FINAL REPORT FOR THE

SUMMER INSTITUTE IN BIOMEDICAL ENGINEERING

— 1973 —

Prepared by

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Howard University

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GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

ACKNOWLEDGEMENTS

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This report included the written record of work performed
by ten student participants of the 1973 Summer Institute in
Biomedical Engineering.

STUDENT PARTICIPANTS

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CONTENTS

CONTENTS (Continued)

FINAL REPORT FOR THE
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INTRODUCTION

Biomedical engineering is that branch of engineering whose problems are found
among the phenomena spanning the broad-based fields of biology and medicine.
Due primarily to its vast nature the field has continued to defy capsulation into
a simple, universally acceptable, definition. In an attempt to arrive at such a
definition, in 1971 the National Academy of Engineering (NAE) proposed that the
field of biomedical engineering might be viewed as the union of the following
three broad categories:

> "1. The application of engineering concepts and technology to scientific
>   inquiries into biological phenomena as a basis for advancing the under-
>   standing of biological systems and medical practices.
>
> 2. The utilization of engineering concepts and technology in the develop-
>   ment of instrumentation, materials, diagnostic and therapeutic devices,
>   artificial organs, and other constructs relevant to application in biology
>   and medicine.
>
> 3. The application of engineering concepts, methodology, and technology,
>   to the improvement of health services delivery systems in the context
>   of interrelated institutions (hospitals, clinics, governmental units,
>   universities, industry, etc.) as well as within the specific confines of
>   individual components of the health care system."

What should be appreciated in attempting to assess whether this definition
possesses merit, is that the preceding categories were arrived at some fifteen
years following the recognized period of the emergence of biomedical engineering
as a viable discipline. However, since this definition was coined with the assis-
tance of a far-reaching survey, one might logically assume these results to be
reflective of the legitimate health-care needs of the society at large.

The cost of routine medical care to the "average" American family continues to
escalate, while the practice of medicine continues to escape extensive moderni-
zation of methods and/or the wide-spread utilization of the techniques and ma-
terials of engineering and technology. Although it is clear that the indiscriminant
application of engineering concepts and constructs in the biomedical area will
neither improve medical services nor reduce costs to the patient, it is just as

clear that some well-planned, carefully assembled attack on specific medical problems, assisted by engineering, could yield quite acceptable dividends.

In an attempt to lend order to the interdisciplinary systems approach needed in integrating engineering know-how with the requirements of biomedicine, the second Howard University-NASA Summer Institute in Biomedical Engineering was conducted, with funding provided by the National Aeronautics and Space Administration University Affairs Division. This unique program was designed with the ultimate goal of addressing itself to some of the existing and pressing needs of the clinically-oriented practice of medicine.

The Technology Utilization Office of the Goddard Space Flight Center, in the spirit of this program, has been on record as being interested in finding new ways to narrow the gap between the current technical needs of the medical community, and the existing capabilities of its engineers and scientists to fulfill these needs. Through the expertise, developed over the many years of the space program, it is felt that NASA possesses an enormous potential to contribute to the solution of many engineering-based medical problems.

This report is submitted as an assembled record of a specific project indicating how the NASA expertise and facilities were coordinated with the engineering and medical facilities at Howard University in an attempt to solve five interesting problems of potential benefit to society. It is believed that the results are supportive of the idea that a well-coordinated team approach, involving cooperating medical and technical persons, can go a long way toward outlining practical solutions to previously unsolved problems in the biological and medical areas.

THE PROGRAM

The Summer Institute in Biomedical Engineering was pivoted about a ten week engineering design oriented project, commencing June 11, 1973, and terminating on August 17, 1973. The goals of the Institute were inclusive of the following:

a) to provide an opportunity for undergraduate engineering students to engage in the study of carefully selected biomedical engineering problems which have not, heretofore, been solved.

b) to provide a mechanism to expand the channels of communication between engineering and medical professionals.

c) to test the potential of a proposed mechanism intent on reducing the time lapse between the original concepts and the actual working models

of clinically applicable biomedical engineering instruments and/or devices.

d)   to assess the strengths and weaknesses of the engineer as a member of medical and health science teams.

e)   to test the feasibility of space technology transfer, via NASA-based knowledge, to problems in medicine and related areas.

To accomplish the above, a total of ten (10) undergraduate engineering/science students were invited to participate in the Institute. Recruited via open invitation, participants represented ten American colleges and universities. Their selection was based on their own expressed interest in biomedical studies as well as predicted capabilities as displayed by their academic backgrounds and accomplishments.

MEDICAL AND TECHNICAL PERSONNEL: THE PROBLEMS

The medical and technical personnel needed to conduct this program were drawn from fields related to the problems to be studied. It was anticipated that a close cooperation would be required if the detailing of practical problem statements and the outlining of feasible engineering solutions was to be realized.

The philosophy put forth was that the original problem identification and definition should come from the medical professionals involved. After it was ascertained that a sufficient need and interest did exist, a final description of the problem would be developed by the doctor in concert with a technical (engineering) professional.

The problems selected for study, the medical investigators and the cooperating technical advisors were as follows:

"SURGICAL SUITE ENVIRONMENTAL CONTROL SYSTEMS"
    Stated by:
            Dr. Edward Briscoe (Freedmen's Hospital)
    Technical Advisor:
            Mr. Frederick Gross

"DESIGN OF AN AUTOMATIC WEIGHT SCALE FOR AN ISOLETTE"
    Stated by:
            Dr. F. Rabhar (Freedmen's Hospital)
    Technical Advisor:
            Mr. Leonard Kleinberg

"SURFACE POTENTIAL MAPPING ELECTRODE SYSTEM"
Stated by:
Dr. Eugene Fischmann (Freedmen's Hospital)
Technical Advisor:
Mr. Warner Miller

"THE USE OF SPEECH-MODULATED-WHITE-NOISE TO
DIFFERENTIATE HEARERS AND FEELERS AMONG THE
PROFOUNDLY DEAF"
Stated by:
Dr. Henry Tobin (Gallaudet College)
Technical Advisor:
Mr. Roland VanAllen

"INTERNAL TIBIAL TORSION CORRECTION DEVICE"
Stated by:
Dr. Charles Epps (Freedmen's Hospital)
Technical Advisor:
Mr. Lawrence Kobren

THE INSTITUTE STAFF AND ORGANIZATION

Since the program represented an attempt at "true" interdisciplinism, as well as organization cooperation (NASA-Howard University), it was believed that the staffing and the authority for action be minimally pyramidal.

a) Howard University — Dr. Eugene M. DeLoatch, Associate Professor of Bioengineering at Howard University, served as Principal Investigator of this project. His duties were to see that the Howard University portion of the contract was fulfilled and that the results obtained during its tenure were properly reported.

The second active staff member at Howard University, contributing eighty per cent (80%) of her time during the summer, was Dr. Anna J. Coble. Dr. Coble, an Assistant Professor of Biophysics, served as the assistant to the Principal Investigator. Among her duties were: the performance of a preliminary study on the scientific merit of some of the proposed problems and the continued guidance of the students in their search for pertinent reference materials.

b) NASA — Mr. Wayne T. Chen of the Technology Utilization Office at the Goddard Space Flight Center directed the bulk of the day-to-day

operations of the NASA portion of the program. Granted the authority by Mr. Donald Friedman, Mr. Chen was responsible for a wide variety of activities inclusive of contacting technical advisors, tracing materials and equipment for prototypes, arranging fabrication and conference schedules for student participants and honoring requests to NASA made by the Howard University staff members.

Lending support services to the staff at Howard was Ms. Christine Williams, a sophomore Chemical Engineering student. Her duties were numerous and her fulfillment of them was an integral part of the Institute effort. At NASA the efforts of Ms. Helen Attick and her secretarial staff associates were supportive of the needs and reasonable requests of members of the Howard University as well as the NASA staff personnel.

THE TEN WEEK PERIOD: JUNE 11 - AUGUST 17

The ten students participating in this program were awarded weekly stipends in return for their study of the previously cited problems. The program was opened with a two-day orientation period during which the students were exposed to the design of the program, the key people and divisions of the participating organization, and given a briefing on the problems to be studied. Following this orientation, students were asked to make their own problem preferences known, leading to matching of students and problems for five two-member teams — one team for each problem.

Acting as project engineers, the students were given full responsibility for identifying and gathering all the information and items needed to effectively research their problems. Any reasonable requests for assistance in securing materials or gaining access to key personnel were immediately acted upon by the program coordinators at Goddard and/or Howard as required. This was done with the realization that tight scheduling would be required to achieve reasonable results in the ten-week period.

To track the progress of the students, frequent informal student group assemblies were held. This allowed the students to exchange ideas and discuss areas of common difficulty which they may have been experiencing. It was found that this exchange served to add to the over-all efficiency of the Institute as well as to periodically reinforce the students' confidence. At the end of the seventh week, a preliminary presentation of their progress was given at a meeting at the Howard University School of Engineering. The medical doctors were here invited to observe the direction in which their problem was being taken and to receive projections of the results that were expected in the ten-week period. It

was later found that this session served as an ideal forum in which to prepare for presentation of the final reports.

CLOSING THE PROGRAM: THE TECHNICAL REPORTS

Results of the studies were presented at a public meeting held at the Goddard Space Flight Center on August 16th. Each of the five teams was given twenty minutes to condense and present its problems, outline the solution and chart the future course of the development of its device as collectively perceived. A question and answer period followed each oral presentation.

The section which follows consists of the technical reports submitted by the students as by-products of their study. Each report is prefaced with the problems as originally stated. Following these statements are the reports as written by the students. Some reorganization of the materials has been done for continuity, but for the most part, with a minimum amount of editing. This was done purposefully to fulfill the educational nature of this program, and in an attempt to preserve the general purpose of the Summer Institute.

The order of presentation of individual reports has no particular significance.

SECTION 1

SURGICAL SUITE ENVIRONMENTAL

CONTROL SYSTEM

Submitted by:

Eve Higginbotham

Marc Jacobs

MEDICAL ADVISOR:

Dr. Edward Briscoe

TECHNICAL ADVISOR:

Mr. Frederick Gross

ORIGINAL PROBLEM STATEMENT

As paraphrased by: Written by:

     Dr. Edward Briscoe   Eugene M. DeLoatch, Ph.D.

TITLE: SURGICAL SUITE ENVIRONMENTAL CONTROL SYSTEM

STATEMENT OF THE PROBLEM: When persons associated with medically based problems seek to identify areas of potential hazards, the primary concern often becomes that of maximizing patient safety while optimizing the delivery of service. Often overlooked in this planning process are many of the less obvious dangers, both physical and biological, central to attending personnel. This factor has been exhibited dramatically in the area of anesthesiology where environmental pollution caused by anesthetic gases, has proven deleterious to personnel after long-term exposure.

With 90% of the hospitals in this country being those consisting of 400 beds or less, it is not likely that Laminar-Flow Clean Room techniques will be employed in the immediate future by large numbers of hospitals in Surgical Suites. It is thought that a more plausible solution is a scheme similar to the exhaust valve-charcoal cannister system, recently proposed in a Howard University/ NASA joint study. Modifications of this scheme, establishment of procedures for use, and quantified test results are needed to complete this problem.

