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GEORGIA TECH SONIC BOOM SIMULATOR

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First Annual High-Speed Research Workshop
Williamsburg, Virginia
May 14-16, 1991

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GENERAL

To examine the building and human response to sonic boom in the range 3 Hz to 30 Hz, Georgia Institute of Technology is building a special acoustic driver system to simulate sonic boom. To support NASA Langley program on building and human response, this simulator's capability has been extended to an upper frequency of 4 KHz. A residential test house has been made available by Georgia Tech for these tests.

At the time of preparation of this document, most of the acoustic drivers and the associated electronics have been built and assembled. The system has, however, not been fully tested.

The following pages provide an overview of the progress to date. The acoustic driver systems, and the principle of their operation together with the test house are described. Future plans are also summarized.

Figure 1 Outline of presentation

Outline of Presentation

- Source requirements
- Very low frequency source details
- Test house
- Future plans

MOTIVATION

Guidelines for the assessment of exposure to interior aircraft noise are currently available in the form of methodology for predicting speech interference and hearing damage. Further, relative annoyance due to conventional aircraft flyovers may be assessed by objective measures such as EPNL, SEL, or DNL. However, currently there is no accepted way to assess the human response in an indoor environment where reaction critically depends on secondary emissions, such as noise induced building vibrations and rattling of bric-a-brac and associated acoustic radiations. Human reaction to outdoor sonic booms is more predictable.

There is considerable evidence to indicate that sonic boom signature can be shaped in such a way as to minimize the resulting human response. There also exists some indication that in comparison to subsonic aircraft noise, sonic booms are relatively more objectionable indoors than outdoors. This difference may primarily be due to the ability of sonic booms to induce more structural response than subsonic aircraft noise. Although, considerable work has been done to examine the building response to noise, most of the controlled experiments have been restricted to frequencies much higher than 10 Hz. The sonic boom simulator described here was developed to produce very low frequency noise to determine both human and structural response, both indoors and outdoors at frequenciies as low as 3 Hz.

Figure 2

Motivation

1. Structural / human response at low frequency

2. Effect of boom shaping

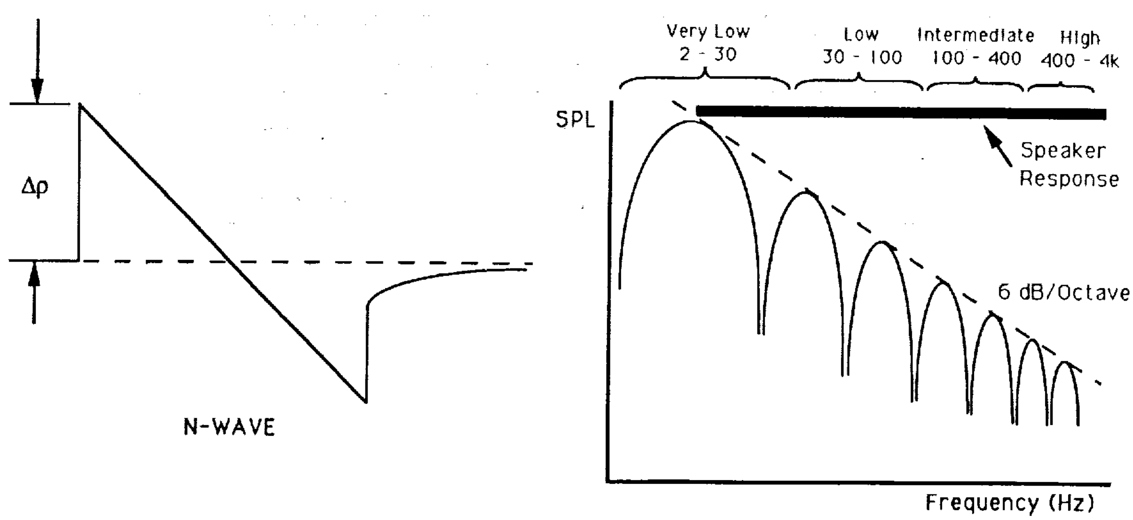
SONIC BOOM

The N-shaped disturbance shown here is an idealized shape. The actual shape may vary because of the atmospheric effects and aircraft design and operation. The effects on people and structures are better understood by examining the spectral contents of such waves. The peak level takes place at a frequency dependent upon the total duration of the boom. Longer the duration, the lower the frequency. Larger airplanes and planes flying at higher altitudes will have longer duration and thus lower peak frequency. As shown in this figure, spectrum consists of several convolutions that are tangent to a 6-dB-per-octave line at higher frequencies.

The system described here was designed to have flat frequency response in the range 3 Hz - 4 kHz.

Figure 3

Sonic Boom



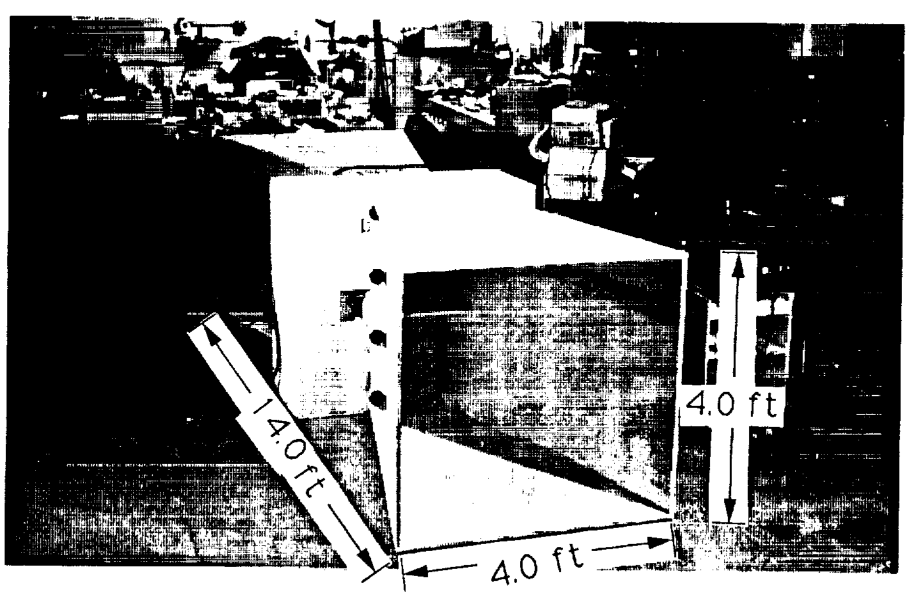
VERY LOW FREQUENCY SOURCE REQUIREMENTS

Electro-acoustic drivers that generate large amplitudes at frequencies higher than 30 Hz are available commercially. Our very low frequency driver was required to produce flat frequency response in the range 3 - 30 Hz. It was also required to produce in excess of 2 psf sound pressure level over a 10 ft x 12 ft area of the wall of a test house. This figure, taken during the development phase, shows the dimensions of a single unit of the driver. Georgia Tech sonic boom simulator system consists of six such units. As described later, other high frequency speakers are also part of this system.

