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DEPARTMENT OF THE ARMY

U.S. ARMY MEDICAL RESEARCH AND MATERIEL COMMAND
FORT DETRICK, MARYLAND 21702-5012



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ATTENTION OF:

MCMR-RMI-S (70-1y)

AD-13176684

29 Aug 95

MEMORANDUM FOR Administrator, Defense Technical Information
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Cameron Station, Building 5, Alexandria, VA
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2. Point of contact for this request is Ms. Judy Pawlus,
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J. R. Gilbert
for *Judy Pawlus*

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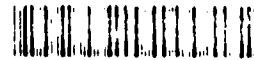
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CONTRACT NO: DAMD17-93-C-3088

TITLE: AN ACTIVE NOISE CONTROL STETHOSCOPE

PRINCIPAL INVESTIGATOR: Thomas R. Harley

CONTRACTING ORGANIZATION: Noise Removal Systems
Route 2, Box 635
Oxford, MS 38655

REPORT DATE: August 24, 1993

TYPE OF REPORT: Phase I Final Report

PREPARED FOR: U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Distribution authorized to DOD
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13. ABSTRACT (Maximum 200 words) The objective of this effort is to develop an electronic stethoscope that enables emergency medical personnel to auscultate in the presence of high background noise levels. A stethoscope is being developed which incorporates digital active noise control (ANC) technology. This technology is used to remove noise detected by the stethoscope sensor and noise which would otherwise reach the physician's ear. The noise penetrating to the ear is treated differently according to whether the noise is random or periodic. Initial efforts will be directed at completing a prototype ANC stethoscope with periodic noise cancellation capability. During Phase I, the P.I. will develop an electronic stethoscope and provide background, level II drawings, and documentation of all other efforts related to the project. The project involves developing sensors, circuit boards, programming digital signal processors, extensive testing of a prototype in the laboratory and with medical personnel and an audiologist, cost analysis and attracting a manufacturer to produce and market the device.			
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FOREWORD

For the protection of human subjects, the investigator(s) have adhered to policies of applicable Federal Law 45CFR56.

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Section I. Introduction

The objective of this effort is to develop an electronic stethoscope that enables emergency medical personnel to auscultate in the presence of high background noise levels. A stethoscope is being developed which incorporates digital active noise control (ANC) technology. This technology is used to remove noise detected by the stethoscope sensor and noise which would otherwise reach the physician's ear. The noise penetrating to the ear is treated differently according to whether the noise is random or periodic. Initial efforts will be directed at completing a prototype ANC stethoscope with periodic noise cancellation capability. During Phase I, the PI will develop an electronic stethoscope and provide background, level II drawings, and documentation of all other efforts related to the project. The project involves developing sensors, circuit boards, programming digital signal processors, extensive testing of a prototype in the laboratory and with medical personnel and an audiologist, cost analysis and attracting a manufacturer to produce and market the device. Some progress will be made on all of these aspects of the project during Phase I. The needs of particular emergency military vehicles, such as the UH-60Q will be investigated. While a commercial prototype is a long term goal, initial efforts will focus on developing a version of the prototype that is fully integrated with the SPH-4B helmet.

The electronic hardware of the prototype is to evolve through a three step process as it is miniaturized into a commercial product. We have completed the first step by completing an initial prototype, built from many large, general purpose electronic devices and DSP workstations that were available in the NCPA laboratory. The second step is to replace the laboratory equipment with a much smaller customized circuit board incorporating components that perform the same function. Finally, a production model circuit board, chassis, and power supply will replace the customized circuit board and DSP workstation. The circuit boards which constitute the second step of this process were completed during the fourth month of the contract period.

Section II. Progress

During the final month of the Phase I effort, three trips were taken. Between 8-3-93 and 8-7-93, Jim Hendrix and Tom Harley traveled to USAARL in Fort Rucker, Daleville, AL. On 8-12-93, Jim Hendrix, Tom Harley, Matt Miley, and Andrew Poynot traveled to Memphis Wings in Memphis, TN. Between 8-17-93 and 8-21-93, Jim Hendrix and Tom Harley travelled to Armstrong Laboratories at Brooks Air Force Base in San Antonio, TX. The final trip to Armstrong Laboratories delayed this final report beyond the 8-15-93 deadline. A large vehicle was driven in order to transport scientific equipment for making sound, analyzing data and storing data, in addition to the ANC stethoscope prototype itself. A total cost of \$ 1875.40 in travel expenses resulted from the three trips, which was considerably higher than the \$ 1000 estimate included in the Phase I proposal for two trips. However, Noise Removal Systems will absorb this loss.

USAARL Fort Rucker visit

The trip to Fort Rucker was very successful. We are indebted to Ben Mozo for always lending a hand when needed and insuring that things ran smoothly. At 9:00 AM Friday, 8-6-93, an audience of about ten people listened to a one hour and 15 minute presentation, including a live demonstration of how the ANC stethoscope performs. In addition to Charles Paschal and Fort Rucker personnel, Bradley Hall of the Naval Air Warfare Center Aircraft Division attended. At 10:30 AM, about 8 people training to be flight surgeons also came. The medical personnel took turns listening to Tom Harley's lung sounds using the innovative electronic sensor and then collectively listened to a tape recording of the ANC stethoscope working in a noisy environment (which was made for the prior group that met at 9:00 AM). Because of time constraints and other reasons, it seemed impractical to pass around the SPH-4B helmet and give each person a two minute demonstration while others waited. Therefore, the performance of the stethoscope was recorded from the ears of a Knowles Kemar mannequin wearing the SPH-4B helmet, and a recording from one ear was played back for everyone to hear at once. The recording was also played back in stereo over a pair of headphones, for two people at a time to listen to. The medical personnel who listened to the sensor alone and the entire ANC stethoscope

were pleased with the performance.