SCOPE OF THE WORK: An entire systems analysis approach to the problem is needed. It should include all device performance evaluations, a test of equipment and materials to be employed in the system, and a cost effectiveness study relating the existing procedures and systems to those which have been proposed. It is expected that the performance evaluations will be arrived at through employing both theoretical and clinical laboratory methods. The intact system should be tested and expected results verified through the use of laboratory animals.
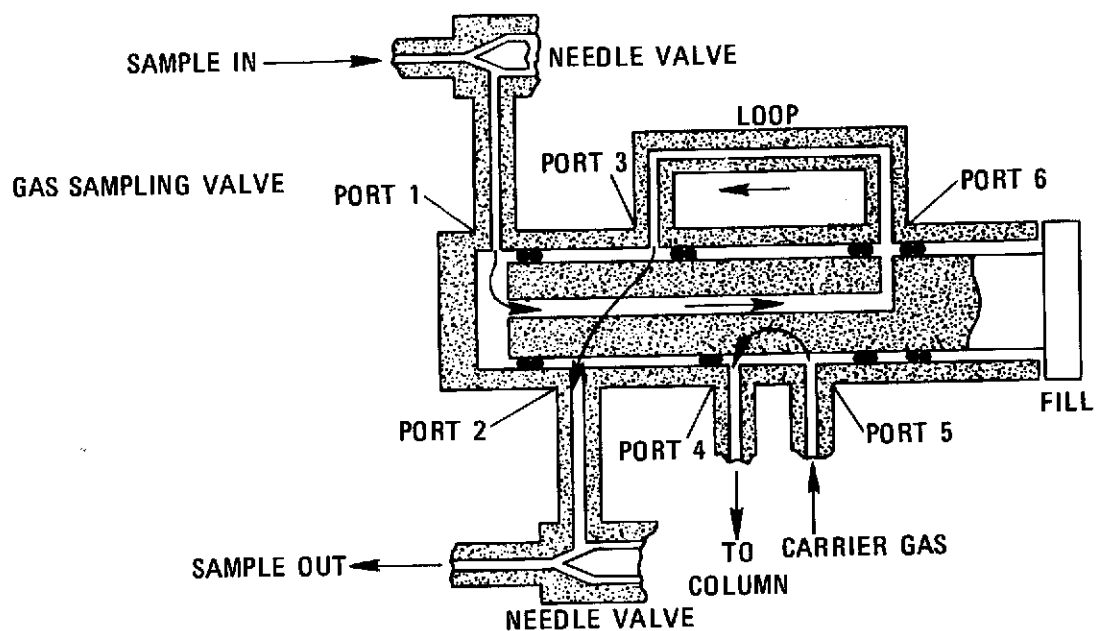
THE ADSORBENT SEARCH

EXPERIMENTAL

The experiments in the adsorbent search involved the sampling of gases in the inlet and outlet streams after exposure to the adsorbent being tested. The instrument used was a gas chromatograph. The carrier gas was He and its flow rate was about 41 ml/sec; the column used was OV 17 Chromasorb W at ambient conditions. Gas samples were injected into the machine via gas sampling loops located on the side of the machine (Figure 1-1). At time t, one loop can be opened and its content purged into the column by the carrier gas.

In our case halothane was detained about 40 seconds immediately preceeded by the N_2O - O_2 peak. Thus, at an attenuation of one, the halothane peak was observed preceeded by an off scale N_2O - O_2 peak (Figure 1-2). Furthermore since the concentration of the component is directly proportional to peak area, not only a method of detecting the presence of halothane had been established but also the concentration.

The test setup was fairly simple as shown in the diagram (Figure 1-3). The O_2 and N_2O flows were 2 liters/minute and 3 liters/minute respectively. These flows were chosen because they coincide with flows used during actual operations. From the flow meters the gas mixture was circuited to the vaporizer which contained the liquid halothane. The mixture was then directed to the adsorbent and finally to the gas chromatograph.

SAMPLE IN ——→ NEEDLE VALVE

GAS SAMPLING VALVE   LOOP

PORT 1   PORT 3   PORT 6

PORT 2   PORT 4   PORT 5   FILL

SAMPLE OUT ←—— TO CARRIER GAS
COLUMN
NEEDLE VALVE

VALVE IN "LOAD" POSITION

SAMPLE   LOOP   STROKE
5/16

PORT 1   PORT 3   PORT 6

PORT 2   PORT 4   PORT 5   INJECT

CARRIER GAS   CARRIER GAS
AND SAMPLE
TO COLUMN
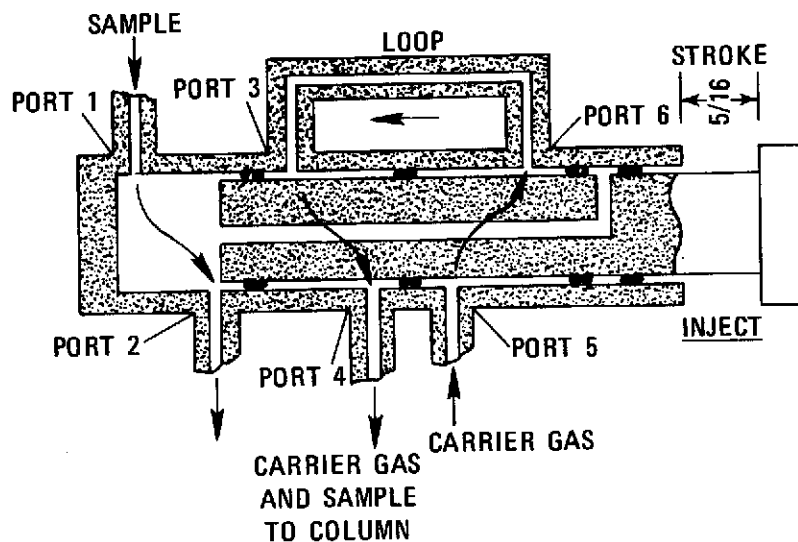
VALVE IN "INJECT" POSITION   JS0507

Figure 1-1. Research Gas Chromatograph

N₂O - O₂ PEAK
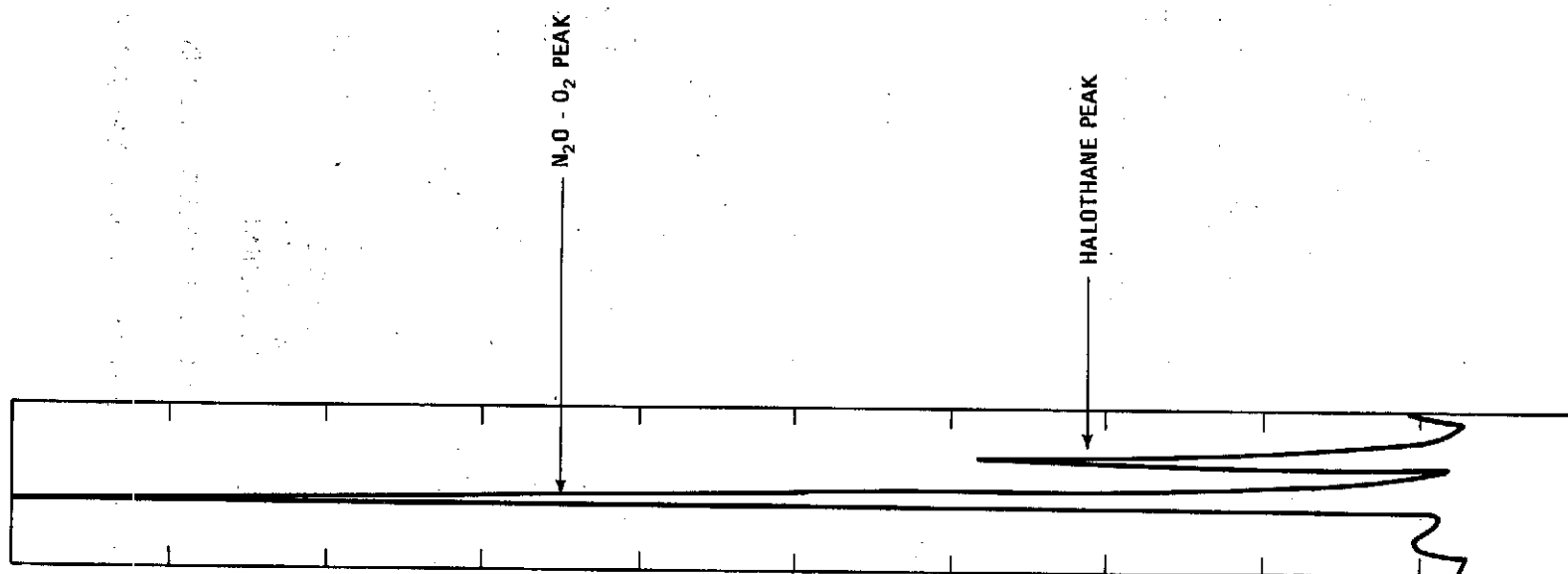
HALOTHANE PEAK

Figure 1-2. Examples of Output from Gas Chromatograph
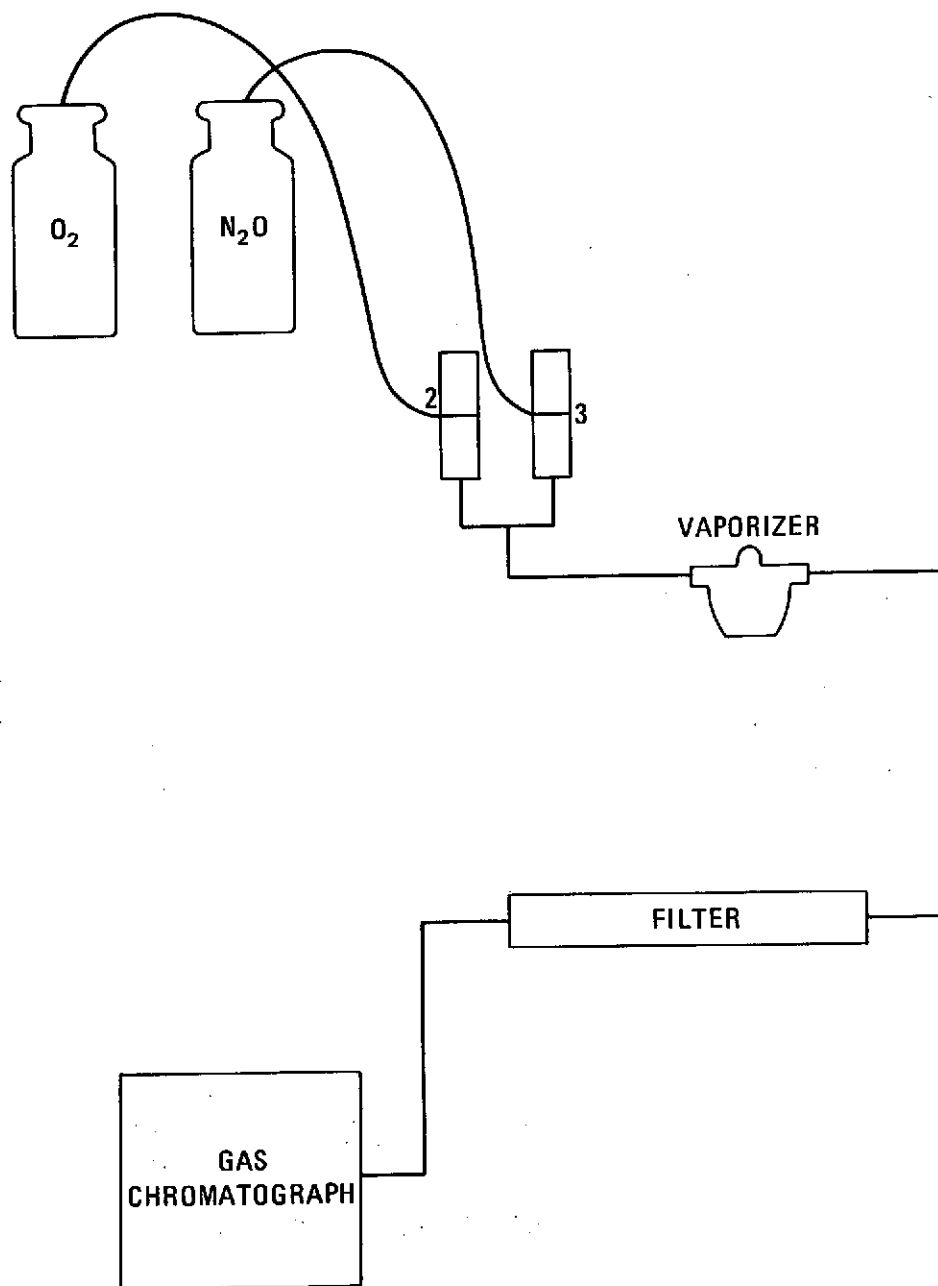
Figure 1-3. Test Set Up

SURGICAL SUITE ENVIRONMENTAL CONTROL SYSTEM

AMENDED STATEMENT OF THE PROBLEM

The persistent exposure of surgical personnel to halothane has recently grown into a problem. Reports have linked halothane to hepatitis, miscarriages, liver, and renal disorders. A filter is needed to remove the leaking halothane from the surgical suite atmosphere. Modifications must be made on an air tight "pop-off" valve proposed by the team of 1972. A proper adsorbent or combination thereof must be found which is effective, i.e. eliminates measurable amounts of the contaminant exhausted from the modified "pop-off" valve.

