NASA TECHNICAL NOTE

NASA TN D-3204

c. 1

NASA TN D-3204

DESCRIPTION OF LANGLEY LOW-FREQUENCY NOISE FACILITY AND STUDY OF HUMAN RESPONSE TO NOISE FREQUENCIES BELOW 50 CPS

by Philip M. Edge, Jr., and William H. Mayes

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1966

NASA TN D-3204

DESCRIPTION OF LANGLEY LOW-FREQUENCY NOISE FACILITY AND STUDY OF HUMAN RESPONSE TO NOISE FREQUENCIES BELOW 50 CPS

By Philip M. Edge, Jr., and William H. Mayes

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $1.00

DESCRIPTION OF LANGLEY LOW-FREQUENCY NOISE FACILITY AND STUDY OF HUMAN RESPONSE TO NOISE FREQUENCIES BELOW 50 CPS

By Philip M. Edge, Jr., and William H. Mayes
Langley Research Center

SUMMARY

This paper describes a facility designed to provide a research capability for large-scale acoustic tests in the frequency range below 50 cycles per second. The capability exists for sinusoidal-, random-, and impulse-type environmental testing in the test chamber, 24 feet (7.3 meters) in diameter and 21 feet (6.4 meters) in length. Initial applications of the facility to extend the knowledge of man's behavior in low-frequency noise are described. These tests included whole-body exposure pressures of two orders of magnitude greater than man's previous experience in laboratory exposure at subaudible frequencies. Results obtained indicate that man can tolerate short-time exposures at spectrum levels in the range from 135 to 150 decibels; however, the subjects experienced some annoyance, discomfort, and fatigue and had a slower task performance rate.

INTRODUCTION

The Langley low-frequency noise facility has been built to generate intense noise for large-scale environmental testing in the frequency range from 1 to 50 cps. Environmental testing in this low-frequency range is important in noise-induced problems associated with the launch environments of vehicles in the multimillion-pound-thrust class (ref. 1).

A characteristic of noise generated by rocket-powered launch vehicles at lift-off is a decrease in frequency with increasing thrust of the vehicle. Launch vehicles of above one-half million pounds (2MN) of thrust, have predominant frequencies below 50 cps, with multimillion-pound-thrust vehicles having high acoustic levels in the subaudible frequency range of below 20 cps. In this low-frequency range there is very little experience with acoustic environments, and the concern is for effects of this environment on flight structures and systems, buildings, and humans. Effects on both flight and building structures relate to structural response, structural integrity, and acoustic transmission as it affects the internal environment. Of special concern is the presence of acoustic inputs below the fundamental vibration frequencies of the structure.

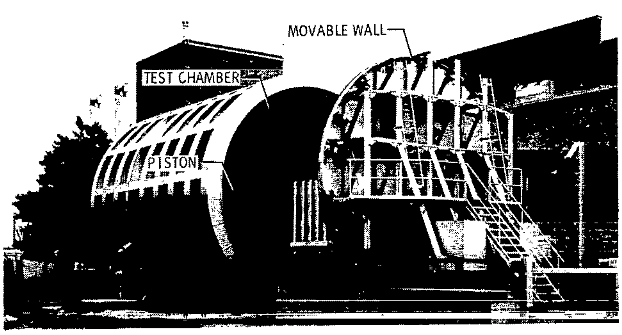
Flight systems and similar equipment at the launch complex must withstand the direct acoustic loads and the associated acoustic-induced vibrations without the risk of malfunction or loss in reliability of performance. Also, assurance must be obtained that man himself can take intense noise in this low-frequency range. Here the concern must go beyond the interest in hearing functions and in the ear alone; it is for the well-being of man's entire body, his ability to perform tasks, and his psychological sensations.

The Langley low-frequency noise facility has unique capabilities for acoustic environmental studies in the near-subaudible and subaudible frequencies. There also exists the capability for studies relating to noise transmission and propagation and for simulation of the sonic boom. A brief description of the facility is given in reference 2 and initial results of low-frequency noise research are given in reference 3. The purpose of this paper is to describe the facility, to indicate its noise generating and testing capabilities, and to discuss some initial tests of humans in the facility.