Many important contacts were made during the visit to Fort Rucker. The Contracting Officer's Representative, Charles R. Paschal, was contacted in person for the first time. In the past Paschal had only seen paper work regarding the ANC stethoscope, so it was important for Paschal to see the ANC stethoscope demonstration in order to better evaluate the prototype. In addition to the time spent with Paschal, productive collaboration with Ben Mozo and Major Barclay Butler took place. This resulted in a better understanding of various technical issues, including the military specifications for an Air Worthiness Release (AWR). It is anticipated that in the future a facility such as USAARL could be used to obtain AWR approval for in-flight testing of the ANC stethoscope. Captain Brendan Squire took Harley and Hendrix aboard a UH-60 helicopter for the first time. A rack of experimental equipment needs to be carried aboard for in-flight testing, and the floor was inspected for means to secure the rack. According to Army AWR regulations, the rack should be able to take 8 g's of acceleration in any direction without allowing anything to fly off.

Memphis Wings visit

Al Williams, the director of Memphis Wings in Memphis, TN invited Noise Removal Systems to use his helicopter flight facility for field testing of the ANC stethoscope prototype. The ANC stethoscope was tested in a jet engine American Eurostar helicopter, owned by Memphis Wings. Al Williams was extremely hospitable, and has even arranged for the Memphis police to fly in a UH-1 helicopter for a future testing of the ANC stethoscope. The Memphis Wings organization is jointly owned by four Memphis hospitals. Two helicopters are in operation and a third is being ordered. It was understood that in the event of a real emergency, all experimental testing would be aborted and the test equipment would be removed from the helicopter. While the facility averages four to five missions a day, Noise Removal Systems had the good fortune of coming on an afternoon when no emergency calls came in.

The field testing illuminated several areas where the ANC stethoscope needs improvement. A personal computer (PC) houses the four circuit cards that contain the electronic circuitry of the ANC stethoscope. The PC's power supply outputs 20 A at 5 V DC. When the PC and circuit cards are operating, the 5 V output is pulled down to 4.75 V, which is barely enough. In fact, the marginal power supply occasionally leads to failures of the system in the laboratory. In the field, the American Eurostar (A-Star) helicopter voltage supply was 116 V (not 120 V) and was a 60 Hz square wave (not sinusoidal). This compromised voltage supply to plug the PC into, which in turn powered a marginal 5 V DC output, resulted in the ANC stethoscope not being able to work using the electrical power supplied by the A-Star. This meant that instead of flying the helicopter, we were limited to on the ground testing while the ANC stethoscope was tethered to a 120 V AC 60 Hz line from an outlet on the ground. After the Memphis trip, we replaced the PC power supply with a device that puts out 24 A at 5 V DC and eliminated this problem.

While on the ground, the doors of the helicopter were left open to increase the relatively low noise levels in the cabin. We discovered that the support beams of the helicopter acted like a spring, so that the vibration levels were much higher on the ground than when the helicopter is airborne. The signal from the electronic sensor immediately went off scale. Unfortunately, the gain put on the electronic sensor is determined by a chip on

one of the four circuit boards in the computer, and there was no way to adjust this gain without returning to Oxford. It was determined that by holding the sensor very firmly against a real person, the vibration levels did not send the electronic sensor output off scale (of the A/D convertor in the ANC stethoscope). The relatively heavy human is harder to accelerate than the relatively light human torso simulator. (This solution was indirectly suggested by Major Joe Hatch.) However, by using a real person instead of the human torso simulator we sacrificed the ability to obtain repeatable results.

As was also seen in the USAARL UH-60 accelerometer results, recently obtained from Major Barclay Butler, most of the vibrations (that dominated the sensor signal) are at 40 Hz and below. The lowest human sounds needed for diagnosis are heart murmurs that start at 45 Hz and go up. Also, the primary need of the stethoscope is for lung sounds which start at even higher frequencies. Therefore, it became apparent that a strong high pass filter should be incorporated into the ANC stethoscope system. It is possible that such a mechanism would adequately block out noise due to vibration without having to resort to additional "bells and whistles" in the adaptive digital system that are specifically designed for eliminating the noise due to vibrations.

Another unexpected problem arose when trying to operate the PC housing the ANC stethoscope circuitry. Previously, the system had only been used indoors. Outside, in bright daylight, the computer screen was very difficult to see. The current ANC stethoscope prototype incorporates several adaptive digital filters, which have convergence parameters that need to be chosen so the device will work optimally in a particular noisy environment. Setting these parameters correctly was not accomplished because it was too hard to see the computer screen. The next PC ordered to house the ANC stethoscope circuitry and facilitate software development will have a liquid crystal display monitor, to eliminate this problem. Many other details were learned that will help a subsequent field test to go more smoothly. For example, we thought the A-Star had 52" of vertical room for our experimental equipment, when in fact there was only 42". This resulted in a long delay while we reconfigured the equipment to fit in the available space. Also, the microphone gains were set too high, and the calibration of the earcup speaker impulse response needs some adjustment. While some active noise reduction in both the sensor and earcup were achieved, the initial

field testing of the ANC stethoscope ran into too many problems to sound very impressive. However, the experience was extremely productive. The testing will enable Noise Removal Systems to make great advances toward improving the ANC stethoscope to overcome relatively simple real world problems.

Figure 1a depicts Tom Harley discussing the testing procedure with Al Williams, the director of Memphis Wings. Figure 1b depicts two of the pilots, Bob Randall and Phil Scruggs, helping make room for the experimental equipment. Figure 1c depicts Andrew Poynot (normally the photographer from the NCPA) getting the equipment in the helicopter. Figures 2a and 2b depicts Jim Hendrix and Matt Miley making sure everything is working. Figures 3a and 3b depict Bob Randall getting on board and running the helicopter while Jim Hendrix takes data.