Figure 4

Very Low Frequency Source Requirements

- **Flat response 3Hz - 30Hz**
- **2 psf peak pressure on the test house wall**

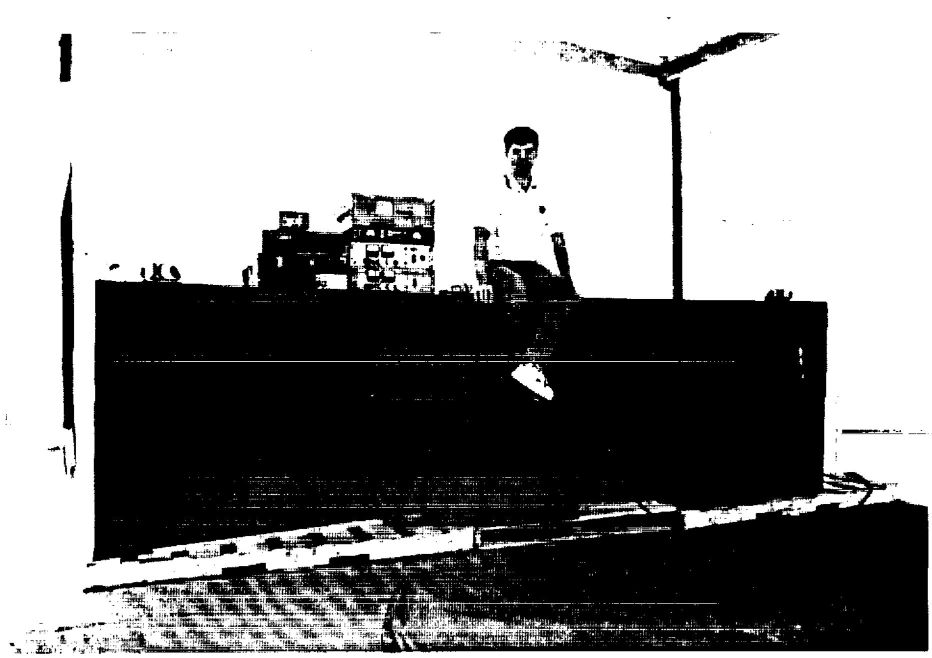


VERY LOW FREQUENCY SPEAKER

The system shown in Figure 4 is shown here in its finished form.

Figure 5

Very Low Frequency Speaker



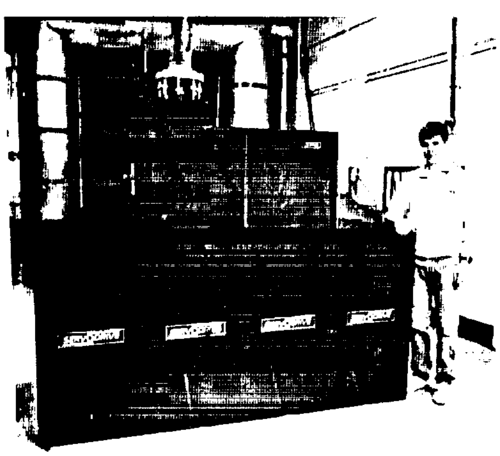
LOW AND INTERMEDIATE FREQUENCY SOURCE

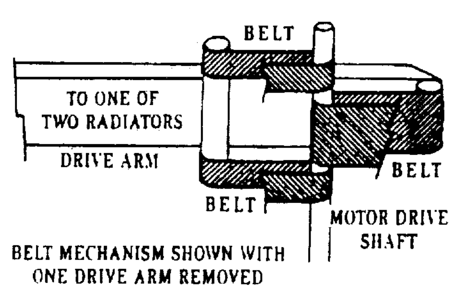
The driver units for the low and intermediate frequency noise are servo-driven units. The units shown in Figure 6a are some of the units to be used in conjunction with the very low frequency drivers. The sketch in Figure 6b shows the principle of operation of the servo-driven system. It shows a rotary-to-linear motion converter which is connected to specially strengthened radiators by means of drive shafts. Servo-drive design eliminates fragile voice coils, heavy magnets, and compromised low frequency response typical of inherently weak voice coil designs. Unlike a voice coil that becomes nonlinear with large motion, a motor can provide unlimited motion or rotation. Rotation in either direction is exactly proportional to the input signal voltage and current.

Figure 6

Low and Intermediate Frequency Source

- Servo driven units





SPEAKER ENCLOSURE AND THE TEST HOUSE (FRONT)

The complete noise simulator unit is housed in an enclosure outside a house ("test house") that used to be a residential unit. As shown here, the enclosure has walls made out of an awning material which can be drawn like a curtain.

Figure 7

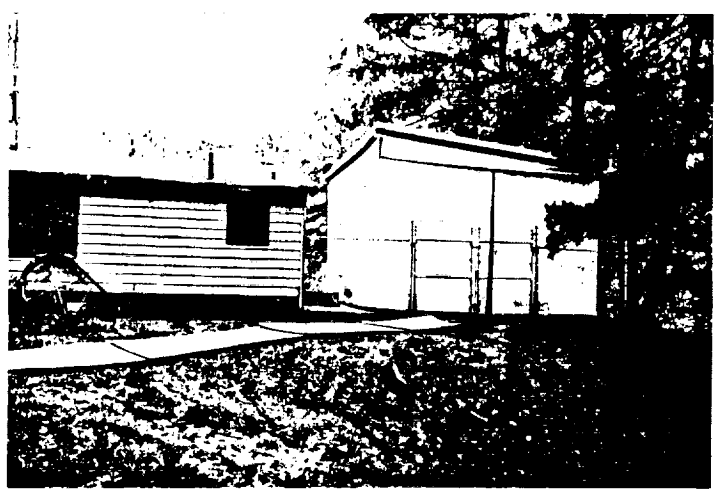
Speaker Enclosure and the Test House (Front)

SPEAKER ENCLOSURE AND THE TEST HOUSE (BACK)

Figure 8 shows the back view of the speaker enclosure and the test house.