LANGLEY LOW-FREQUENCY NOISE FACILITY

A photograph of the Langley low-frequency noise facility is shown as figure 1, and some of the primary components are illustrated in the sketch of figure 2. The main features of this facility are a cylindrical test chamber, a large piston in one end of the chamber, and a movable wall which can be positioned to close the opposite end of the test chamber. The facility may be operated with the chamber open (fig. 1) or with the chamber closed (fig. 2) by the movable wall being positioned to tune the chamber. The piston is hydraulically driven to generate sound pressures in the test chamber. The facility is of sufficient size to accommodate a small building structure or a space vehicle of the Apollo command-module class. The test chamber is man-rated so that complete manned vehicles can be tested.

The overall outside dimensions of the facility are 30 ft (9.1 m) in length by 27 ft (8.2 m) in diameter. Along one side of the facility is a building, 10 by 30 ft (3 by 9.1 m),



L-65-6765.1
Figure 1.- Langley low-frequency noise facility.

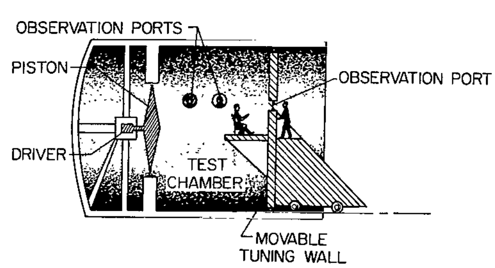


Figure 2.- Cross-sectional sketch of Langley low-frequency noise facility.

which houses hydraulic-system equipment on the first floor and a control room on the second floor.

The cylindrical test chamber (24 ft (7.3 m) in diameter by 21 ft (6.4 m) in length) was designed to be a relatively stiff structure with the natural frequencies above the top operating frequency of 50 cps. Analytical and model studies conducted in support of this design effort are reported in reference 4. The cylinder was fabricated of 1-in-thick (2.54 cm) steel, rolled and welded to form a continuous shell structure, and was stiffened by 18-in-deep (45.72 cm) T-rings of 1-in-thick (2.54 cm) steel on 48-in. (121.92 cm) spacings along its length. Longitudinal stiffeners of similar construction were welded between the rings on spacings of 24° around the cylinder.

The movable wall is also of heavy steel construction. This wall is installed on railroad-type tracks and, in addition to counterweighting, has locking devices to prevent tipping or moving from a locked position. Movement of the wall, which weighs 26 tons (231 kN), is accomplished by a cable system operated from an air winch. The wall is equipped with a pneumatic seal for use in closed chamber testing.

The 14-ft-diameter (4.3 m) piston is of aluminum honeycomb construction. The piston, like the cylinder, was designed for high stiffness with frequencies above the facility operating frequency. The piston cross-section shape is a double cone with a depth through the center of 2 ft (0.6 m). The core consists of a 3-lb/ft^3 $\left(4.8\ \text{kg/m}^3\right)$ honeycomb, and the 0.040-in-thick (0.1 cm) skin was autoclave-bonded to the core. In addition to a requirement for high stiffness, the piston weight must be kept low so as to minimize inertia forces during operation of the facility. In the development of this piston, a series of model studies was made, and information from these studies is presented in reference 5. The piston is driven by a hydraulic driver, and its perimeter is equipped with an adjustable teflon seal which provides close clearance (within 1/16 in. (0.16 cm)) with the adjacent teflon wall surfaces.

The electrohydraulic system used to drive the piston is illustrated in the block diagram of figure 3. The main component of the hydraulic driver is a piston with an area of 8 in^2 $\left(51.6\ \text{cm}^2\right)$ and a maximum rated stroke of 9 in. (22.9 cm). The hydraulic pressure $\left(\text{maximum of 3500 psi } \left(24\ \text{MN/m}^2\right)\right)$ is electronically controlled by a system where the desired acoustic environment is obtained by putting the necessary electric inputs into the system with a function generator such as a discrete-frequency oscillator, the playback of

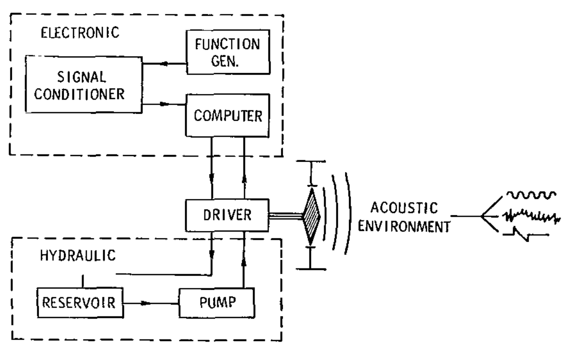


Figure 3.- Electrohydraulic driver system of the Langley low-frequency noise facility.

a random signal recorded on tape, and the momentary closing of contacts. This signal is then conditioned and fed into a computer circuit which forms part of a servo-loop circuit controlling the operation of hydraulic valving at the driver. The hydraulic system thus operates on command of the electronic circuit. In this manner, desired acoustic output environments such as sinusoidal, random, or impulse types including the N-wave pressure-signature characteristic of sonic-boom overpressures can be obtained.