Figure 1b



Figure 1c

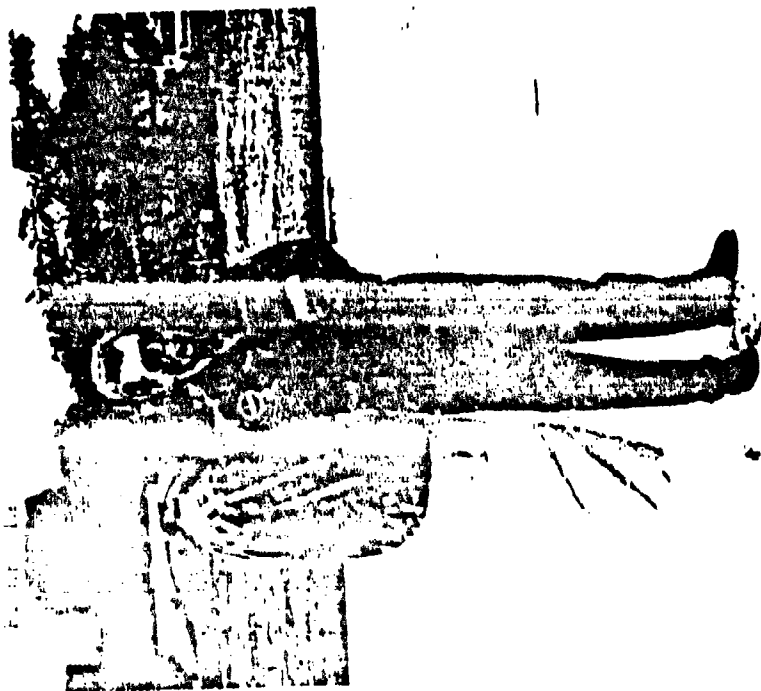
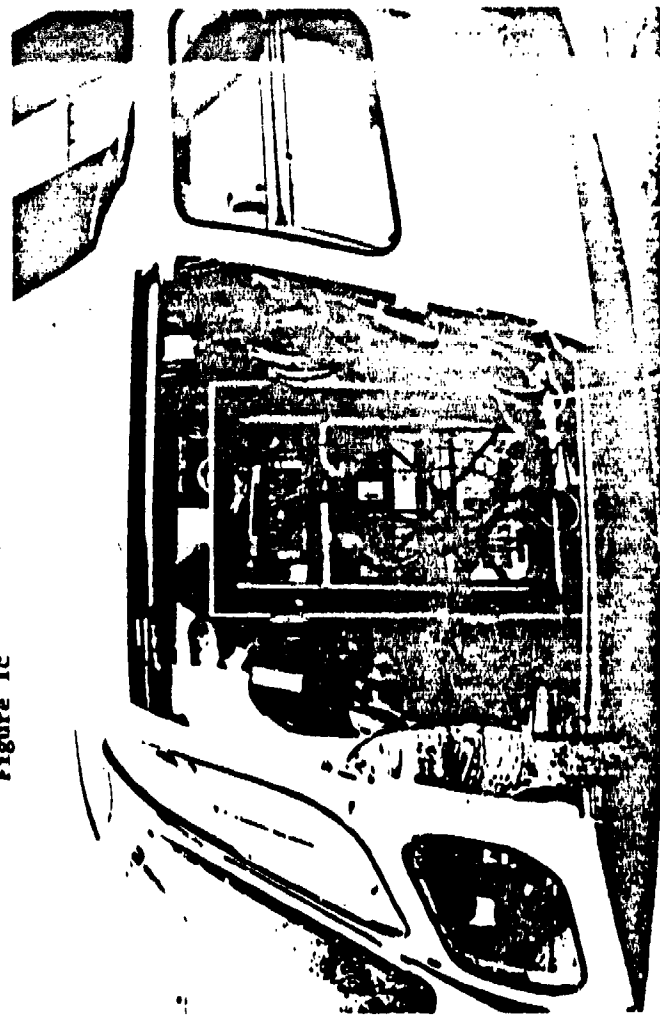