Figure 8

Speaker Enclosure and the Test House (Back)



SPEAKER ENCLOSURE AND THE TEST HOUSE (SIDE VIEW)

Figure 9 shows the side view of the speaker enclosure and the test house.

Figure 9

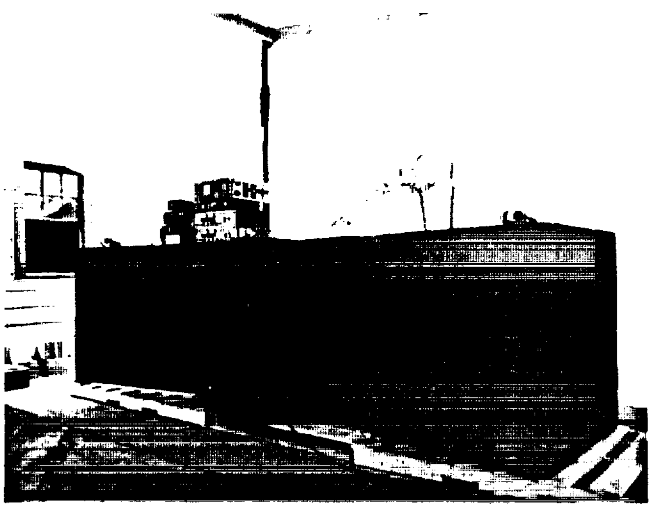
Speaker Enclosure and the Test House (Side View)

VERY LOW FREQUENCY SPEAKER (2 Hz - 30 Hz)

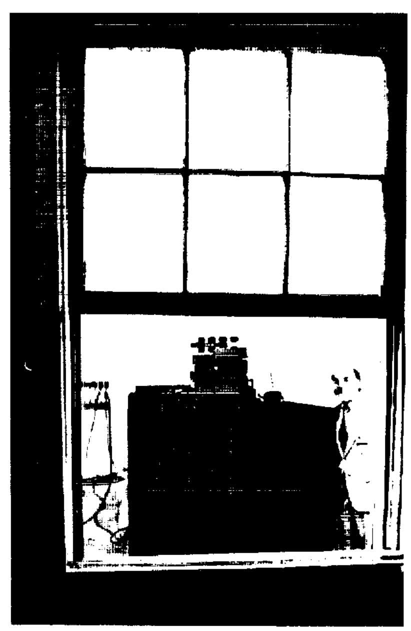
Only a single unit of the very low frequency speaker is shown here in Figure 10. Figure 10a shows the window of the house that faces one of the openings of the driver. Figure 10b is a view of the driver opening through the window from inside the house.

Figure 10

Very Low Frequency Speaker (2Hz - 30Hz)



(a)



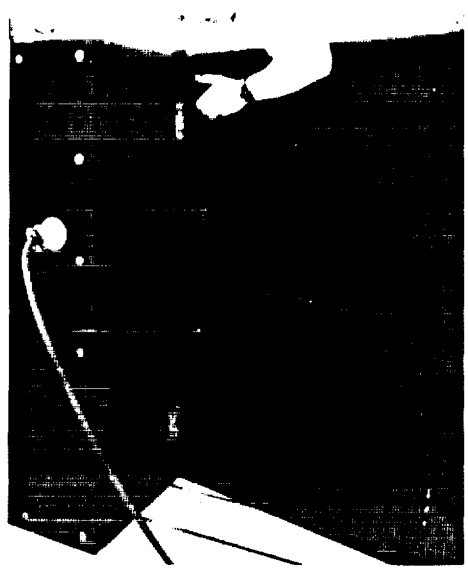
(b)

EASILY DISMOUNTABLE ARRANGEMENT

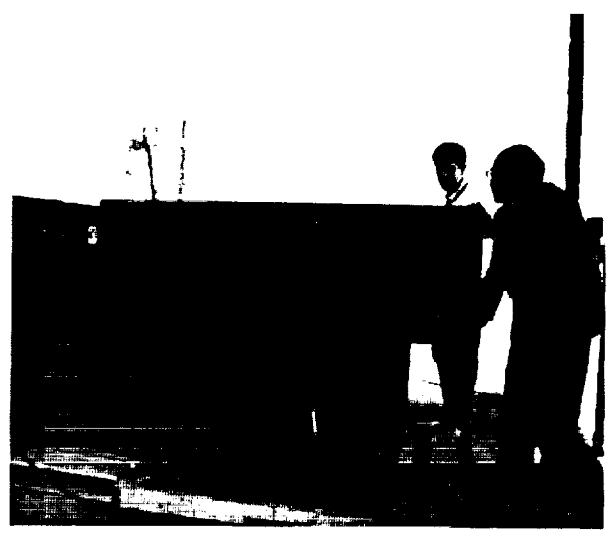
The very low frequency speaker system was designed so that two people could mount and dismount various components as shown here in Figure 11. The holding bolt is undone in Figure 11a and the diffuser is moved away from the noise producing unit.

Figure 11

Easily Dismountable Arrangement



(a)



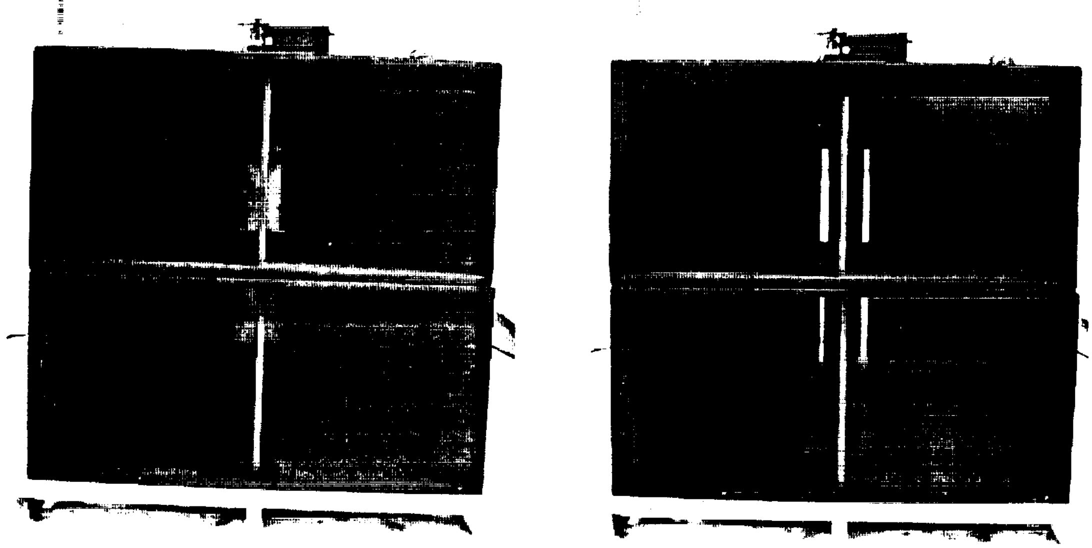
(b)