This electrohydraulic driver system has limitations which confine the facility's operations to the range defined by figure 4. Essentially the operations are limited only by the 9-in. (22.9 cm) stroke of the piston up to a frequency of 3.3 cps. Above 3.3 cps, there is a velocity limitation of 92 in/sec (234 cm/sec) up to a frequency of approximately 19 cps where the operation is further limited by acceleration resulting from the inertial forces involved. The operational frequency ranges limited by amplitude and velocity are fixed; however, the acceleration boundary can be extended to higher amplitudes by operational techniques involving inertial balancing of the system with air springs in the chamber cylinder. The operational range shown in figure 4 was fully covered during evaluation tests of the facility.

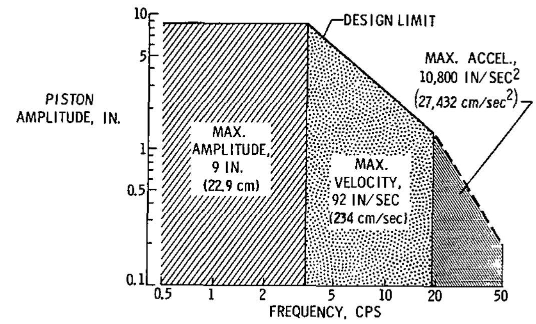


Figure 4.- Operational range of the hydraulic driver system of the Langley low-frequency noise facility.

In support of the development of the Langley low-frequency noise facility, theoretical analyses were performed to predict the sound pressure levels produced by this equipment. The theoretical methods used, along with experimental verification obtained with a 1/10-scale model, are described in reference 6. A comparison is made of the predicted sound pressure levels with those obtained in the test chamber during operations and is presented for a sine-wave environment in figure 5 for a piston velocity normalized to 1 in/sec (2.54 cm/sec). The measurements shown were taken with the tuning wall at a position such that the test chamber was less than 10 ft (3 m) long. The microphone was located midway in the length of the chamber and 0.8 of the way to the chamber wall. Close agreement between the calculated and the measured sound pressures is obtained over most of the frequency range; however, at frequencies below 5 cps and above 30 cps, the measured values fall short of the calculated values. This disagreement at the low frequencies

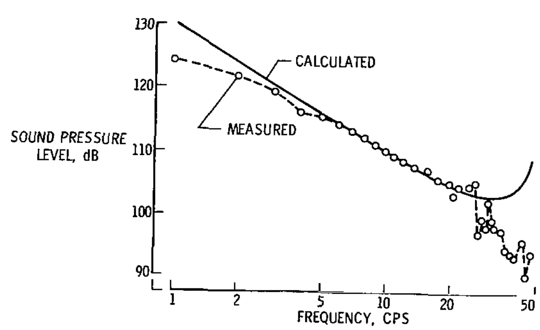


Figure 5.- Comparison of measured and calculated sound pressure levels in Langley low-frequency noise facility for driver piston velocity of 1 in/sec (2.54 cm/sec).

is attributed to leakage around the speaker and movable wall. For these initial tests, this leakage was excessive because the piston was operated without the peripheral seal. It is anticipated that further adjustment of the recently installed teflon seal will improve the agreement obtained at these very low frequencies. With regard to the sound pressure levels above 25 cps, the differences between the measured and the calculated levels are not fully understood; however, they can be partially explained by the effects of temperature variations, geometric details, and structural dynamic responses which were not fully accounted for in the calculations.

The measured acoustic capability during initial operation, along with the potential capability for the facility, is shown in figure 6. The capabilities indicated are for a sinusoidal environment for closed-chamber operation. The existing capability was measured during initial operations with no speaker seal installed. Levels above 160 dB were obtained at frequencies below 3 cps, with a dropoff in level to 140 dB at approximately 20 cps. Above 20 cps the movable wall provided tuning capability which resulted in levels on the order of 155 dB in the frequency range from 30 to 50 cps.