Figure 2a

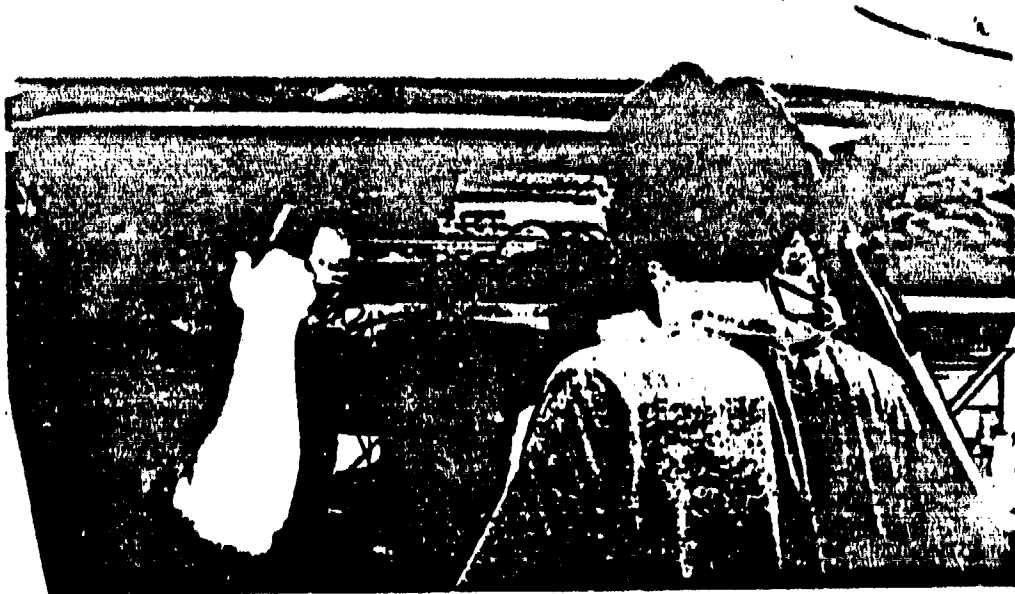


Figure 2b

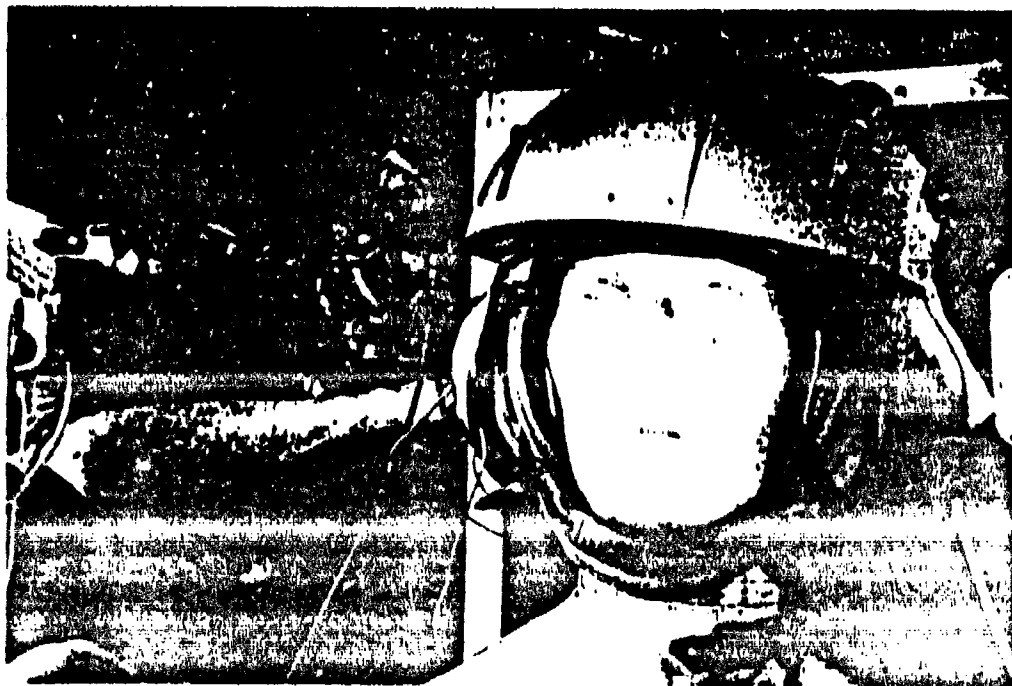
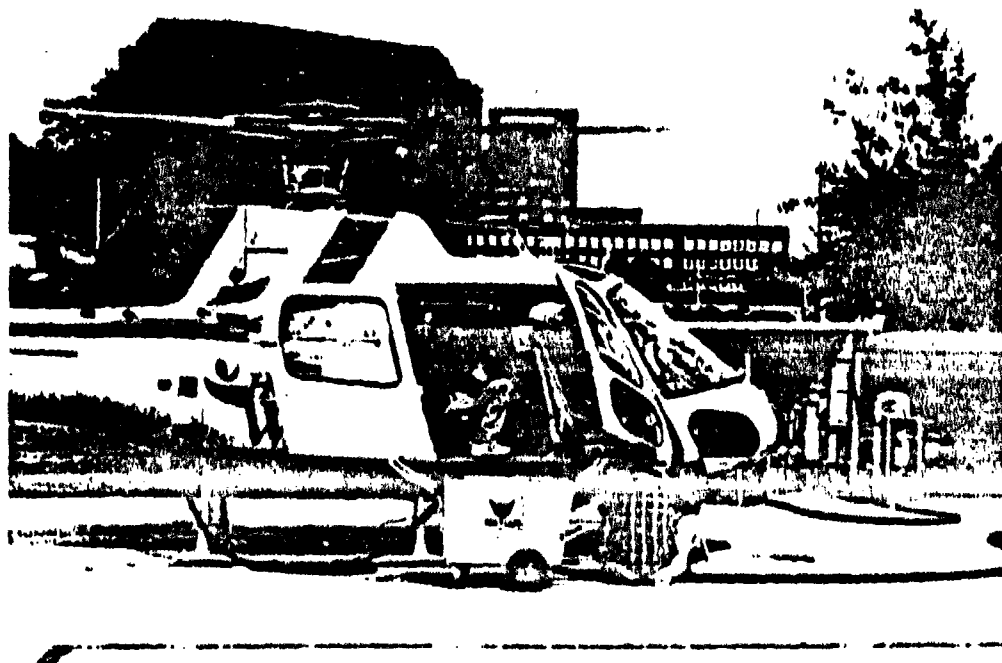


Figure 3a



Figure 3b



Armstrong Laboratories Brooks Air Force Base visit

Major Anne Bell invited Noise Removal Systems to make a presentation at Brooks Air Force Base. It was originally hoped that actual in-flight testing could take place during this visit, but it was discovered that this would not be possible without AWR flight certification. At 9:30 AM on Friday, 8-20-93, about ten people attended a one hour 15 minute presentation was made, which included a demonstration of the ANC stethoscope. This presentation was similar to the presentation made earlier in Fort Rucker. About a dozen other people from Brooks Air Force Base, who could not make the scheduled presentation came by at various times to listen to the ANC stethoscope on 8-19-93 and 8-20-93. Contacts were made with people familiar with active noise reduction technology and AWR flight certification testing procedures. Facilities needed for AWR testing are at both Fort Rucker and Brooks Air Force Base. One of these agencies would be chosen to test the ANC stethoscope for AWR approval in the event that Phase II is funded. During the afternoon of 8-20-93, Major Pfeiffer came from Fort Sam Houston to listen to the ANC stethoscope prototype. Major Pfeiffer is in charge of the program to develop the UH-60Q helicopter. The ANC stethoscope prototype performed flawlessly for all these demonstrations.

