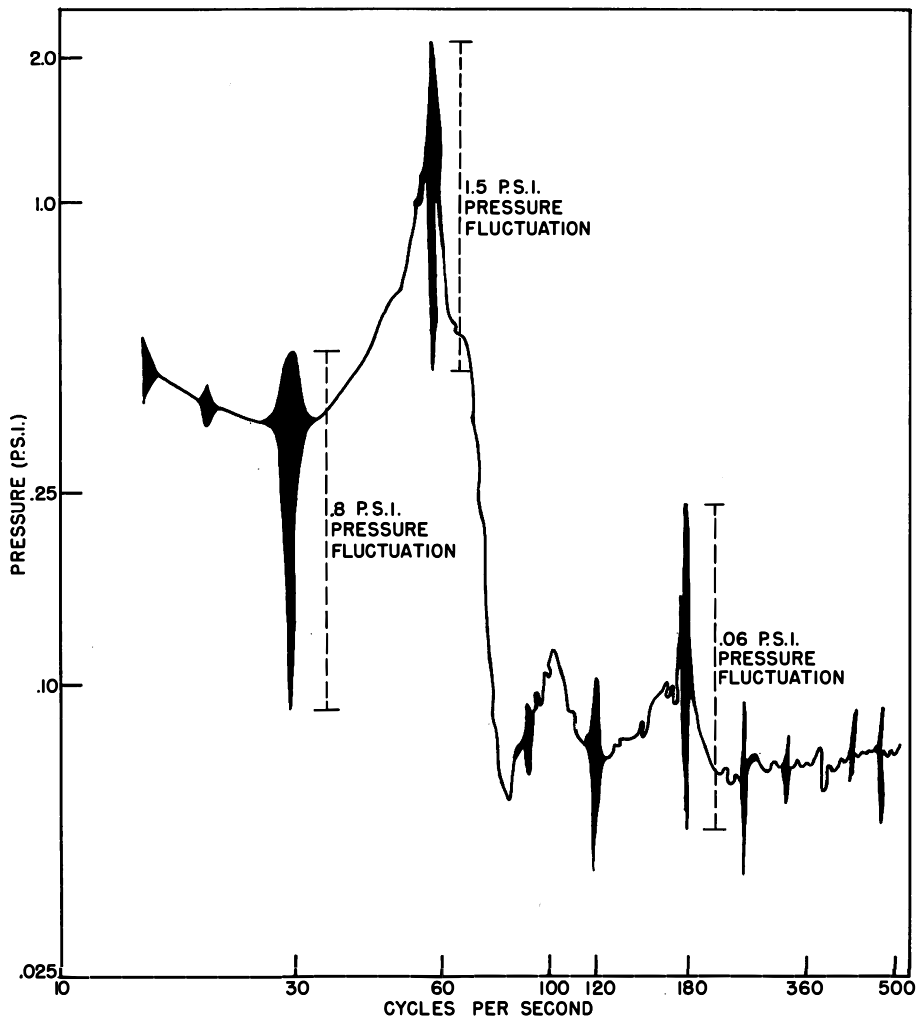

Figure 5.--Pressure within test chamber at frequencies from 15 to 500 cycles per second. Note fluctuation around 30, 60, and 180 cycles per second.

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