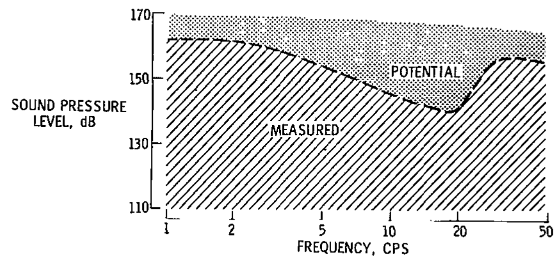


Figure 6.- Measured and potential acoustic environment capability for Langley low-frequency noise facility.

The potential exists for higher acoustic levels of 165 to 170 dB over the operating range of 1 to 50 cps. Possible techniques for achieving these levels include finer adjustment of the piston peripheral seal, additional test-chamber tuning length, reduced chamber volume, and chamber resonator devices.

In the Langley low-frequency noise facility capability exists for environmental research studies of large structural components or complete structures within the 24-ft-diameter (7.3 m) test chamber. Discrete-frequency, random, and impulse loadings can be imposed on either building- or flight-type structures. Since the chamber is man-rated, the test buildings may be occupied or the flight structures may be manned with onboard systems operational. Some initial tests have dealt with the effects of low-frequency noise on man alone and on structural specimens.

PREVIOUS EXPERIENCE OF MAN IN LOW-FREQUENCY NOISE

The general concern for man during space-flight launch includes his ability to communicate, his ability to perform assigned tasks, and his physiological and psychological well-being during exposure to low-frequency noise at intense levels. From the standpoint of acoustics, there is concern not only for the effect of noise on the ears but also for the effect on man's entire body.

Attention to whole-body exposure to low-frequency noise is important because the natural frequencies of many parts of the body are in the frequency range of intense noise associated with the lift-off of large manned spacecraft. In figure 7, some of the natural frequencies of the body are indicated (ref. 7). The natural frequencies of the body are dependent upon the position support and are in the range from 3 to 12 cps. Frequencies of the head range from 2 to 3 cps in the transverse direction to 20 to 30 cps relative to the body. Frequencies of the arm are in the range from 30 to 40 cps. These natural body frequencies are in the near-subaudible and subaudible frequencies where man's whole-body exposure experience is limited.

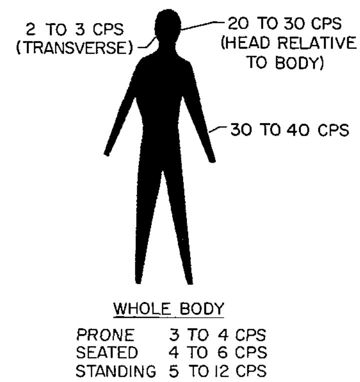


Figure 7.- Some natural vibration frequencies of human body. (Data taken from ref. 7.)

For purposes of evaluating potential hazards of noise exposure, the levels at which ear pain occurs have been used as a guide; however, for exposure at frequencies near and in the subaudible range, there is the possibility of other body components being more sensitive to noise. Man's experience in laboratory exposure of his whole body is compared in figure 8 with the levels at which ear pain has been indicated by exposure of the ears alone (refs. 8 and 9). Ear pain occurs at levels on the order of 170 dB at 2 cps to 140 dB at 50 cps. However, laboratory experience with whole-body exposure is limited to levels on the order of 110 dB at 2 cps and 120 dB at 50 cps. The comparison shown is of special concern because the crews of future space vehicles might receive exposures well above the levels of man's laboratory experience previous to the present tests.

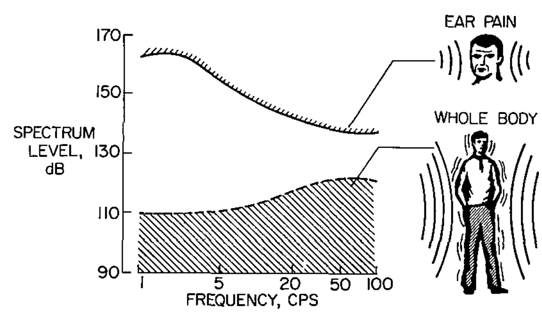


Figure 8.- Previous laboratory experience of human exposure to low-frequency noise.

EXPERIMENTAL PROCEDURES

An experimental study in the Langley low-frequency noise facility was undertaken to obtain information on the effects of low-frequency noise on humans. The study was a cooperative effort of the Langley Research Center and the Manned Spacecraft Center.