Other Developmental Work

Two approaches have been used to determine the frequency dependent gain needed to make the new electronic sensor sound like a conventional stethoscope. Several additional efforts were made to get agreement between human threshold measurements and Knowles Kemar mannequin in the ear microphone measurements. However, satisfactory agreement has still not been found. Figure 4 gives the frequency dependent gain determined by an audiologist by performing human testing and Figure 5 depicts the frequency dependent gain determined by attaching both stethoscopes to the Knowles Kemar mannequin. Future work during Phase II will be required to determine the source of the discrepancy, which is not currently understood.

All of the work scheduled in the prior monthly report was completed, with the exception of modifying the SPH-4B earcup retrofit for human comfort and recreating UH-60 vibrations in the NCPA noise simulation laboratory. Tape recordings of UH-60 accelerometer data from USAARL

Figure 4

INRS Research Aug 21, 1993 15:21 PM

Gain needed by the ANC Sensor to match a conventional Stethoscope (taken from threshold measurements made on Matti Mäyry)

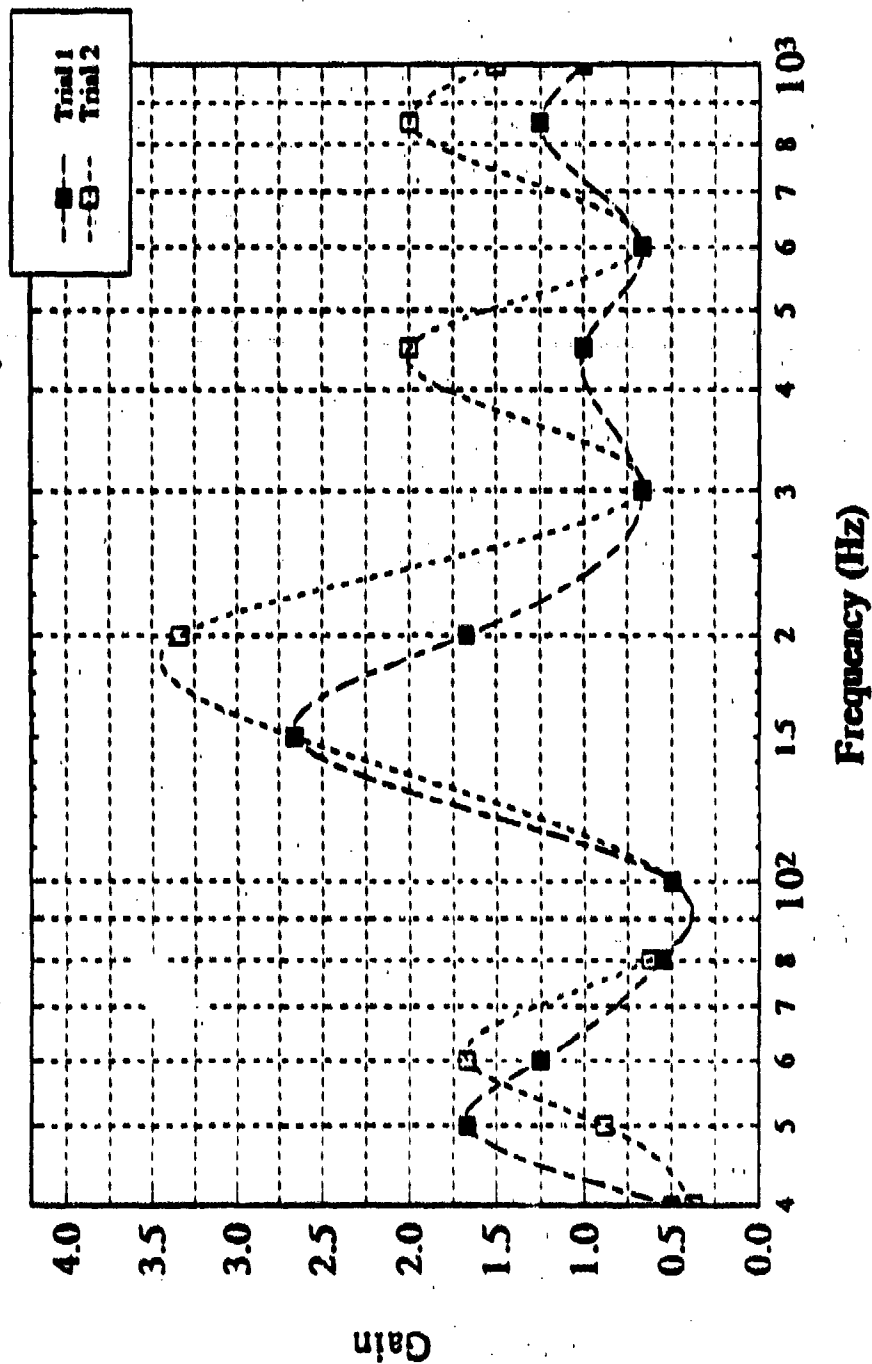
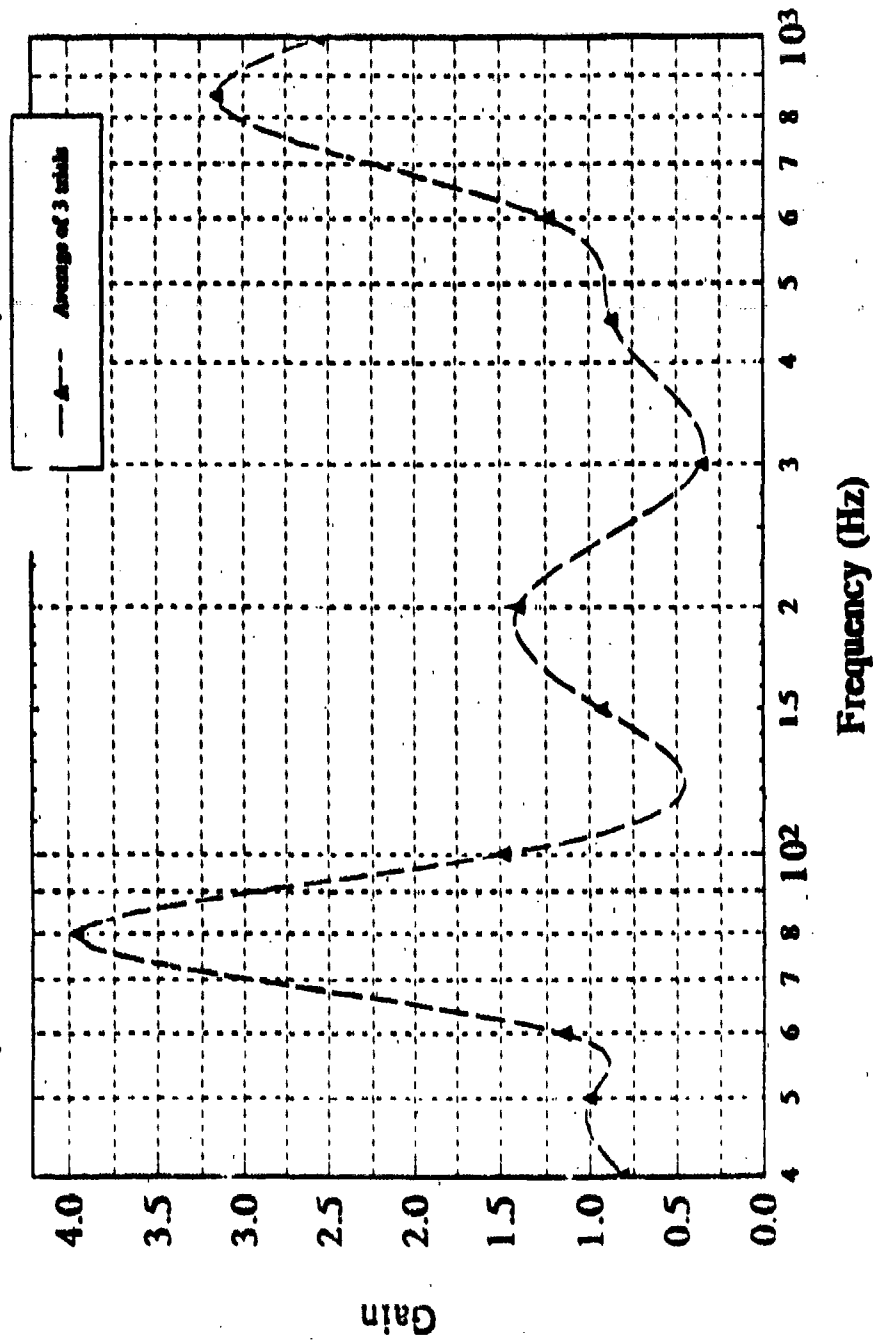