STANDARD ANESTHETIC CIRCUIT
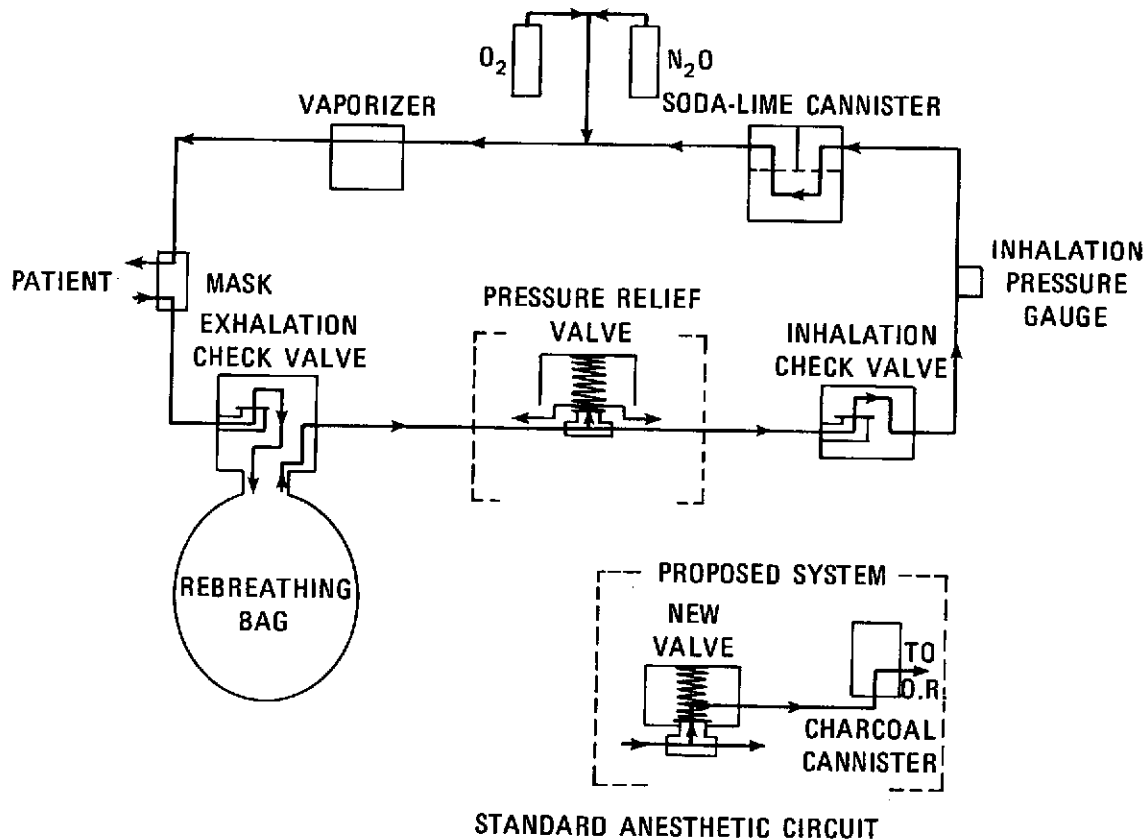
TAKEN FROM: 1972 SUMMER INSTITUTE FOR BIOMEDICAL ENGINEERING REPORT

The following general test procedure for rating adsorbents was adopted:

1. Gas was sampled for halothane concentration before flowing to the filter.

2. Gas was sampled for halothane concentration in the outlet stream.

3. The two readings were compared for relative halothane concentration.

PART A: MOLECULAR SIEVES VS. CHARCOAL

Molecular sieves are synthetic adsorbents; they are alunosilicates which have undergone heating to remove water of hydration. Two types were tried: Linde molecular sieves type 13x and Davison molecular sieves type 5A. Type 13X adsorbs molecules with diameters up to 10 Å. On the other hand type 5A adsorbs molecules with diameters up to 5 Å. The activated charcoal tested was Grade LCK, a gas adsorbing carbon produced by Linde. (Activated carbon is free from stabilized hydrocarbons which are normally associated with it. The hydrocarbons lessen the adsorbent's power to combine with or adsorb other substances.)

In testing the materials above an additional step was added to the procedure described in the introduction. A saturation time was defined when the halothane peaks reached a steady plateau in height. These times were taken during the tests.

Ninety grams of the adsorbent sample were placed in a modified Rego air filter shown in Figure 1-4.

The gas was routed to the bottom of the filter and allowed to diffuse upward. The inlet and outlet concentrations were monitored.

RESULTS (See Qualitative Graph and Figure 1-5)

Sample	Approximate Saturation Time
Molecular Sieves 13x	3 minutes
Molecular Sieves 5A	4.5 minutes (Not Shown)
Grade LCK	8.5 minutes
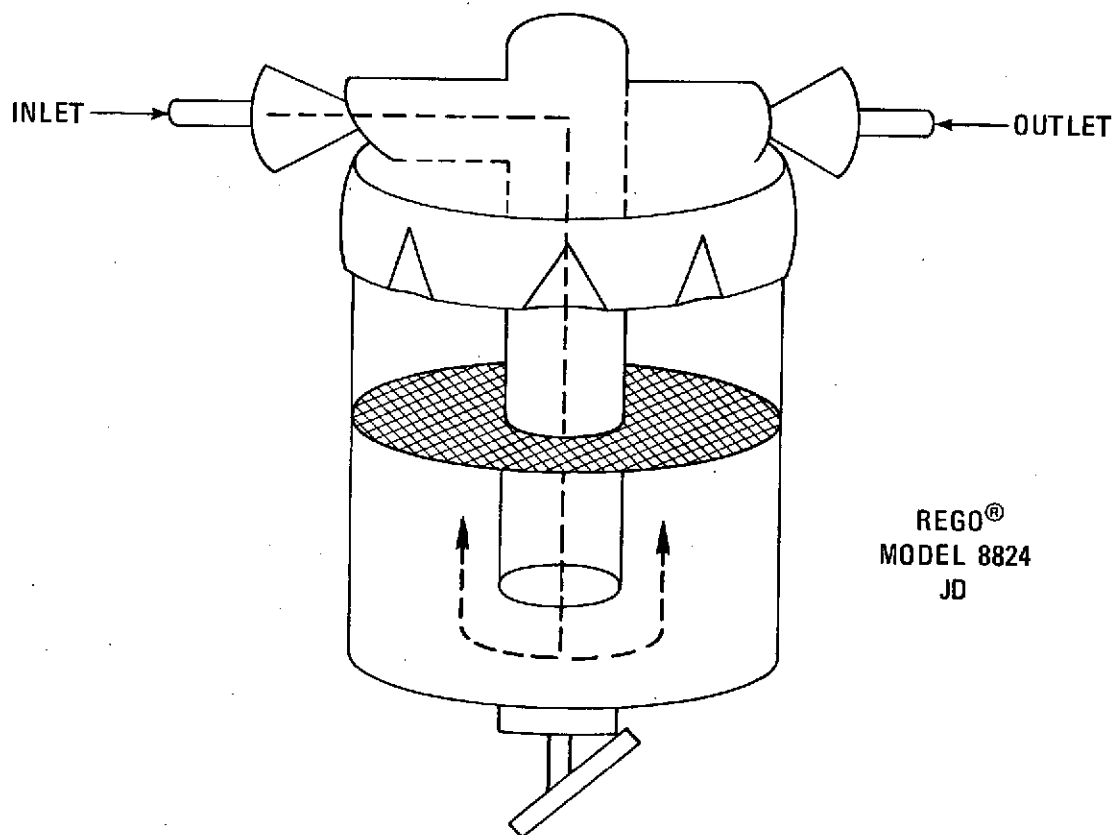
Figure 1-4. Adsorbent Container for Part A

CONCLUSIONS

Molecular sieves were eliminated at this point as possible adsorbents for a filter. Molecular sieves cost about 2.5 times that of charcoal and seem to saturate at too fast a rate.

PEAK HEIGHT

MOLECULAR SIEVES 13X

LCK CHARCOAL

TIME IN MINUTES
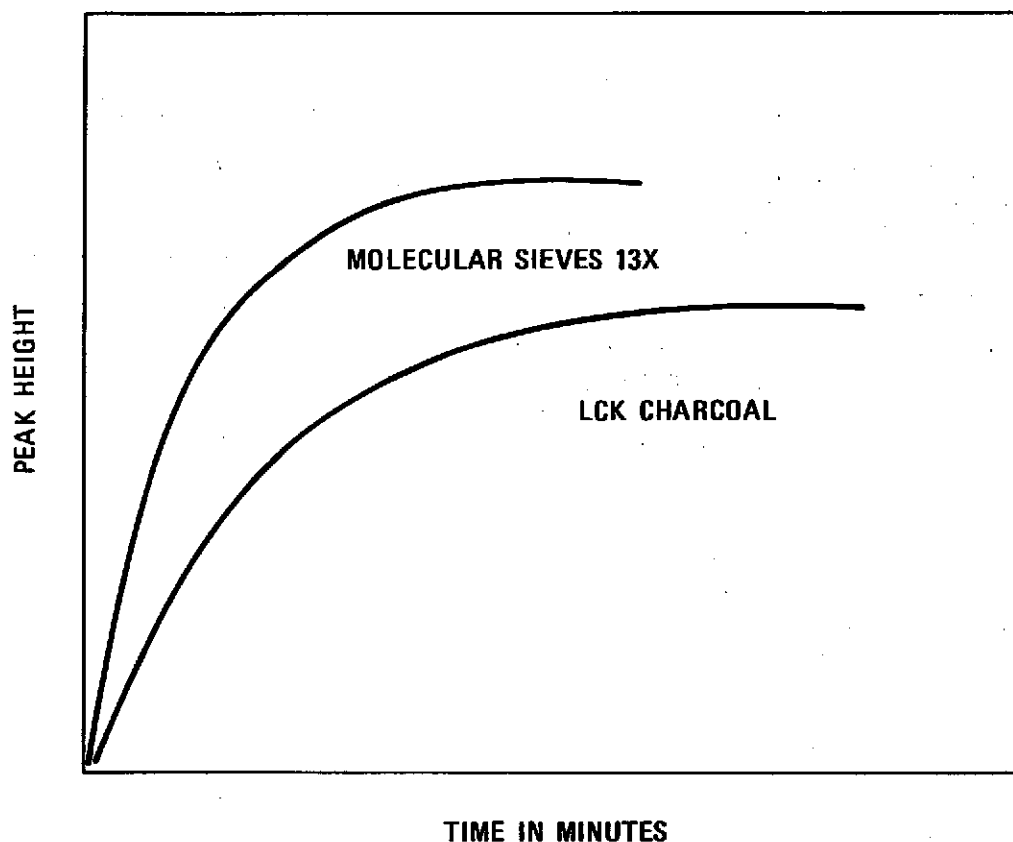
Figure 1-5. Rough Comparative Graph of the Adsorbency
of Sieves Versus Charcoal

PART B: THE INVESTIGATION OF CHARCOALS AND COMBINATIONS

Several charcoal companies were asked to send samples of their gas adsorbing
carbons. In testing these the same protocol as discussed in the introduction was
used. The adsorbents and combinations were ranked according to relative imme-
diate efficiency in removing halothane. Twenty seven inches of each sample
were packed in a 32.25" long tube.