Medical services for the study were obtained from the Aerospace Medical Research Laboratories at Wright-Patterson Air Force Base, Ohio.

The study involved testing of a team of five people from the Aerospace Medical Research Laboratories in a series of short-duration exposures to narrow bands of random noise over a range of sound pressure levels. The five team members were military people and included one female. They had a background in the fields of both medical and engineering activities. Their experiences in the field of vibrations and acoustics included exposures to jet- and rocket-engine noise environments and may be considered to be similar to those of astronauts. The members of the team ranged in age from 25 to 45 years, in height from 68 to 76 in. (173 to 193 cm), and in weight from 130 to 200 lb (5.8 to 8.9 kN).

The test setup used is illustrated in figure 2. In the test chamber the test subjects were located on a balcony attached to the movable wall which was positioned in the test chamber for closed-chamber operations. Available on the balcony were lightweight lawn-type chairs so that the subjects could be tested in a seated position. The subjects were dressed in light clothing and were tested two at a time. The team members were equipped with fitted ear protection devices (plugs and muffs) which they could remove during the exposure. The other three members of the team served as medical monitors on the outside of the test chamber. The procedure followed in carrying out the tests was to expose each pair of subjects to random noise (one-third octave bands) at sound pressure spectrum levels from 110 dB to 150 dB for periods of 2 to 3 minutes. During the periods of exposure, observations were made relative to human performance and well-being.

The factors monitored during the noise exposure tests and the corresponding measure for each are given in the following table:

Factors monitored	Measure
Vision	Snellen E
Motor function	Circle tracing
Spatial orientation	Past pointing target
Cardiac rhythm	Pulse rates (EKG)
Speech intelligibility	Rhyme
Subject response	Acceleration and reaction
Tolerance	Subject opinion

These factors and measures relate to both the physiological and psychological well-being of the test subjects. The techniques employed in measuring these factors were taken generally from standard clinical test procedures; however, because of the nature of the test setup, some improvised techniques were necessary. These techniques were devised by Dr. George Mohr who headed the medical team.

The monitoring of vision was accomplished by use of modified Snellen E tests. In these tests the charts were located outside the testing chamber and were viewed through the observation ports by the test subjects.

As a measure of motor function the subjects were assigned the task of drawing circles between adjacent concentric circles printed on a piece of paper held on a board in the subject's lap. The subject's ability to perform this task was taken as a measure of motor function.

The same type of concentric circle target was also used as a measure of the effects on spatial orientation. The concern here was for possible effects on the inner ear function in controlling orientation. With the target in a position known to the subject, the subject was required to seek the center of the circles with his eyes closed.

Electrocardiogram (EKG) measurements of pulse rate were taken during the exposure to obtain a measure of the general physical well-being.

Effects of the environment on speech intelligibility were measured by having the test subjects read prepared listings of "rhyme" words into a noise-canceling microphone so that they could be recorded on tape. A few measurements were also made of chest vibrations.

Of special interest were the reactions of the subjects and the opinions expressed by the subjects during and following the exposure periods.

TEST RESULTS

The general results obtained during noise-exposure tests of five medical subjects in the Langley low-frequency noise facility are indicated in figure 9. Shown in this figure are the sound spectrum levels of the present tests along with those of previous experience of man in laboratory exposure. Also shown are levels of ear pain for this frequency range. The listings on the figure are a summary of the general findings.

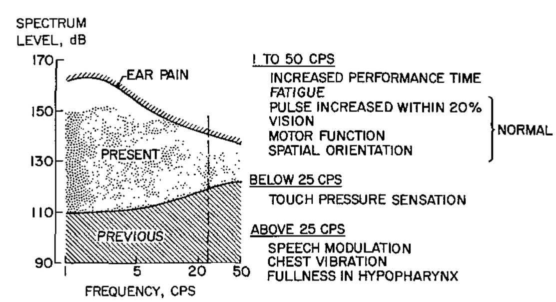


Figure 9.- Summary of noise exposure levels and general results obtained for noise exposure tests in Langley low-frequency noise facility.

The present tests extend man's previous noise exposure range by 40 dB (sound spectrum level) at the low frequencies of 1 to 2 cps, by 35 dB over the frequency range to 10 cps, and by about 15 dB at the higher frequencies to

50 cps. These tests closely approached the levels at which ear pain is known to occur. The results obtained indicate that man can withstand low-frequency noise exposures at these levels without physical damage. However, the subjects experienced some annoyance, discomfort, and fatigue and had a slower task performance rate.