Figure 5

PHS Research Aug. 23, 1993 3:38:09 PM

Gain needed by the ANC Sensor to match a conventional Stethoscope

(taken from measurements made on the Knowles-Kennar mannequin)



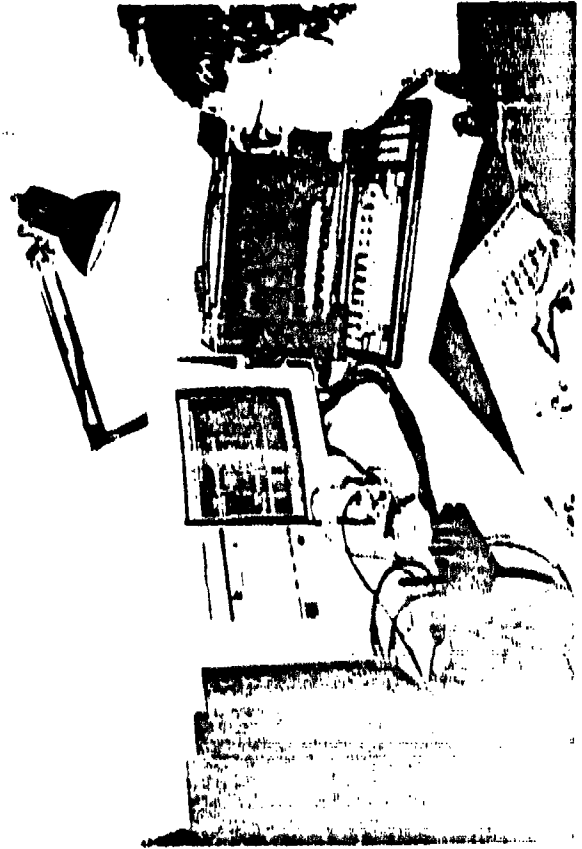
are needed for simulating vibrations, and the SPH-4B retrofit was deferred when it was decided that Noise Removal Systems would make a presentation at Armstrong Laboratory in Brooks Air Force Base, San Antonio, TX. Time spent in preparation, packing, and unpacking required about three days. In addition, the round trip from Oxford, MS required four days of travel and two days were spent at Brooks Air Force Base.

Another omission in the Phase I project was a \$ 1,000 consulting fee for ITD regarding cost estimates of a final product following miniaturization. Jim Hendrix was to oversee this effort, but Jim ended up working on other aspects of the ANC stethoscope in great excess of the amount of time (costing much more than \$ 1 K) estimated by the Phase I proposal. Another reason ITD was not consulted is that ITD's area of expertise did not appear to be as applicable as was originally anticipated. It is anticipated that Noise Removal Systems will finance Jim Hendrix and Frank Lacy to attend a Texas Instruments workshop for training in Field Programmable Gate Array (FPGA) computer chips. This will provide training essential for further development of the ANC stethoscope. This future effort will not occur during the six month period covered by the Phase I contract.