RESULTS (See the Table of Tabulated Results, Figure 1-6)

CONCLUSIONS

The BPL- Alumina-BPL combination seemed to be the best combination for
removing halothane.

ADSORBENT	% HALOTHANE DETECTED
BPL CHARCOAL + ALUMINA	77%
MSA (BLACK CANISTER) FOR ORGANIC VAPORS	83%
BPL CHARCOAL	84%
MSA (YELLOW CANISTER) FOR ORGANIC VAPORS AND ACID GASES	88%
MI CHARCOAL WITH VERY FINE CHARCOAL	90%
PCB CHARCOAL	91%
MSA (RED CANISTER) UNIVERSAL	93%
MI CHARCOAL WITH ALUMINUM OXIDE	93%
MI CHARCOAL	94%
GRADE LCK CHARCOAL	95%
VG CHARCOAL	98%
GRADE LCK + SILICA GEL GRADE LCK CHARCOAL IMPREGNATION WITH THYMOL	(NO APPARENT DIFFERENCE)

BPL	Pittsburgh Activated Carbon
Grade LCK	Union Carbide
MI Charcoal	Barneby Cheney
MSA (Black canister) MSA (Yellow canister) MSA (Red canister)	Mining Safety Appliances
PCB Charcoal	Pittsburgh Activated Carbon
VG Charcoal	Barneby Cheney
"very fine charcoal"	(used for chromatographic analysis)

Figure 1-6

DISCUSSION

The performance of a carbon bed can be described in three ways: the potential parameter, adsorption zone length, and retentivity. The potential parameter A is a function of temperature, molar volume of the vapor adsorbed (V_m), saturation concentration (C_s) and influent concentration (C_i).

$$A = \frac{T^\circ}{V_m} \log \frac{C_s}{C_i}$$

When q, the charcoal capacity is plotted against A, the capacity of charcoals for chosen contaminants can be compared graphically.

As reported by Mr. T. M. Olcott[1] who experimented with adsorbents for several trace contaminants, BPL charcoal proved to be a good adsorbent for substances with high A values, i.e. substances with low molar volume (< 100). (Halothane has a V_m = 74.0.) The A value for carbon tetrachloride on BPL was a 2.3. Halothane seems to behave similarly on BPL as carbon tetrachloride; BPL adsorbs CCl_4 and halothane in the same percentage range (60-65%).

In the same report it was found that compared to a superactivated coconut based carbon and Barneby Cheney GI, BPL has a higher adsorptive capacity at high A values. The micropore mean diameter is smaller than that of the other charcoals and aids in the diffusion of halothane in the pores.

Another aspect that can be noted in rating the filter is the adsorption zone length. The adsorption zone length, I, is a function of the pore diameter, diffusion in the pores, and chemical reactions on the surface of the charcoal. Halothane is essentially an unreactive substance.
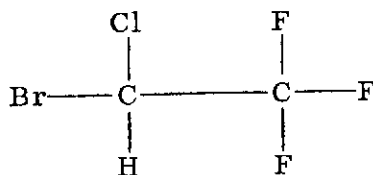
The three flourines on one carbon stabilize that carbon and make it inert. This stability is transmitted to the neighboring carbon atom. These characteristics are also a feature of Freon, a refrigerant.

Thus, in the following equation:

$$I = I_t + I_r$$

the adsorption zone length may be dominated by the contribution of I_t (a function of diffusion rate from the vapor to the charcoal surface) as opposed to I_r (a function of the actual chemical reactions that occur in the pores of the charcoal) since halothane is essentially unreactive. However, it should be noted that halothane has a preference to coal based charcoal over coconut based. Therefore, the nature of the surface does have some effect on adsorption.

The adsorption zone length can be defined as follows:

$$I = \left[\frac{t_c - t_b}{t_c}\right] L$$

L represents the actual length of the bed, t_c = the time at which the effluent concentration is equal to the influent concentration or when the concentration of halothane reaches a steady plateau; t_b is the time at which the adsorption zone begins to penetrate the bed after reaching steady state.

Since it is hard to observe steady state in the experiments with the glass tube, an analysis will be made only on the final filters tested. To obtain the t_b and t_c variables for the MSA and BPL-Alumina-BPL filters which will be explained later in more detail, effluent concentration curves must be drawn (see Figure 1-7).

CALCULATIONS: (ADSORPTION ZONE LENGTH)

BPL-ALUMINA - BPL (Figure 1-7A)

t_c = 16 hours

t_b = 8.4 hours $\qquad$ I = 3.78"

L = 91/16"

RED MSA CANISTER (UNIVERSAL) (Figure 1-7B)

t_c = 5 hours

t_b = 2.84 hours $\qquad$ I = 2.46"

L = 91/16"

1-12
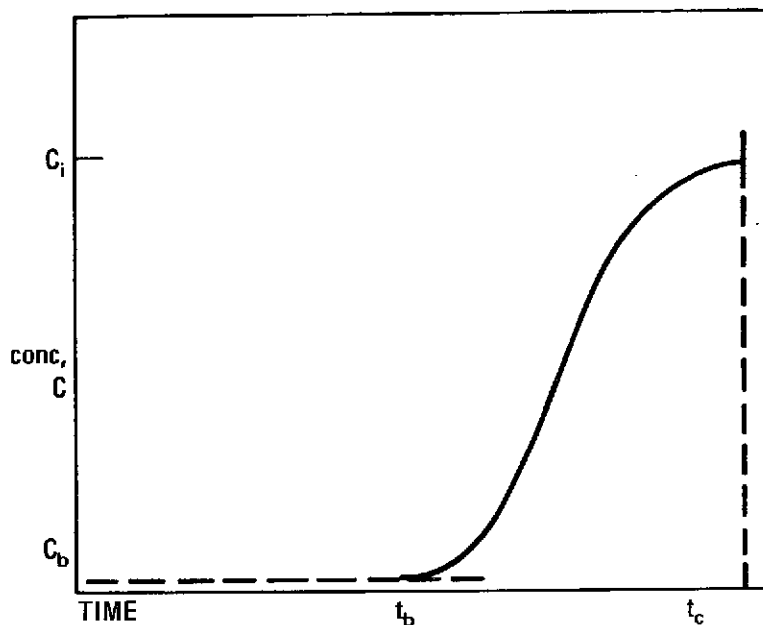
Figure 1-7. Effluent Concentration Curve

YELLOW CANISTER (ORGANIC VAPORS) (Figure 1-7C)

t_c = 8.5 hours

t_b = 11.7 hours   I = 1.5"

L = 91/16"

As one can see the BPL-ALUMINA-BPL filter appears to have the longest adsorption zone length (3.78"). This represents that part of the filter that has not yet been saturated and takes part in scrubbing the remainder of the adsorbate in the stream.

This lies just within the range of the length of the filter. The top layer is 2.25", the middle layer is .625", and the bottom layer is 1.625". The alumina may serve to increase the length of the mass transfer zone and thus contribute to the longer "life" of the filter.

A third aspect is retentivity — the amount of halothane the filter is able to retain per gram of component adsorbent. The weighted average retentivity of the Yellow MSA filter is 38.13% as compared to the average of 51.31% for the

EFFLUENT CONCENTRATION CURVE FOR BPL - ALUMINA - BPL

TIME IN HOURS

% HALOTHANE DETECTED
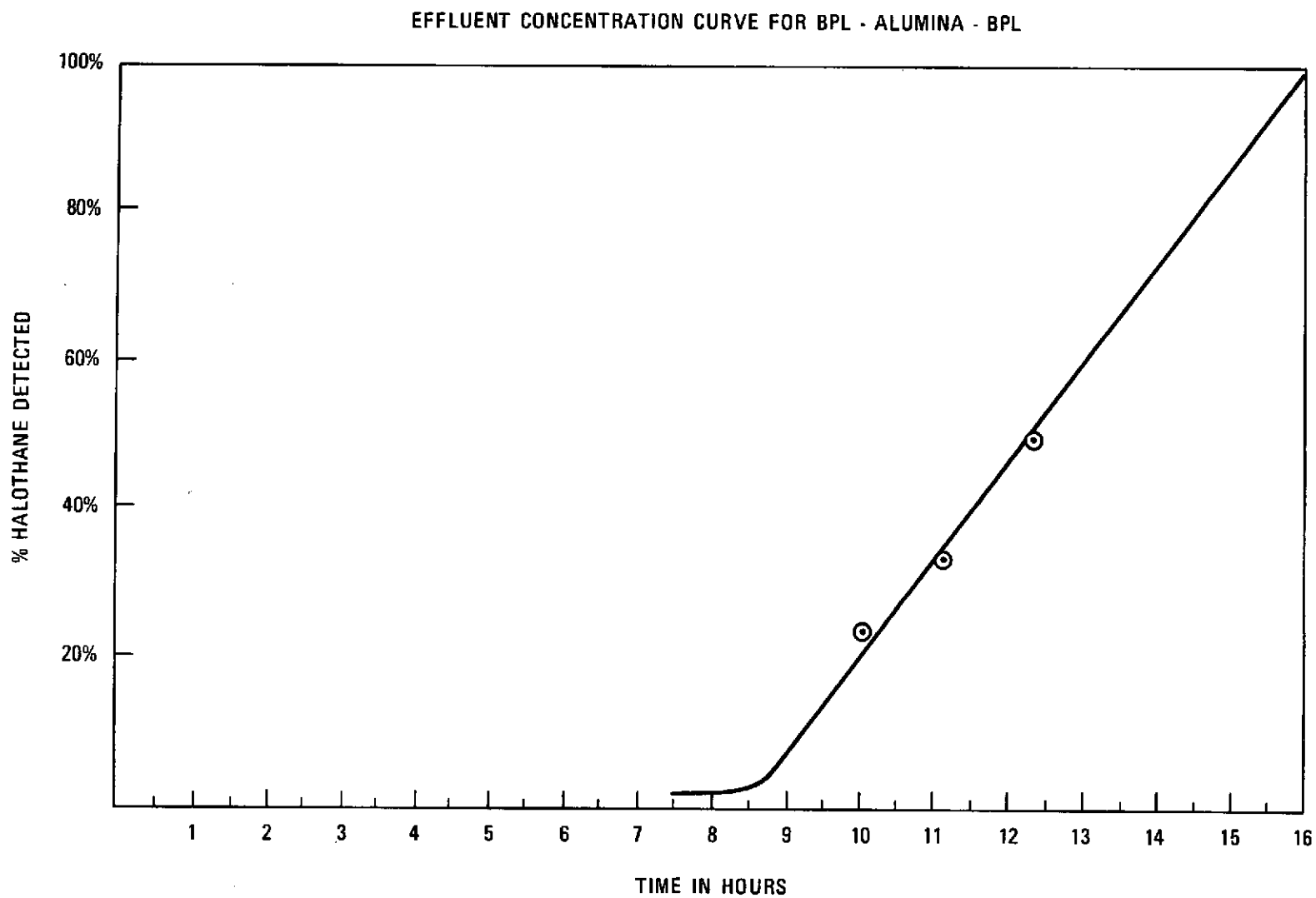
Figure 1-7A. % Halothane Detected Versus Time of Exposure