VANE MOVEMENT

It is the controlled movement of vanes located in the middle section of the very low frequency speaker system that provides the fluctuating force needed to move air in and out of the speaker opening that produces the sound. Each unit has two separate openings, top and bottom in this figure. As shown in the next figure, these vanes help move large amount of air provided by two motor-operated fans placed on the two sides of the vanes. Two vane positions are shown in Figure 12.

Figure 12

Vane Movement

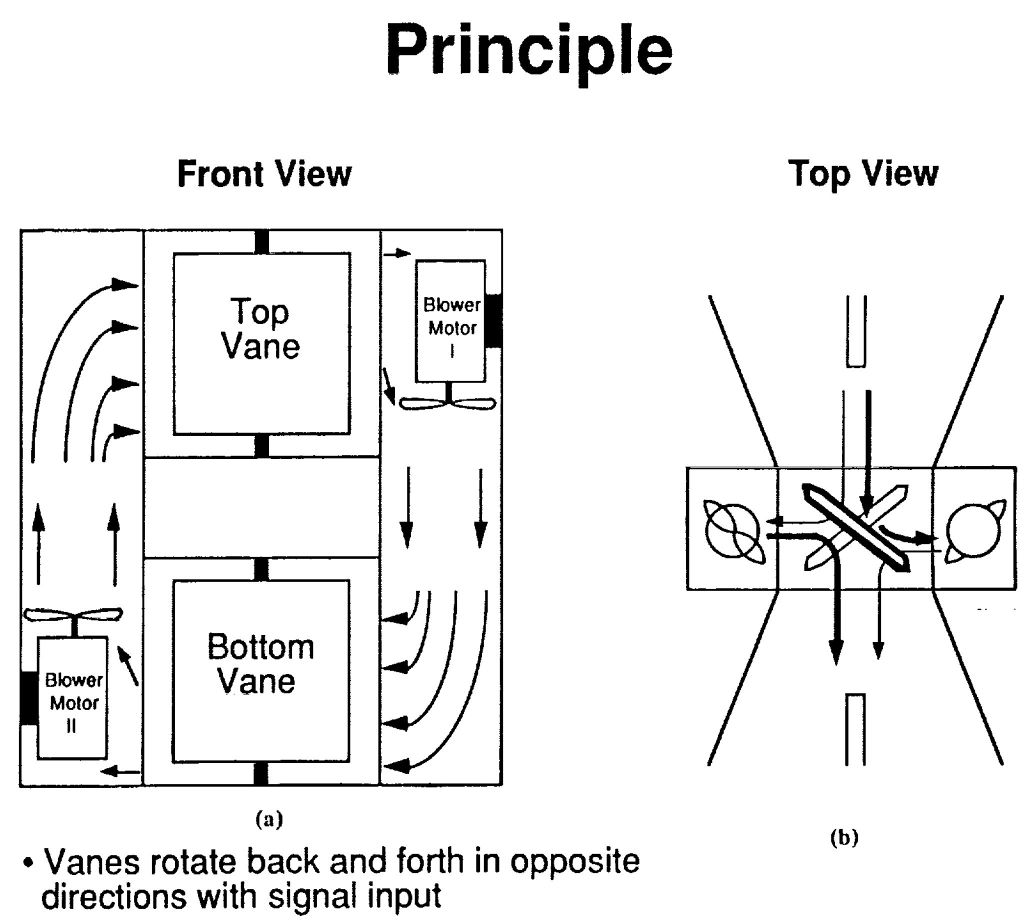


(a) Vanes closed (b) Vanes open

PRINCIPLE OF OPERATION OF THE VERY LOW FREQUENCY NOISE SOURCE

As shown in Figure 13a, air mass for each vane is provided by a blower fan. In Figure 13b, the solid line indicates the vane and flow direction for the top vane and the thin line for the bottom. The vanes are arranged such that the flow moves from the top and the bottom opening in phase. In addition, referring to the top view of Figure 13b, this arrangement provides positive and negative mass flow through the two diffusers. This provides the capability of operating this unit as a dipole, and thus either of the two openings can be placed in front of a test object close by, and as mentioned later, it allows one to reduce the noise radiating in the farfield.

Figure 13



THE VANE AND THE FAN ARRANGEMENT

Close-up view of the vanes and the servo motor that controls its motion is shown in Figure 14a. The connector that carries the electronic input signal is also shown. Figure 14b shows the fan enclosure which, as is obvious in this figure, can be easily replaced if broken. Figure 14c is a close-up view of the fan and the turning vanes for the air flow .

Figure 14

The Vane and Fan Arrangement

(a) (b) (c)