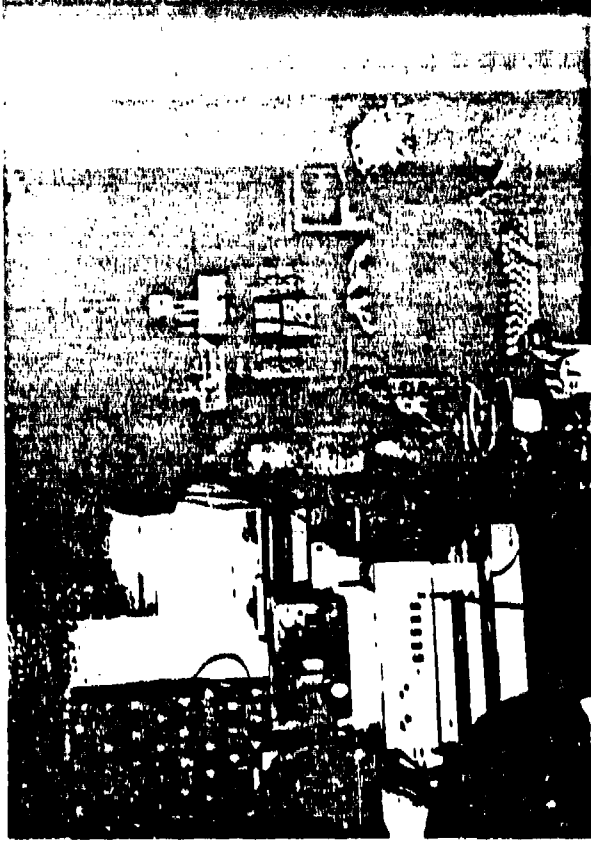
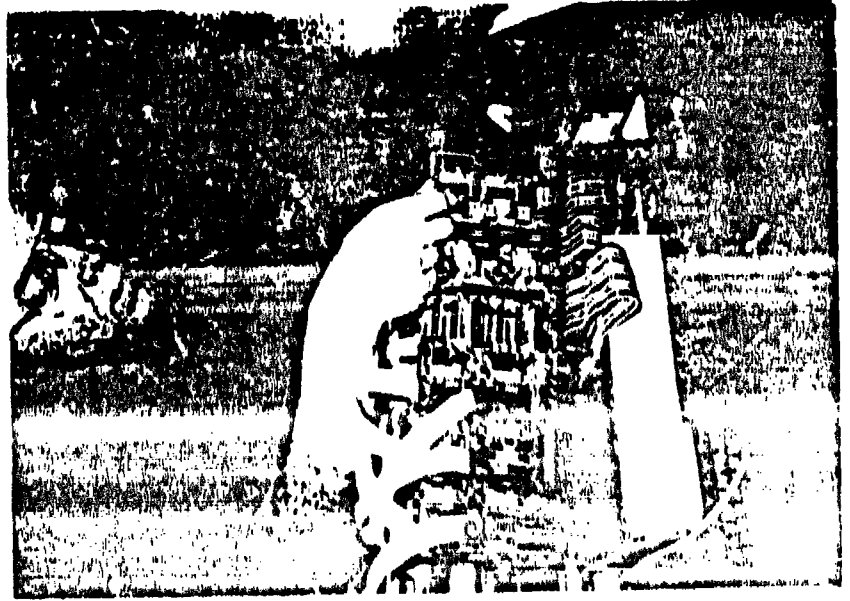
Pictures of Key Personnel involved in the Phase I effort

Best Available Copy

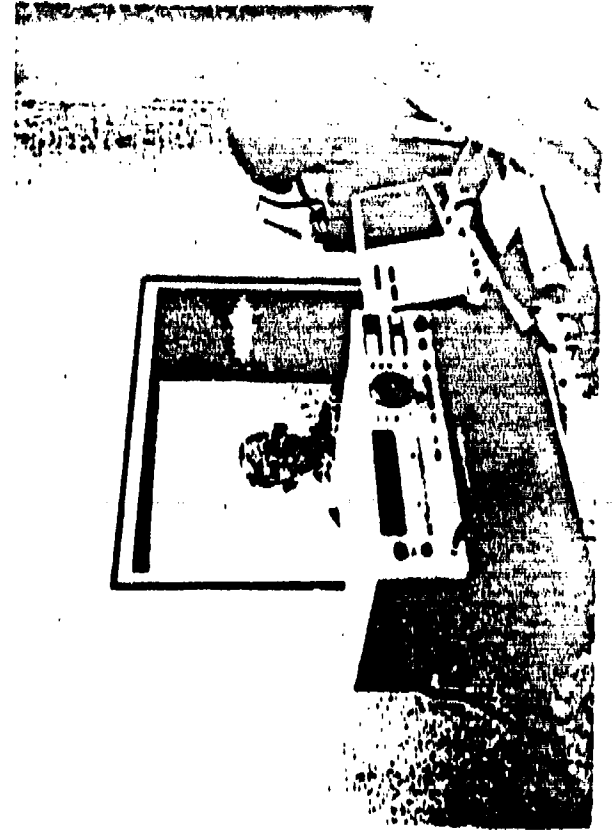
Tom Harley working in his office
at the NCPA.
Jim Hendrix in his office and
showing the circuit board he
designed.