EFFLUENT CONCENTRATION CURVE FOR RED MSA CANISTER
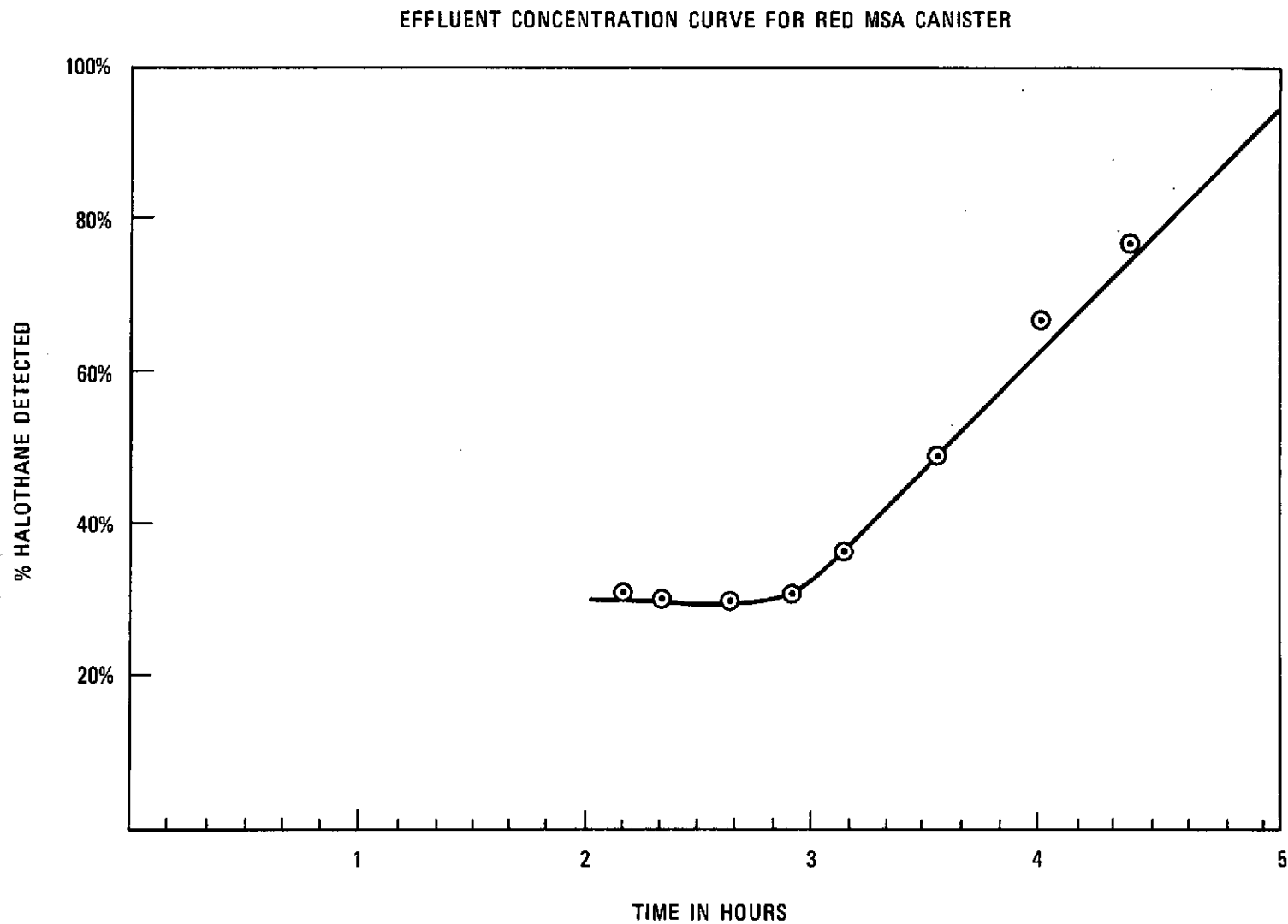
Figure 1-7B. % Halothane Detected Versus Time of Exposure

EFFLUENT CONCENTRATION CURVE FOR YELLOW MSA CANISTER

Figure 1-7C. % Halothane Detected Versus Time of Exposure

BPL-Alumina-BPL filter. This is based on the fact that the BPL charcoal adsorbs .63 times its own weight. Thus, BPL-Alumina-BPL has the higher capacity for adsorbing halothane.

THE "HALOTHANE" FILTER

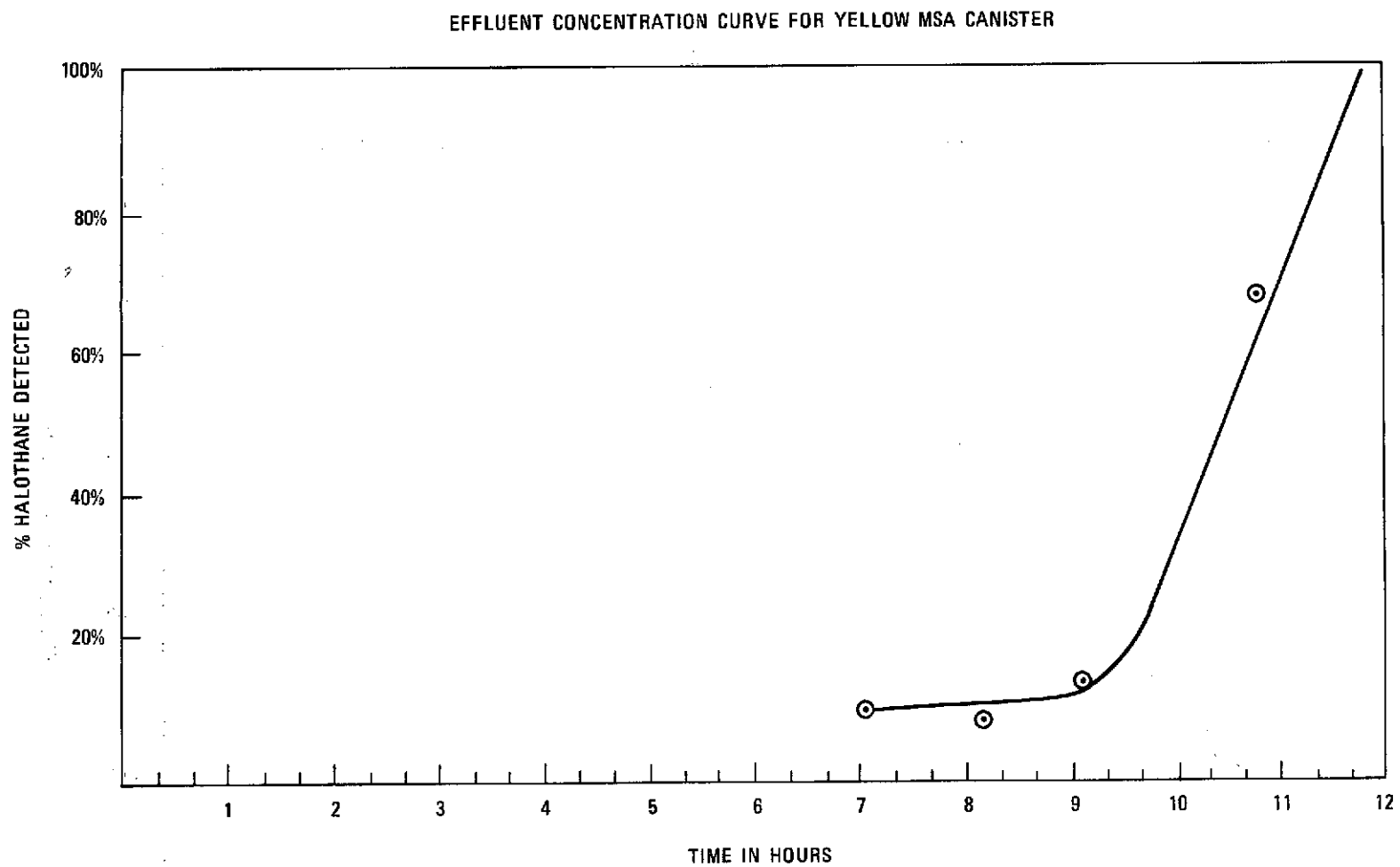The BPL-Alumina-BPL charcoal combination proved to be the best combination in eliminating halothane. BPL charcoal is bituminous coal based and contains binders which contribute to the added hardness of the granular carbon. This carbon is produced by the Pittsburgh Activated Carbon Co. They report as a result of the BET* method for isotherms of adsorbents that the surface area lies somewhere between 1050 and 1150 m^2/g. It is also stated that the pore diameter ranges in size from 18 to 21 Å. The pore volume is enhanced by the presence of gross pores (macropores) on each granule which aids in diffusion of adsorbate and reactivation purposes. BPL adsorbs .63 times its own weight when exposed to halothane. The charcoal is 99.5% reactivated by placing it in a 110°C oven for about 24 hours. The mesh size used is 6 × 16.

Alumina is an adsorbant used in chromatographic analysis. It is a white granular powder which can be reactivated at 400°C with about 100% assurance of total removal of halothane. It was added to the filter for two purposes: 1. To remove any water vapor that may still be present in the gas mixture; 2. Because it is a nonporous solid, it slows down the flow rate to allow a greater period for contact time.[†] The water vapor decreases the adsorptivity of BPL because it takes up places in the monolayer of the adsorbed film. The alumina is packed in the middle to avoid its possible escape to the exhaust system as a mist. Alumina adsorbs .09 times its own weight when exposed to halothane. Its surface area is 250 m^2/g.

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*The BET Method yields an equation which measures the adsorptive capacity of materials. It assumes the multilayer adsorption of molecules passing from the gas phase to the adsorbed film. The specific surface in square meters per gram (Σ) and the monolayer capacity in cubic centimeters per gram (T_m) are related by

$$\Sigma = .269 \, \sigma_m \, T_m \tag{2}$$

where σ_m is the area in square angstroms which one adsorbed molecule would occupy in the completed monolayer.

[†]Experiments show that the adsorptivity capacity of BPL charcoal was increased by about 10% upon addition of alumina.

The canister is an elliptic cylinder with a volume of 1.55 liters. It is very compact and the contents are easily replaceable; at present, there is a metal plate at the bottom which can be removed by unscrewing a specially fitted harness. The layers are separated by screens and a layer of fiber glass. At either end there is a perforated metal plate. The pressure drop across the filter is minimal, i.e., 1 mm Hg (Figure 1-8).

The canister is packed with about 376 g of BPL (~2-1/4") at the top, 176 g of Alumina (~5/8") in the middle, and 275 g of BPL (~1-5/8") in the bottom. These proportions gave better results than dividing the alumina layer in half or having two separate alumina layers. The flow is from bottom to top. The "life" of the canister is graphed as follows (Figure 1-9).

APPROXIMATE ECONOMIC COSTS

The following estimates have been assigned to the components of the filtering system:

"Pop-off" valve replacement	$ 30.00
Pressure reducing valve	50.00
Charcoal canister	10.00
Adapters to the anesthesia machine	25.00
	$115.00

As compared to the cost of laminar flow rooms the price difference is tremendous. Laminar flow rooms have been estimated at $20,000. It should be noted also that the contents of the canister can be reactivated as discussed in an earlier section.

TESTING THE CONTROL SYSTEM WITH DOGS

On August 1, 1973 the valve and filter were tested against a dog. Since the system is intended to be connected to an exhaust system of the hospital, it was necessary to have some type of valve to step up the negative pressure from the exhaust system to atmospheric pressure. The following valve was designed by Mr. Maurice Levinsohn of Goddard Space Flight Center (Figure 1-10). The dog was anesthetized with nembutol and while under halothane he was able to function with the valve.