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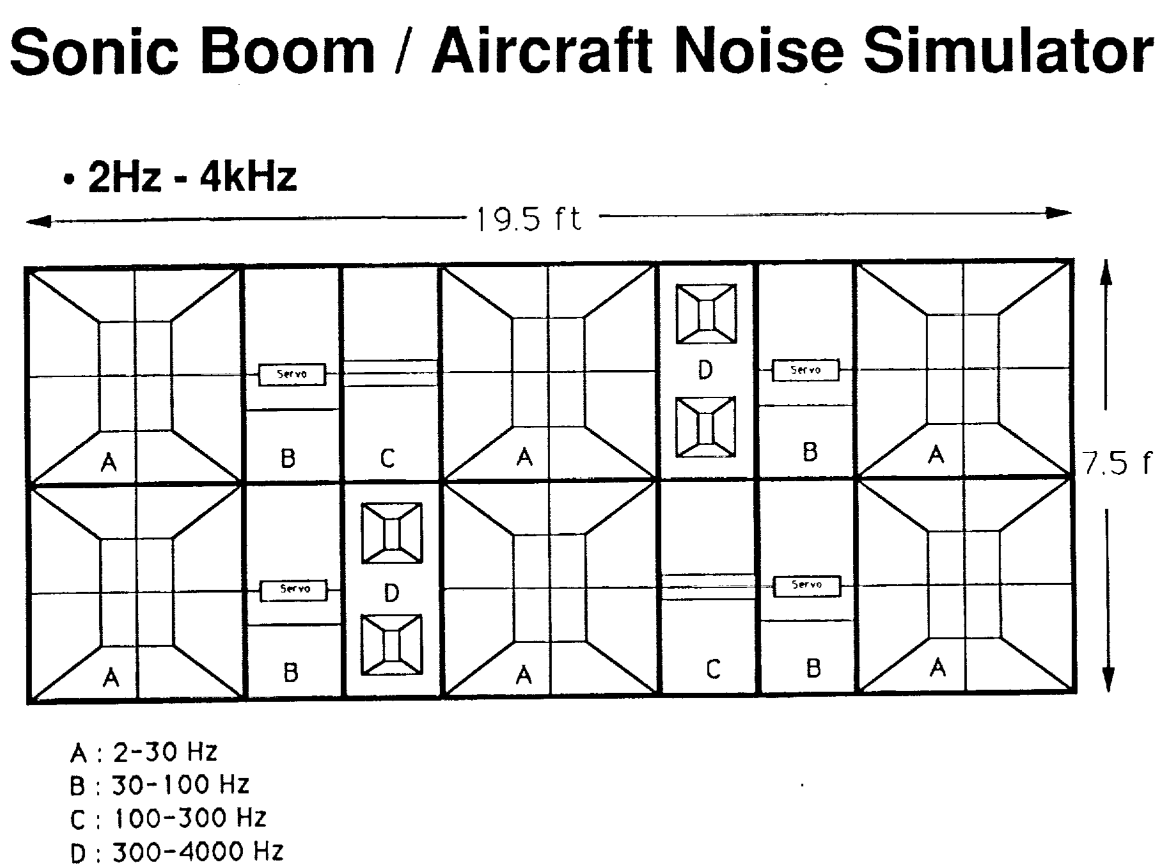
SONIC BOOM/AIRCRAFT NOISE SIMULATOR

Figure 15 shows the arrangement of the complete sound generating system. It includes low and high frequency units and provides a capability of generating sonic boom as well as other types of noise, such as aircraft noise, helicopter noise, truck noise, etc.

Figure 15



CIRCUITRY

Appropriate delay lines, amplifiers and cross-over networks are implemented to get a reasonably flat response. Attempts are being made to obtain a reasonably constant amplitude over the face of the test house wall. Figure 16 shows the circuitry.

Figure 16

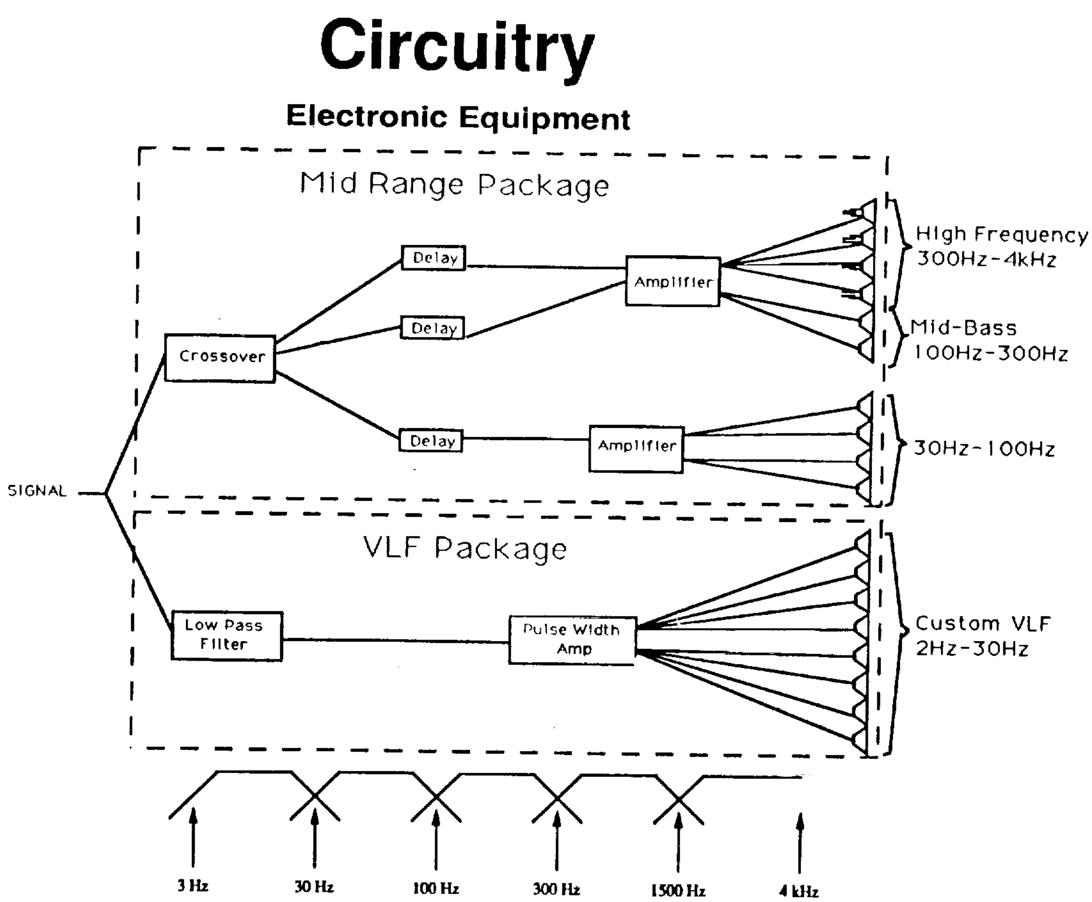
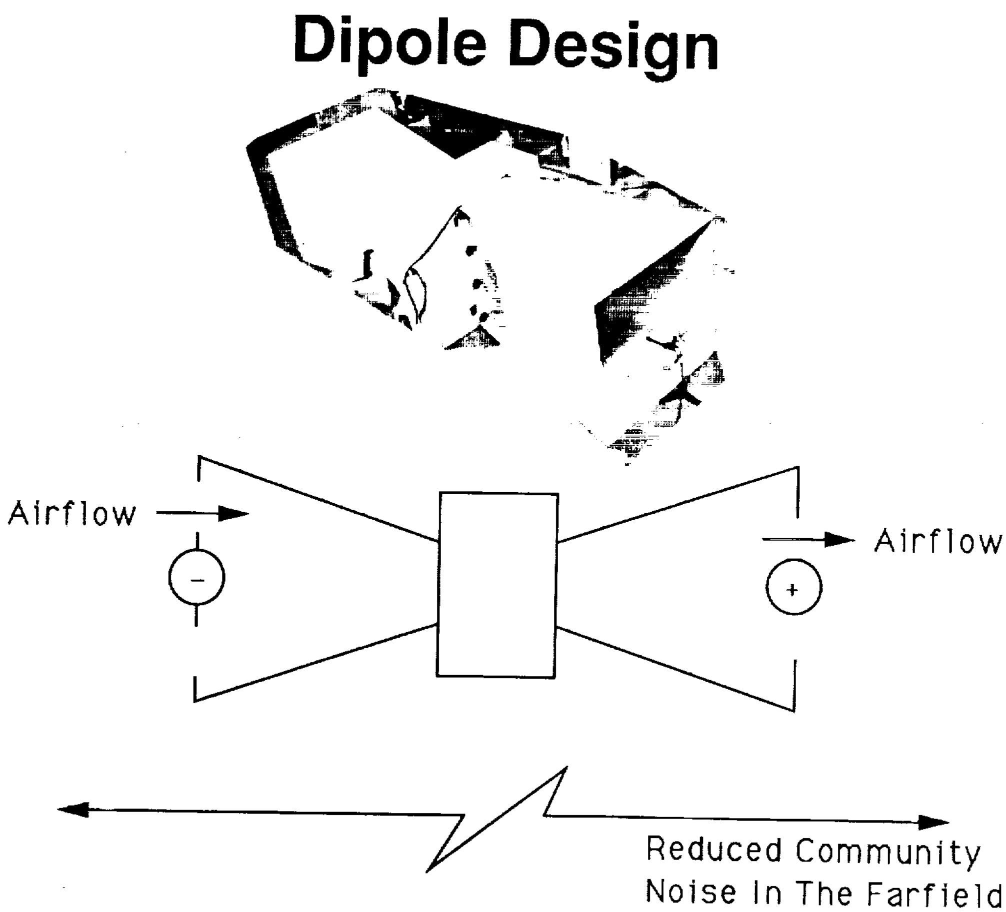