Over the full frequency range from 1 to 50 cps there were indications of fatigue and of increased time required in performing assigned tasks. Other effects over the full frequency range were considered to be normal within the experiences associated with astronaut training. For example, pulse rate increases of within 20 percent were observed and were considered to be normal.

At frequencies below 25 cps, there was a touch pressure sensation within the ear. This sensation has been described as an annoying tickling within the ear and has been compared with the effect one experiences undergoing altitude changes associated with motoring in the mountains. The pressures involved were of an order of magnitude comparable to altitude changes on the order of 700 feet. Also, at frequencies below 25 cps there were modulations of speech; however, speech intelligibility was considered to be acceptable. Also in this frequency range there were moderate vibrations of the chest and a fullness in the hypopharynx with an annoying gag sensation.

In regard to the opinions of those tested, it was indicated that the sensations involved were impressive. Some of those tested expressed the opinion that prior to exposure during launch, an astronaut should be preconditioned to such exposures during his training period.

The results indicated herein are general and represent findings in initial tests in this range of acoustic testing. A need is indicated for further study to provide information necessary for man to protect himself or to condition himself for exposure to these low-frequency acoustic environments associated with space-flight launchings. Detailed analyses of these medical findings are presented in reference 10.

CONCLUDING REMARKS

A description has been given of the Langley low-frequency noise facility which is designed for large-scale environmental acoustic testing at levels of 140 dB and above in the frequency range from 1 to 50 cps. Sinusoidal-, random-, or impulse-type acoustic environments can be generated. In initial tests in this facility, a team of five medical subjects was exposed to random noise environments to 150 dB sound spectrum level in the low-frequency range below 50 cps. General results from these tests indicate that man can tolerate environments of this type; however, there were evidences of annoyance and degradation of task performance.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., October 20, 1965.

REFERENCES

1. Regier, Arthur A.; Mayes, William H.; and Edge, Philip M., Jr.: Noise Problems Associated With Launching Large Space Vehicles. Sound, vol. 1, no. 6, Nov.-Dec. 1962, pp. 7-12.

2. Edge, Philip M., Jr.; and Mayes, William H.: Description and Research Capabilities of the Langley Low-Frequency Noise Facility. Presented at Sixty-Ninth Meeting of Acoustical Society of America (Washington, D.C.), June 2-5, 1965.

3. Edge, Philip M., Jr.; and Mayes, William H.: Some Initial Results of Low-Frequency Noise Research. Conference on Langley Research Related to Apollo Mission, NASA SP-101, 1965, pp. 179-188.

4. Sewall, John L.; Clary, Robert R.; and Leadbetter, Sumner A.: An Experimental and Analytical Vibration Study of a Ring-Stiffened Cylindrical Shell Structure With Various Support Conditions. NASA TN D-2398, 1964.

5. Thompson, William M., Jr.; and Clary, Robert R.: An Investigation of the Natural Frequencies and Mode Shapes of Double Conical Sandwich Disks. NASA TN D-1940, 1963.

6. Lansing, Donald L.; Watkins, Charles E.; and Kantarges, George T.: Oscillating Pressures Within a Cylindrical Chamber That Has a Circular Piston in One End Wall. J. Acoust. Soc., vol. 36, no. 11, Nov. 1964, pp. 2222-2232.

7. Rathbone, Thomas C.: Human Sensitivity to Product Vibration. Product Eng., vol. 34, Aug. 5, 1963, pp. 73-77.

8. Von Gierke, H. E.; Davis, H.; Eldredge, D. H.; and Hardy, J. D.: Aural Pain Produced by Sound. An Exploratory Study of the Biological Effects of Noise. BENOX Rept. (Contract N6 ori-020), Univ. of Chicago, Dec. 1, 1953, pp. 29-36.

9. Cole, John N.; Mohr, George C.; Guild, Elizabeth; and Von Gierke, Henning E.: The Effects of Low Frequency Noise on Man as Related to the Apollo Space Program. AMRL Mem. B-66, U.S. Air Force, Mar. 1964.

10. Mohr, George C.; Cole, John N.; Guild, Elizabeth; and Von Gierke, Henning E.: Effects of Low Frequency and Infrasonic Noise on Man. Aerospace Med., vol. 36, no. 9, Sept. 1965, pp. 817-824.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546