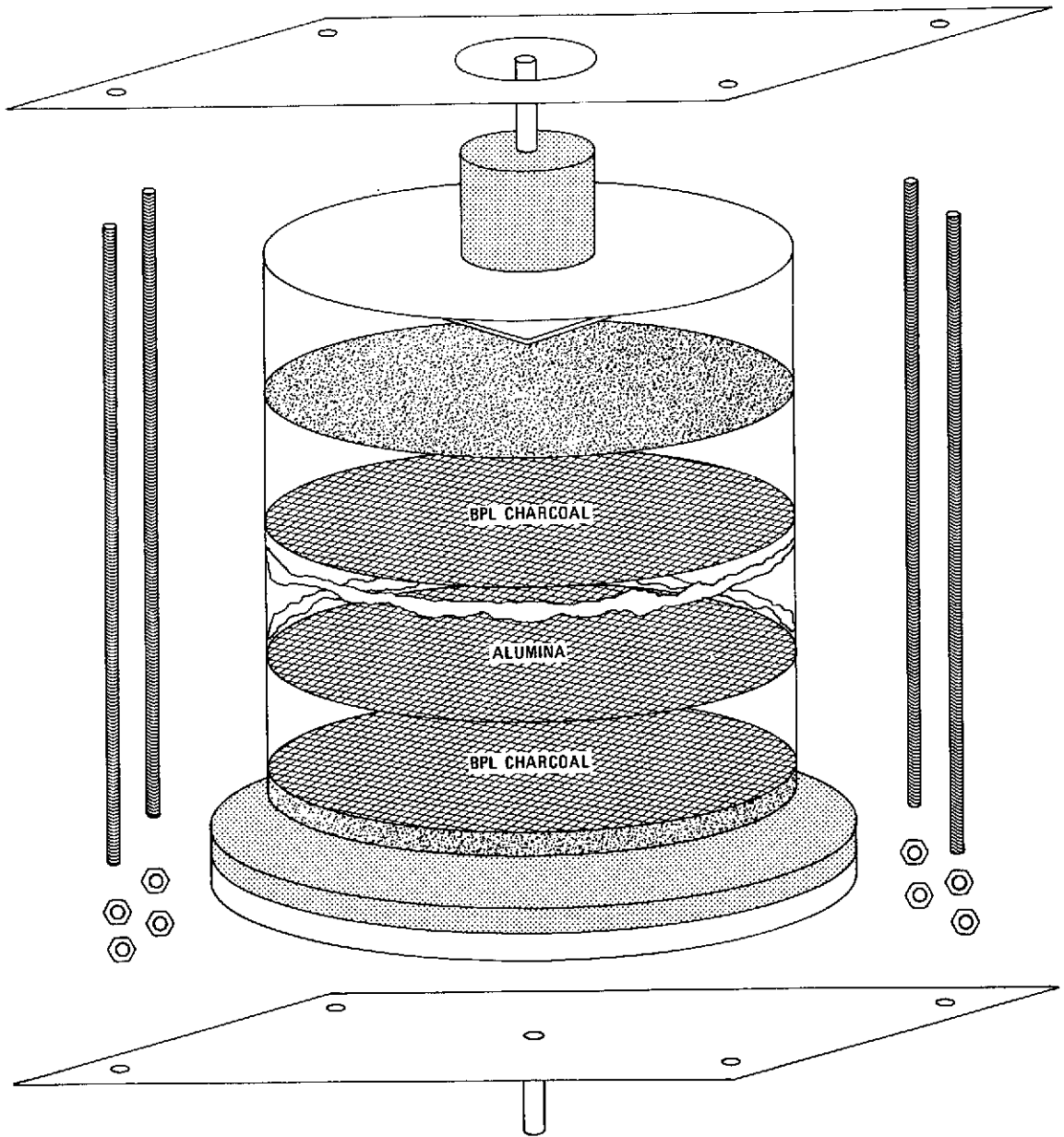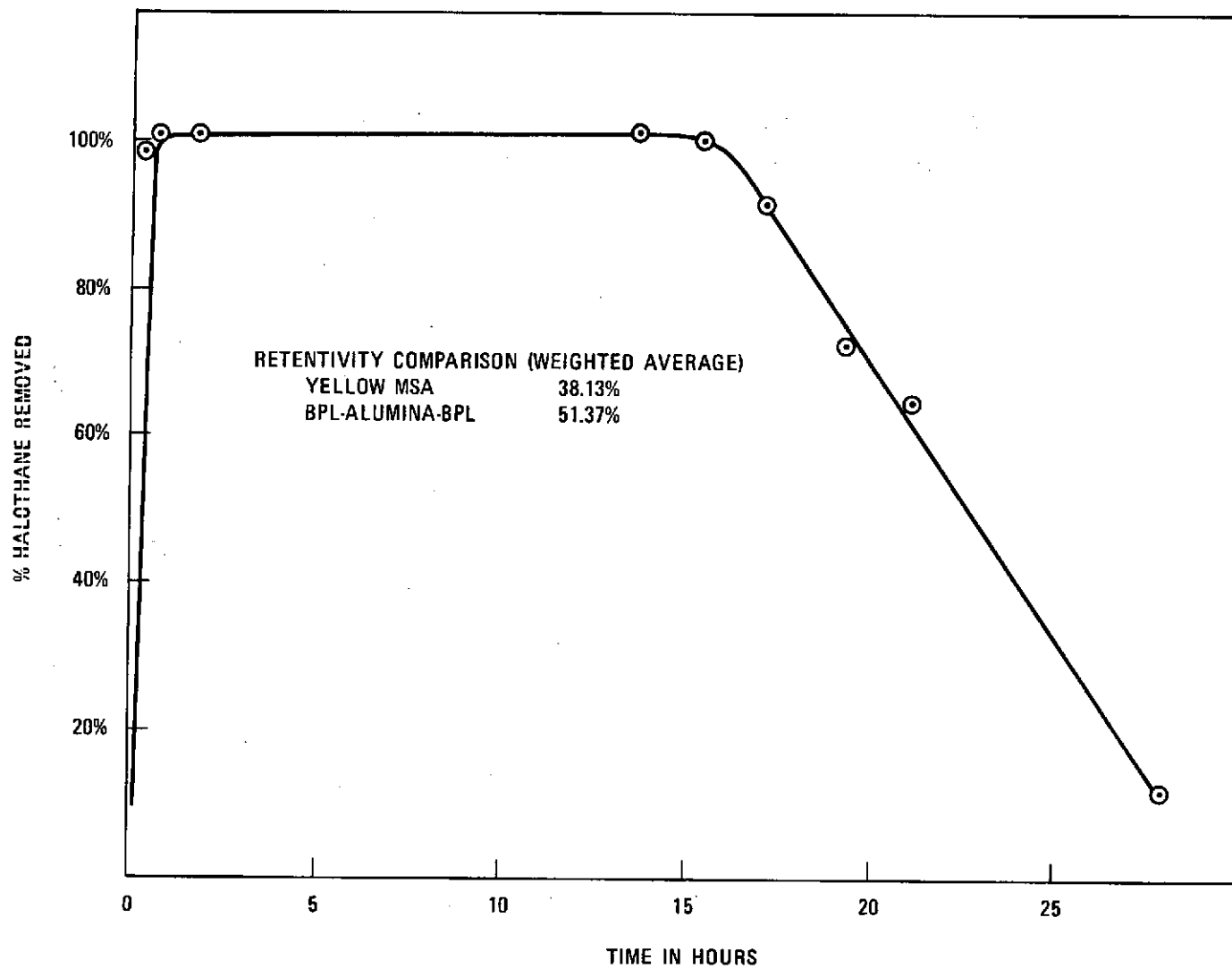Figure 1-8. Design of Canister

Figure 1-9. BPL-Alumina-BPL Filter Adsorption Profile (1% Halothane)

TO SUCTION

THE DISK ABOVE BLEEDS IN AIR
TO STEP UP THE NEGATIVE PRESSURE
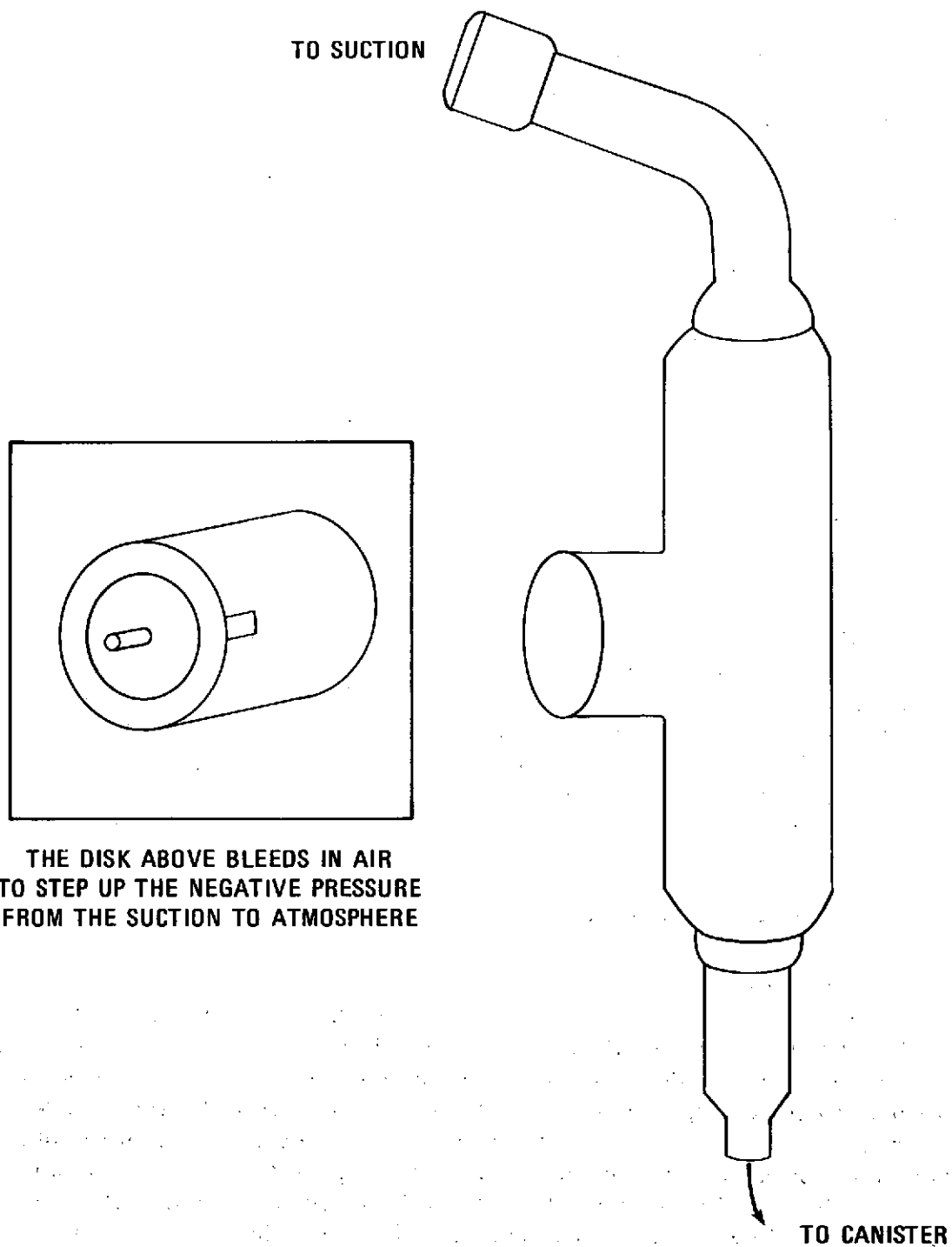FROM THE SUCTION TO ATMOSPHERE

TO CANISTER

Figure 1-10. "The Levinsohn Valve"

In order to sample the air, cartridges from the Boehringer Laboratories, Inc.,
in Wynnewood, Pa., were employed. This is a precision air sampling service
which can analyze levels of anesthesia in surgical suites in units of parts per
million. However, because the cartridges were not sealed properly the labora-
tory was not able to analyze samples from this experiment.

On August 9, the experiment was repeated with a 41 pound dog anesthetized with
Innovar. With the added modifications in the valve of a softer rubber on the
disk and a spring on the center screw, better tension was obtained in the reser-
voir bag. The dog was able to breathe with the valve.

Additional air samples were taken. The results were the following:

	N_2O	Halothane
Old system	4.2 ppm	27.9 ppm
New system	13.9 ppm	20.7 ppm
	94.1 ppm	3.4 ppm

After talking to Mr. Boehringer, the validity of the first two readings may be
questionable on the basis that the N_2O readings are unusual for the associated
halothane levels. Since our system does not scavenge for N_2O the level should
have been higher. On the other hand the last reading gives a more believeable
reading and thus may be the only one acceptable. It has been reported that a
good scavenger system has been as low as 10 ppm. Thus, this control system
appears to give a significant reduction in halothane pollution, (90% effective).