Fig. Frequency Breakdown

DIPOLE DESIGN

As described earlier, the air flow moves through the whole unit in and out. As shown in Figure 17, there are two openings. It thus converts this unit into a dipole source. This will allow reduced noise at long distances because of the cancellations of the noise of opposite sign radiated from the two openings.

Figure 17



TEST HOUSE SURROUNDINGS

The test house to be used for the planned tests was selected very carefully. The house is located with plenty of open space around it. Figure 18 shows the open area. The test house is just behind the trees by the roadway, in front of the utility pole seen in the figure. As will be seen later, one of the openings of the sonic boom simulator points at one of the walls of the test house. The other opening of the dipole arrangement faces the camera used to take the photograph shown in Figure 18. This arrangement of the house surrounding and the two sided opening of the noise source allows us to obtain outdoor response. If needed, other structures can be installed in the open space shown in this figure. As shown later, near the camera location, there is a heavy duty tower that can be utilized, if needed, to mount acoustic equipment to study low frequency noise propagation.

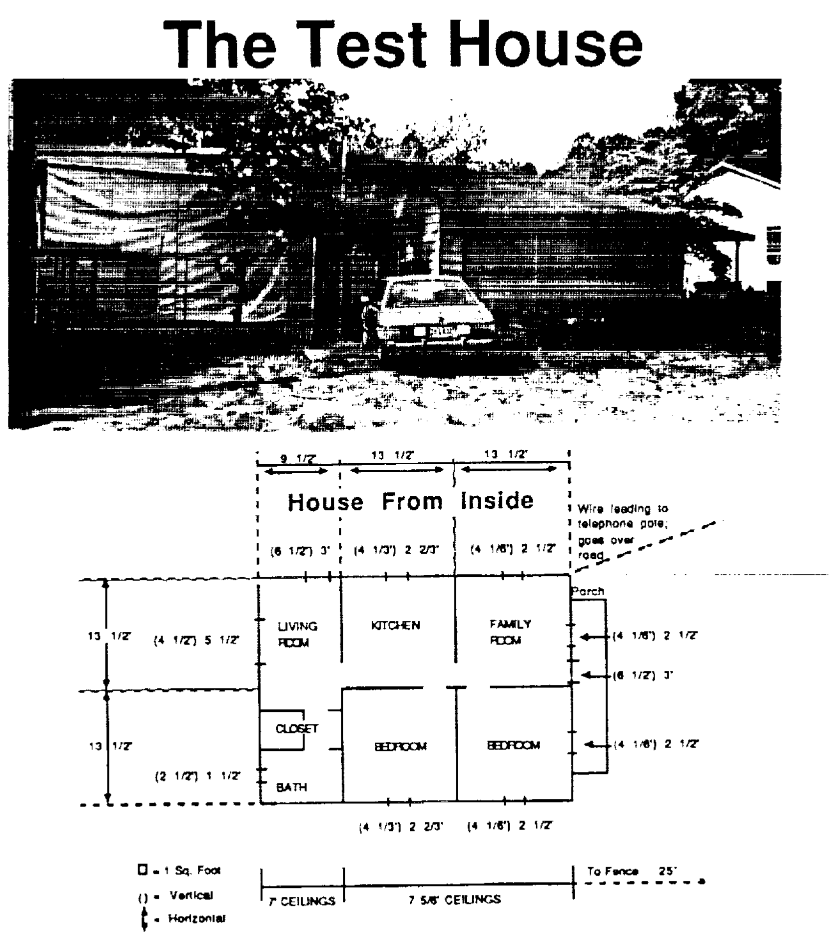
Figure 18

Test House Surroundings

THE TEST HOUSE

Figure 19 shows the test house and the floor plan. It has a total of five rooms. The outer shingles are made out of aluminum.