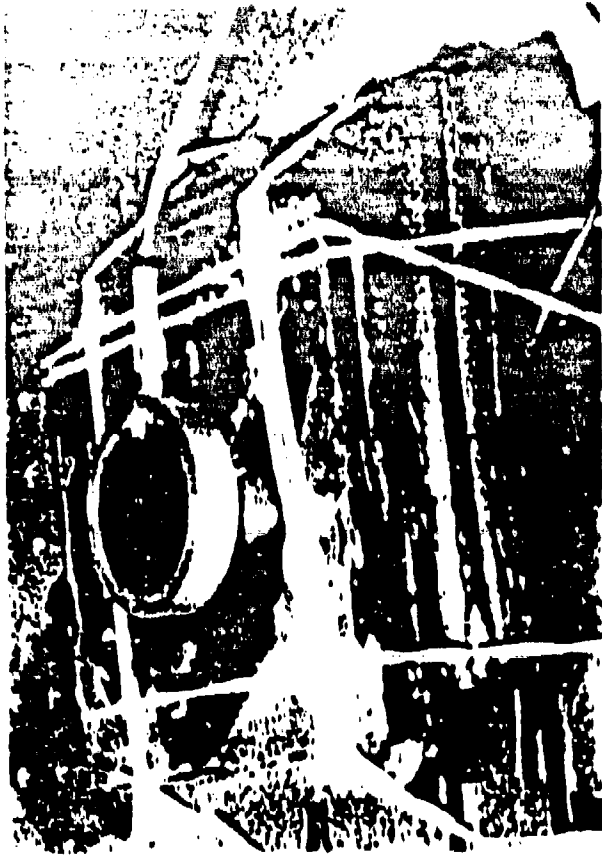
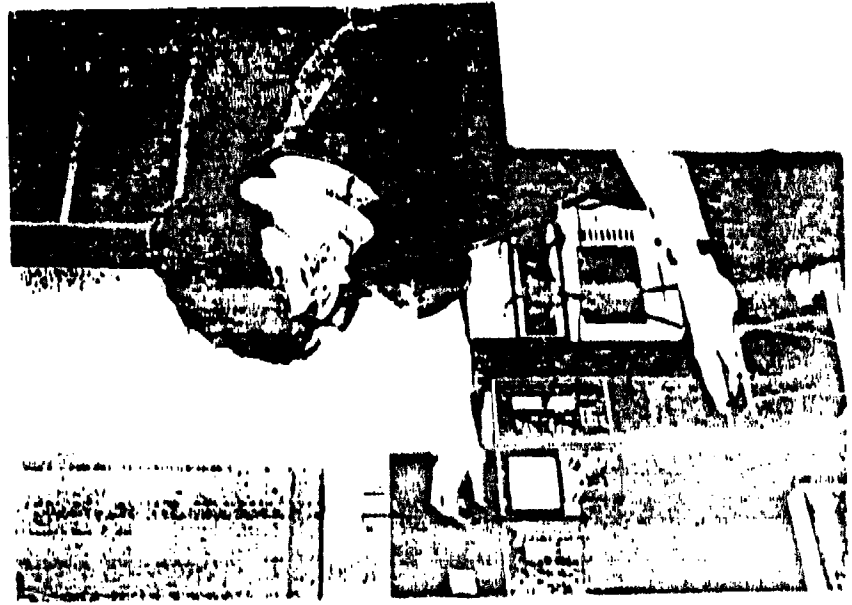
Tom Harley and Jim Hendrix
testing the ANC stethoscope
prototype in the NCPA noise
simulation laboratory.



**Dr. Lisa Lucks Mendel
(audiologist) evaluating the
performance of the ANC
stethoscope with Pat Malone and
Dr. Eric Dahl (medical doctor).**



Graduate students, Matt Miley and Keith Olree, testing the ANC stethoscope using the human torso simulator.



Section III. Problem Areas

In addition to the problems discovered during the field testing at Memphis Wings, minor problems occurred during the demonstrations at Fort Rucker and Brooks Air Force Base. We forgot to plug in two preamplifiers connected to microphones in the earcups of the SPH-4B during the visit to Fort Rucker. When we set up the day before the demonstration, everything worked fine because battery back ups take over when these SRS preamplifiers are unplugged. However, since the preamplifiers were left to battery power all day long, the next day one of them failed during the live demonstration, because the battery ran down. During a break following the formal demonstration the unplugged preamplifier problem was discovered, and corrected. During the formal demonstration we played back the sound heard by the Knowles Kemar mannequin under the earcup that was working properly, and after the break a second demonstration tape was made in stereo with both ears working.

At Brooks Air Force Base, the ANC stethoscope prototype performed flawlessly, but a setup for simply listening to the innovative electronic sensor failed. Low power amplifiers were being used that ordinarily get overdriven whenever a loud sound causes the electronic sensor to temporarily output a DC offset. This is corrected by placing a high pass filter, set at 30 Hz, between the electronic sensor and the amplifier. The electronic device being used for a high pass filter apparently took on one too many bumps between Mississippi and Texas and was not working. It was later found that the particular device being used for a high pass filter had been erratic in the past. A better device is available and will be used for future demonstrations.

Section IV. Work scheduled for next month

Note that there is no charge to the Army for the following work items which were not mentioned in the Phase I proposal or Phase I contract. This work will be done by Noise Removal Systems in support of the ANC stethoscope project during a time period after the Phase I contract has expired and before the start of a Phase II contract.

1. Consult Small Business Administration regarding Phase II budget.
2. Modify Phase II proposal to include budget changes, elaborate on Air

Worthiness Release (AWR) testing, and include Reliability, Availability, and Maintenance (RAM) of the ANC stethoscope prototypes.

3. Resubmit paper on the Random Noise Cancelling algorithm for an adaptive digitally controlled ANR headset, in response to referee's suggestions.

4. Submit paper to Medical Journals regarding the work on the active noise control stethoscope completed during Phase I.

5. Make copies of tape recordings of the ANC stethoscope prototype demonstrations made during presentations at Fort Rucker and Brooks Air Force Base and send these copies to Charles Paschal, Bradley Hall, Major Joe Hatch, and Major Anne Bell.

6. Jim Hendrix and Frank Lacy will attend a Texas Instruments workshop on FPGA technology.

Section V. Administrative Comments

Section VI. Gantt Chart

A copy of the seven itemized tasks from the SBIR proposal is attached. A significant amount of work is not reported in the Gantt chart, involving the development the new sensor using a piezoceramic transflexural disk. The need for this work was not envisioned when the SBIR proposal was written.

GANTT CHART

Prior Work
 This month