ERROR ANALYSIS AND RECOMMENDATIONS

Since the samples were taken by three different people the techniques in sampling
may have caused error. Two differences can be spotted in taking the last samples:
1. The plunger was dipped 13 times as opposed to the prescribed 6 times. (It
may not have been an ideal mixture since the less dense N_2O oxide appeared to
leak out before capping. This marks the other difference.) 2. The cylinder must
be capped and screwed almost simultaneously. Moreover, the solubility of halo-
thane in the surgical tubing is uncertain. The surgical tubing is very flexible
and it was found while experimenting that it did indeed adsorb halothane. Further-
more the stratification of the atmosphere in the room where the control was
taken and the room where the tests were performed might differ.

It is recommended that further experiments be performed to verify the reduced level of halothane. In addition the surgical tubing throughout the system should be replaced with possibly hard rubber tubing currently used on anesthesia machines. Halothane may have diffused through the pores of the surgical tubing. Also, the air samples should be taken by the same person to insure repetition of technique. Finally, all possible leaks throughout the system should be checked.

After verification of these results, it is suggested that this control system could be adopted by hospitals that cannot afford laminar flow rooms as a solution to pollution of surgical suites at low cost.

NOTE: All dog experiments were performed at the Howard University Medical School.

REFERENCES

1. Olcott, T. M., "Development of a Sorber Trace Contaminant Control System Including Pre- and Post-Sorbers for a Catalytic Oxidizer," Lockheed Missiles and Space Company Biotechnology Organization, NASA CR-2027, May 1972.

2. Crowell, A. D., Physical Adsorption of Gases, London, 1962.

3. Gregg, S. J., Adsorption, Surfaee Area and Porosity, Academic Press, London and New York, 1967.

SECTION 2

SURFACE POTENTIAL PROFILES

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William P. Jones, Jr.

MEDICAL ADVISOR:

Dr. Eugene Fischmann

TECHNICAL ADVISOR:

Mr. Warner Miller

SURFACE POTENTIAL MAPPING ELECTRODE SYSTEM

STATEMENT OF THE PROBLEM

All information about the heart that can be obtained by a noninvasive approach is contained in surface potential maps. Surface Potential Maps reduce the distributed potentials on the torso to a manageable graphic image. It takes many electrodes to collect enough data for a complete map. Data reduction by limiting the number of electrodes yields curves referred to as surface potential profiles. These profiles are concerned with the detail of localized potentials on the torso. These are scalar curves, voltage plotted against electrode position, with time as the variable held constant. (See Figure 2-1.)
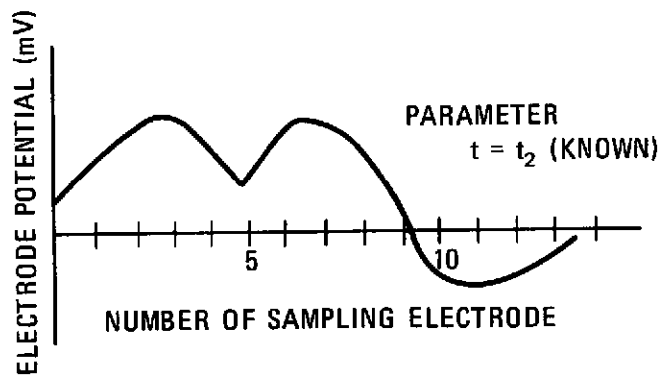
Figure 2-1

Doctors and researchers have chosen to look at these profiles only during specific sections of the electrocardiagram waveform. Most interesting has been the QRS complex (ventricular contraction) because more diseases manifest themselves during this time and the QRS is less susceptible to insignificant changes. Doctors and researchers are just now beginning to look at other portions of the waveform.

Presently it takes 20-30 minutes of recording time for each patient in order to collect the data for these profiles. It takes another 2-4 hours to actually produce these curves even with the aid of a computer. This makes the technique far too laborious and time consuming for wide patient application.

Therefore, it was our problem to develop a method for rapid data collection and display of surface potential profiles, preferably without having to interface with the computer. Additional specifications were:

1) incorporate as many as 42 electrodes into the system. Electrode arrangement would be 3 belts, placed at different levels on the chest, of 14 electrodes each, with electrodes placed on both the front and back of the chest.

2) sample all electrode positions every millisecond.

3) make the analog or real-time measurements available for display on storage scope and record the data on tape and eventually on a strip chart recorder.

SCOPE OF THE WORK

The approach taken was very straightforward. (See Figure 2-2.) The input signal, which has a range of -5 mV to +5 mV, is amplified a thousand times. All electrode positions are then sampled, and held for 8 msecond until a new value is taken. On each belt, these 14 values are multiplexed together to form a serial stream of data. This analog data is then converted to digital data and eventually recorded on tape.

Because of the Institute's time limitations, we felt that the best contribution we could make to the solution of this problem would be to carefully design only one channel and optimize this design with respect to performance and cost. Afterwards, it becomes only a matter of repeating this same design to fabricate the desired number of channels.

AMPLIFIER

As expected, the most difficult problem we encountered was interfacing our system with the body. Normal electrocardiagram machines only amplify the signal to 40 to 100 times and are still concerned with noise problems. In our system the large amplification of 10^3 was needed in order to eliminate noise problems in the digital data processing portion of our circuit.

We built many circuits trying to find a reliable amplifier with this large gain. Problems of oscillation in the operational amplifiers were frequent. Several circuits were taken from application notes of large electronics firms using only
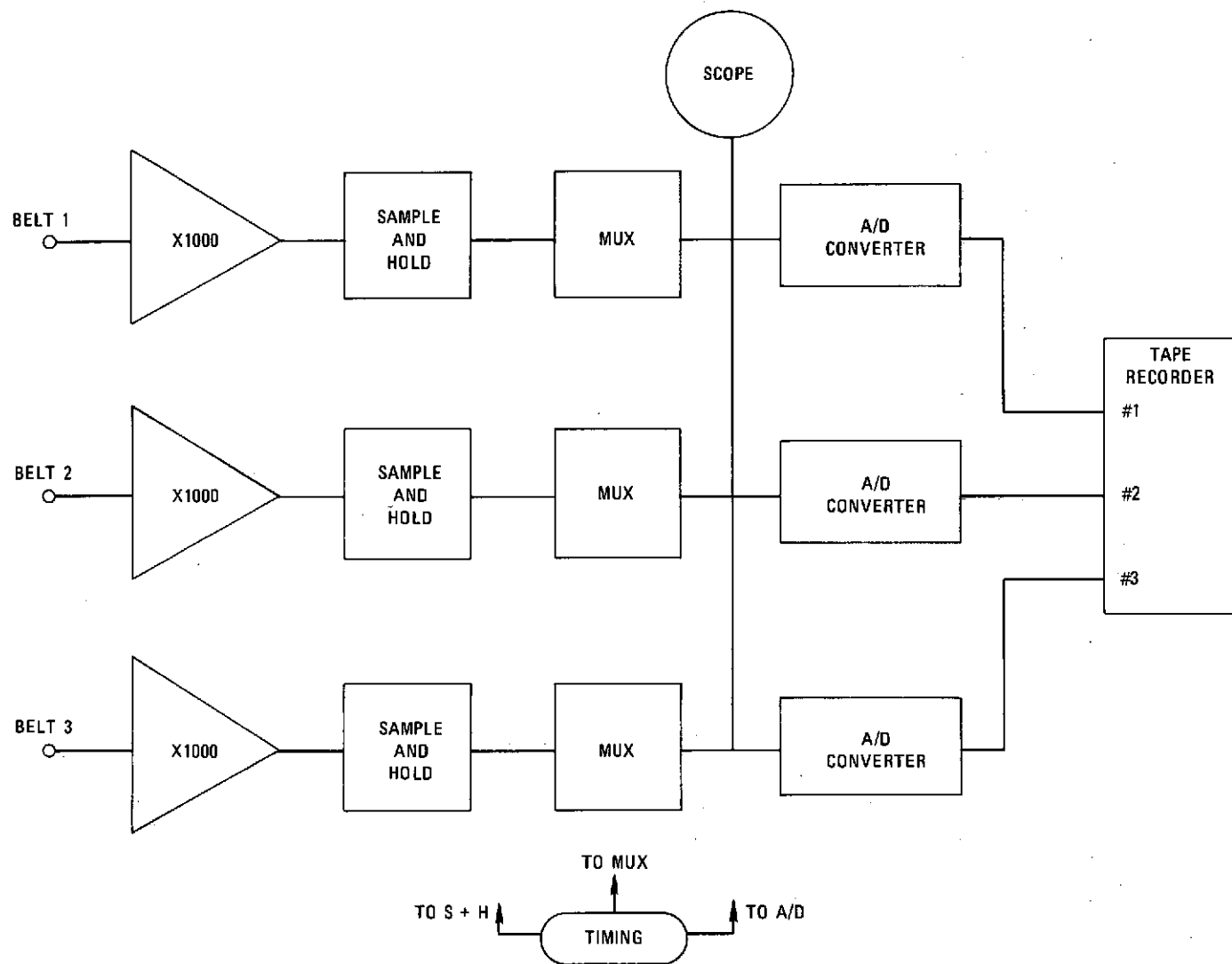
Figure 2-2

two operational amplifiers. But often, instability arose when adjusting resistor values for a gain of 10^3. The amplifiers were all tested with a 5 mV p-p sine wave as an input signal. Even when the amplifier gave good results in this test, we found we were unable to get a signal from the body because 60 Hz noise had latched the op amps.

Our technical advisor, Warner Miller, put us in contact with John Balla, who gave us a circuit that had previously been used at NASA as an electrocardiagram preamplifier. In testing, we finally realized that, as in normal procedures of taking ECG's, we needed a ground electrode in addition to the reference and input electrode. From this point on, we began getting signals from the body; however, they had considerable noise. All amplifier circuits would now work and we decided to stay with the NASA circuit.

The problem of noise had to be solved at this point. Further filtering by changing capacitor values was considered, but we felt we should first inspect the frequency response of our amplifier.

FREQUENCY RESPONSE CALCULATIONS

$$A_v = \left[\frac{Z_1 + Z_3}{Z_2}\right]\frac{Z_6}{Z_4}$$

$$A_v = 2\frac{(1/j\omega C_1 \| R_1)}{R_2}\left(\frac{1/j\omega C_6 \| C_6}{R_4 + 1/j\omega C_4}\right)$$

$$A_v = \frac{2 R_1 R_6 C_4}{R_2} \cdot \frac{j\omega}{(1 + j\omega R_1 C_1)(1 + j\omega R_6 C_6)(1 + j\omega R_4 C_4)}$$

Substituting in values:

$$A_v = 1000 \cdot \frac{j\omega}{(1 + j\omega/\omega_1)(1 + j\omega/\omega_6)(1 + j\omega/\omega_4)}$$

$$\omega_1 = 1/(6 \times 10^4)(1.5 \times 10^{-7}) = 1.11 \times 10^3 \text{ rad/sec} \Rightarrow 175 \text{ Hz}$$

$$\omega_4 \;\; = 1/(10^4)\,(10^{-4}) \;=\; 1 \text{ rad/sec} \Rightarrow .16 \text{ Hz}$$

$$\omega_6 \;\; = 1/(10^6)\,(1 \times 10^{-9}) \;=\; 1 \times 10^3 \text{ rad/sec} \Rightarrow 160 \text{ Hz}$$

See Figure   for graph of frequency response.

After considering the frequency response and consulting with Dr. Fischmann, it was felt that any more filtering might alter the ECG waveform and we looked for other methods to eliminate the noise.