Figure 19

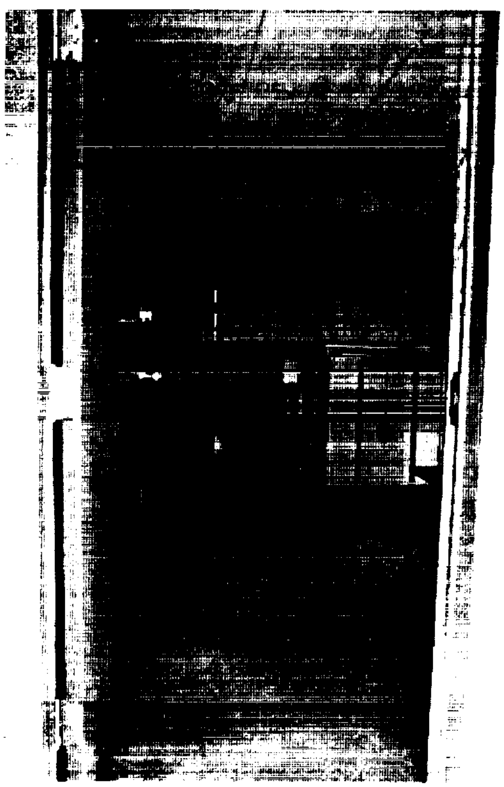


TEST HOUSE INTERIOR

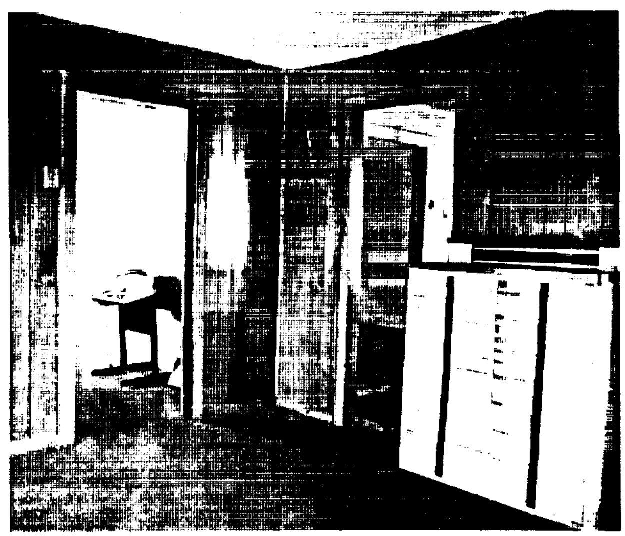
Figure 20a is the view of the family room from the porch entrance. The view of one of the bedrooms adjacent to the family room is shown in Figure 20b. The walls in the family room are made out of paneling material, and the ceiling from acoustic tiles.

Figure 20

Test House Interior



(a)



(b)

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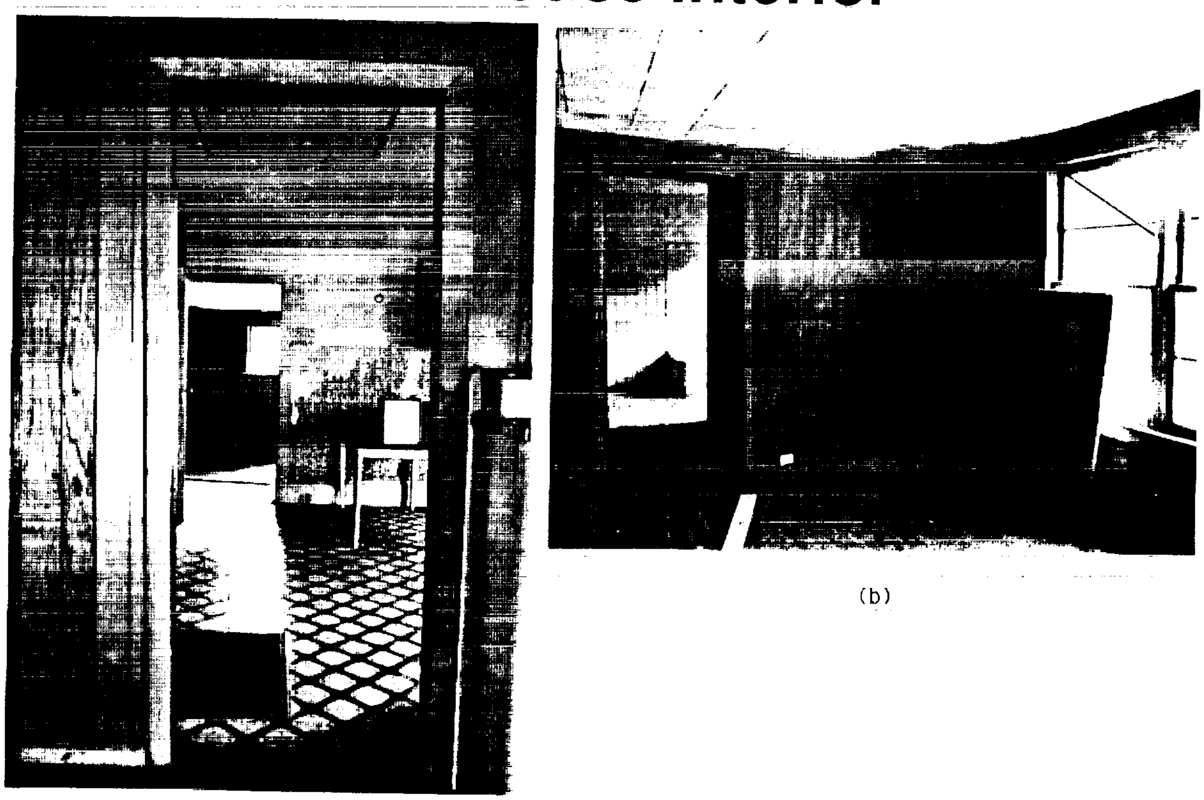
TEST HOUSE INTERIOR

Figure 21a is the view of the kitchen from the family room. The room with the chalk board on the floor is that of the living room. As seen in Figure 21b, its walls and the ceiling are similar to those of the family room . One can also view the bathroom adjacent to the living room in Figure 21b.

Figure 21

Test House Interior



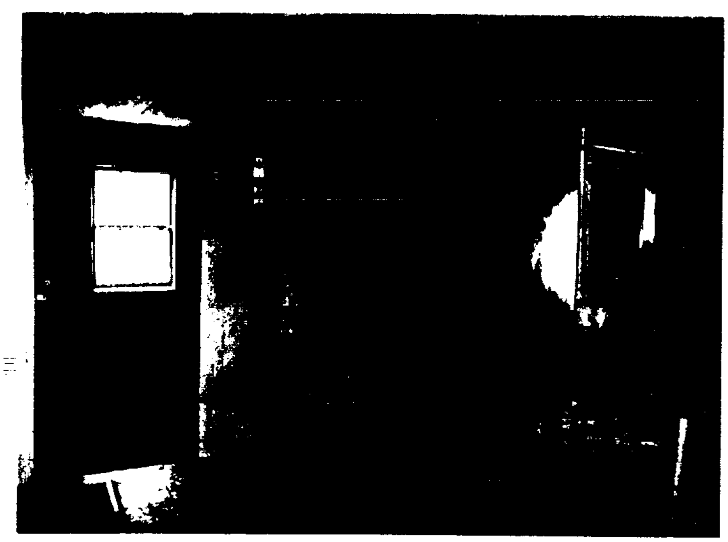
(a) (b)

TEST HOUSE INTERIOR

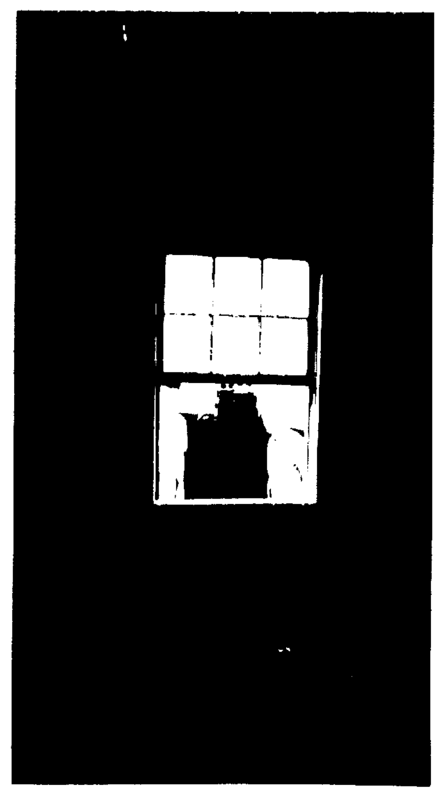
The two windows on the wall facing the opening of the speaker system are shown in Figure 22a and 22b.

Figure 22

Test House Interior



(a)



(b)

WINDOW VIEWS

The view of the sonic boom simulator from the two windows on the wall facing the simulator is shown in Figure 23. These two windows are located in the two bedrooms.

Figure 23

Window Views

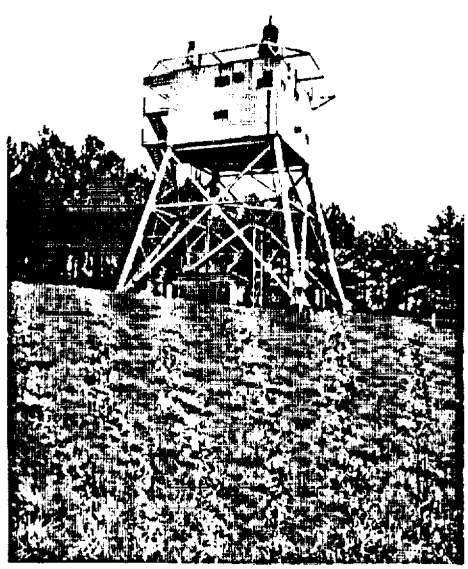
(a) (b)

TOWER FOR POTENTIAL PROPAGATION STUDIES

Adjacent to the test house are located two towers, one of which is shown in Figure 24. These towers are normally used in radar signature propagation studies at Georgia Tech Researh Institute. The same towers can be used in sound propagation studies. As these towers are capable of withstanding the loads of heavy radars, the sonic boom simulator could also be mounted atop these towers. These towers can be used in conjunction with three other facilities owned by Georgia Tech, two located at about 10 miles away and another at about 100 miles away. These facilities will prove invaluable for long distance, low frequency sound propagation studies.

Figure 24

Tower for Potential Propagation Studies



PRELIMINARY DATA

At the time of preparation of this document, only the sound pressure levels at the exit of a single, very low frequency source were obtained. In the initial measurements, a level of 125 dB was obtained at 3 Hz from the single unit. Typical results of amplitude and phase spectrum at the center of the diffuser exit are shown in Figure 25. Note that these measurements were acquired using time delay spectrometry and the source was not operating at its full power.

Initial measurements made with a single unit mounted in the speaker enclosure at a discrete tone of 3 Hz produced considerable vibration in the structural members of the house, which could be felt by placing hands over the window panes. The 3 Hz tone was also picked up in the interior of the house with a microphone. These measurements are continuing at present.

A total of six very low frequency units will be used in the planned experiments.

Figure 25

Preliminary Data

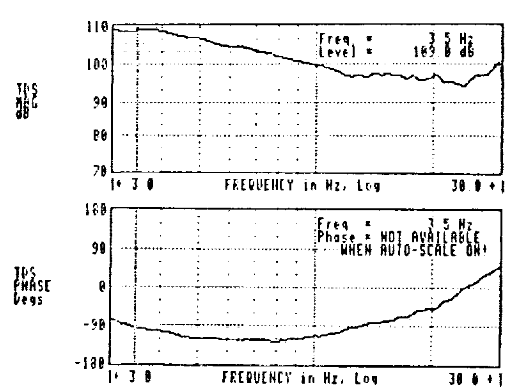


Figure Time delay spectrometry plot of magnitude and frequency reponse from 0-30 Hz (not at full power).

- **Reached 125 db at exit of each unit**
- **Six units to be used**

PLANNED EXPERIMENTS

The acoustic performance of the complete unit will be tested. The goal is to acquire a flat frequency response in the range 2 Hz to 4 KHz. We expect to obtain noticeable levels at frequencies as low as 1/2 Hz. It is planned to screen a number of test subjects through audiometric testing. Their response to sonic boom of various selected shapes will be tested both indoors and outdoors. For indoor testing, measurements of wall vibrations and other secondary emissions are also planned. Response to sonic boom will be compared against other noise sources such as the aircraft noise.

Figure 26

Planned Experiments

- Test acoustic performance of complete unit
    - 2 Hz - 4 kHz
    - Expect to reach 1/2 Hz
- Human Response
- Structural Response

ACKNOWLEDGMENTS

The funds for the very low frequency speakers and the test house were provided by **Georgia Tech Research Institute**. These speakers were built by Intersonics, Inc. The funds for setting up the experiments to a frequency of 4 KHz were provided by **NASA Langley Research Center**. Assistance of Graduate student **Clarke J. Stevens** is gratefully acknowledged.