The noise was reduced to an acceptable level by two methods: (1) assuring good contact of skin electrodes and (2) using a twisted shielded pair of cables from the electrodes to the actual circuitry.

RCA CMOS chips were used throughout the digital circuitry. CMOS was chosen because the availability of the chips at Goddard was established; they have low power characteristics and high stability.

TIMING

The device is to sample 14 electrodes every 8 milliseconds. A period of 8 milliseconds is equal to a frequency of 125 Hz. 15 control pulses are needed in every 8 milliseconds, 14 for sampling the electrodes and one for sampling of the waveform. For this a frequency of 15×125 Hz or 1875 Hz is needed. Every digital word is going to have 6 bits of resolution, now the frequency needs to be 6×1875 Hz or 11.25 K Hz. To get a 50 percent duty cycle and to have twice the bit rate available the initial frequency was set at 4×11.25 K Hz or 45 K Hz.

For the original oscillator an astable multivibrator was used (see Figure 2-3). The 39 K Ω resistor was used to make the frequency independent of supply voltage variations. To divide the 45 K Hz wave by four, two type D flip flops were used. The output now is an 11.25 K Hz wave and this is called the bit rate.

Each word has six bits, so the bit rate is divided by six to obtain the word rate (Figure 2-4). Now 15 control pulses are needed. The control pulses need to be sequential and last for an entire period of the word rate. Two Johnson counters were used to do this. (See Figure 2-5.) The first Johnson counter has the first nine pulses on it. The first pulse is number 1, the second is number 2, and so on. The second Johnson counter controls the last six pulses. The tenth pulse is number 1, the eleventh is number 2, and so on. It takes 8 milliseconds for all 15 pulses to cycle through. 8 milliseconds was the originally desired repetition rate.
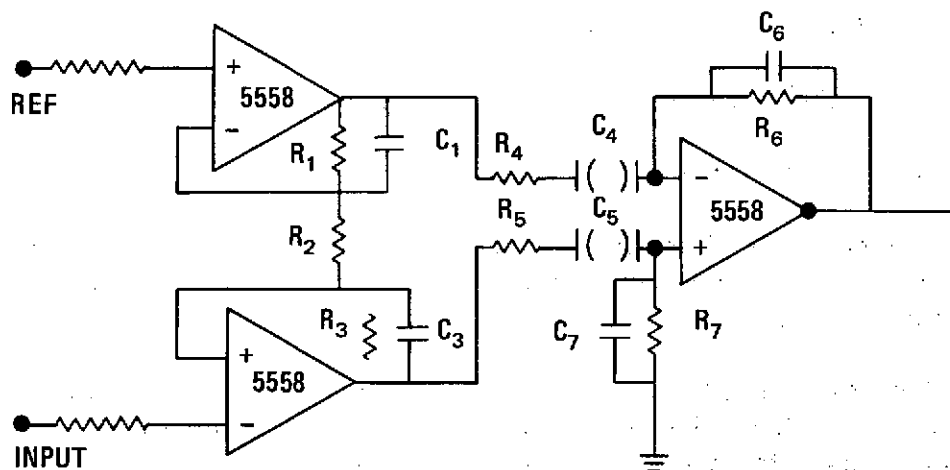
Figure 2-3

R_1 = 60k	C_1 = .15 μf
R_2 = 12k	C_3 = .15 μf
R_3 = 60k	C_4 = 100 μf
R_4 = 10k	C_5 = 100 μf
R_5 = 10k	C_6 = .001 μf
R_6 = 1M	C_7 = .001 μf
R_7 = 1M	

Figure 2-3

SAMPLE AND HOLD

Several sample and hold circuits were considered. Here the consideration was primarily the cost of the circuit. In all circuits built, the same problems occurred: (1) the value stored on the capacitor would leak off during the 8 milliseconds; (2) the response time of the circuit was sometimes too slow; and (3) occasionally there was crosstalk between the input signal and switching signal.

The circuit which was finally adopted was the same configuration proposed by Walter E. Oliver, Jr. [1] who had previously worked on this problem at Howard. (See Figure 2-6.)

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[1] "Analog Shift Register," unpublished report of work done as a participant in the Howard University Minority Schools Biomedical Project, May 1973.
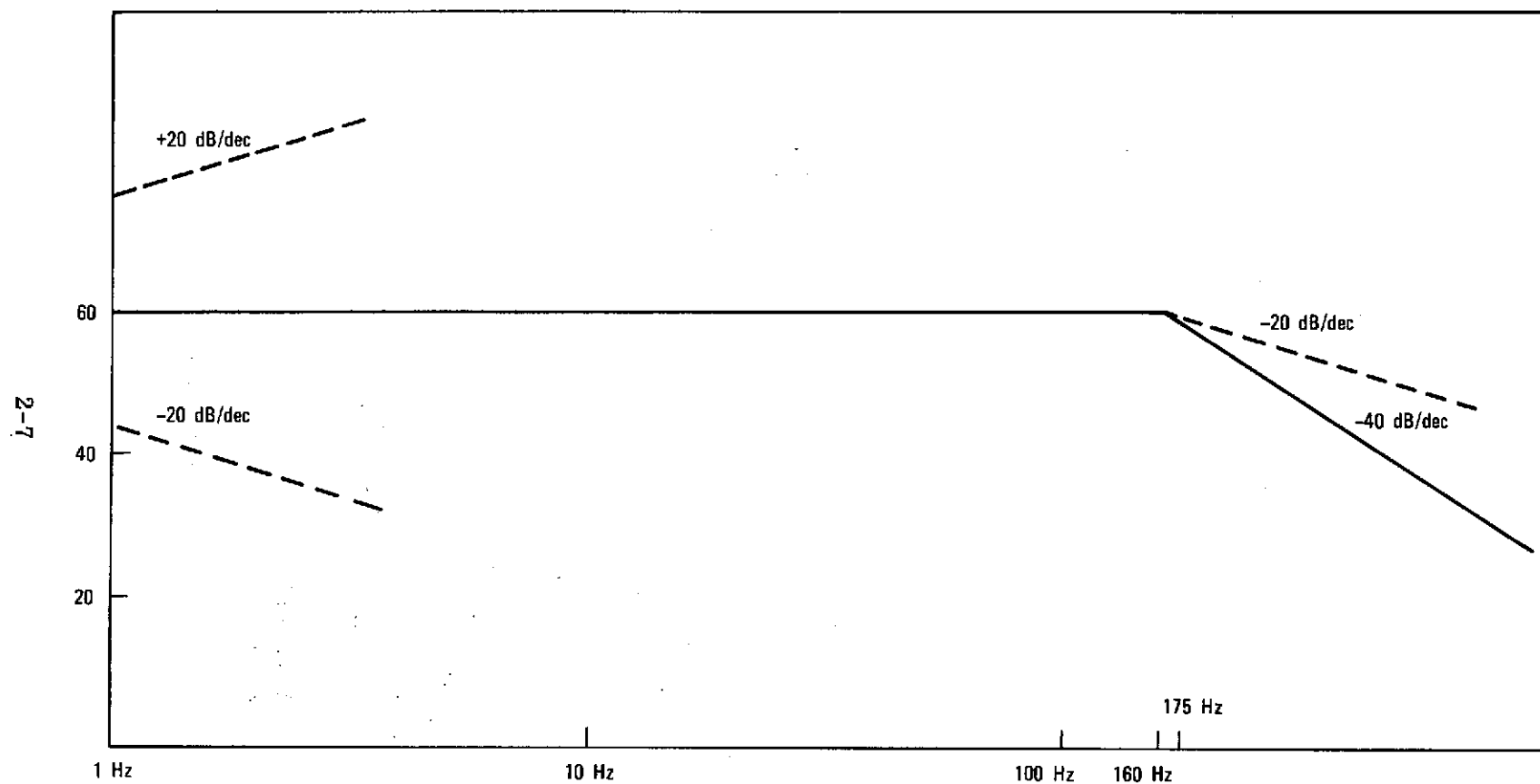
Figure 2-3A. Frequency Response of ECG Amplifier

OSCILLATOR

WORD RATE
DIVIDE BY 6

Figure 2-4

2-8
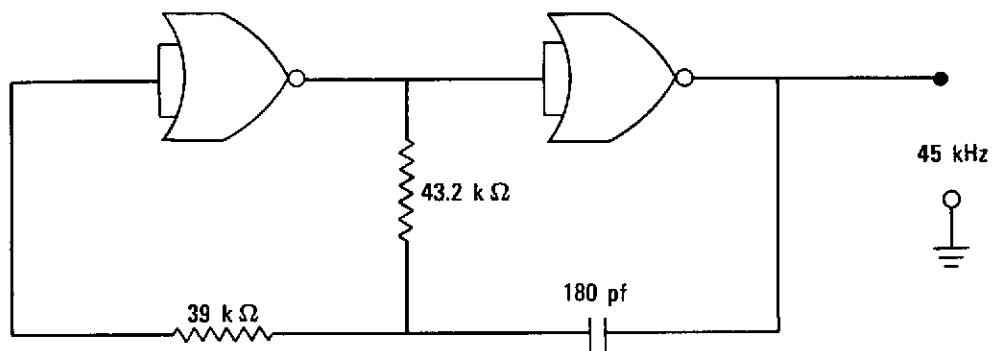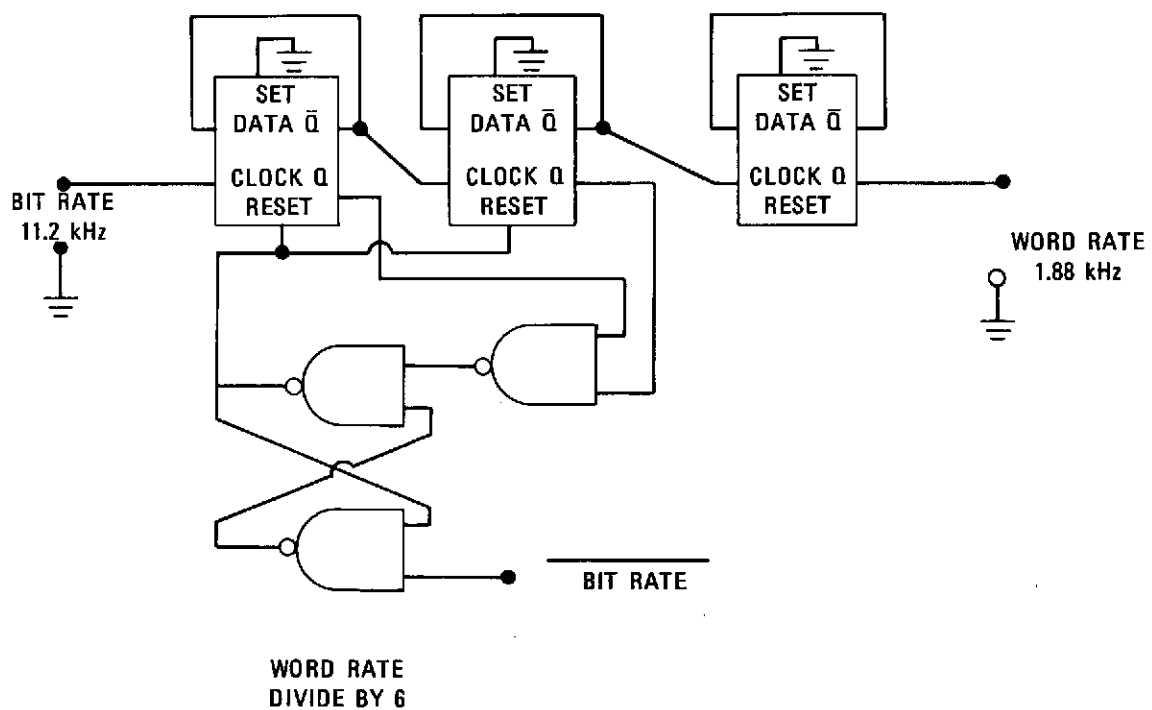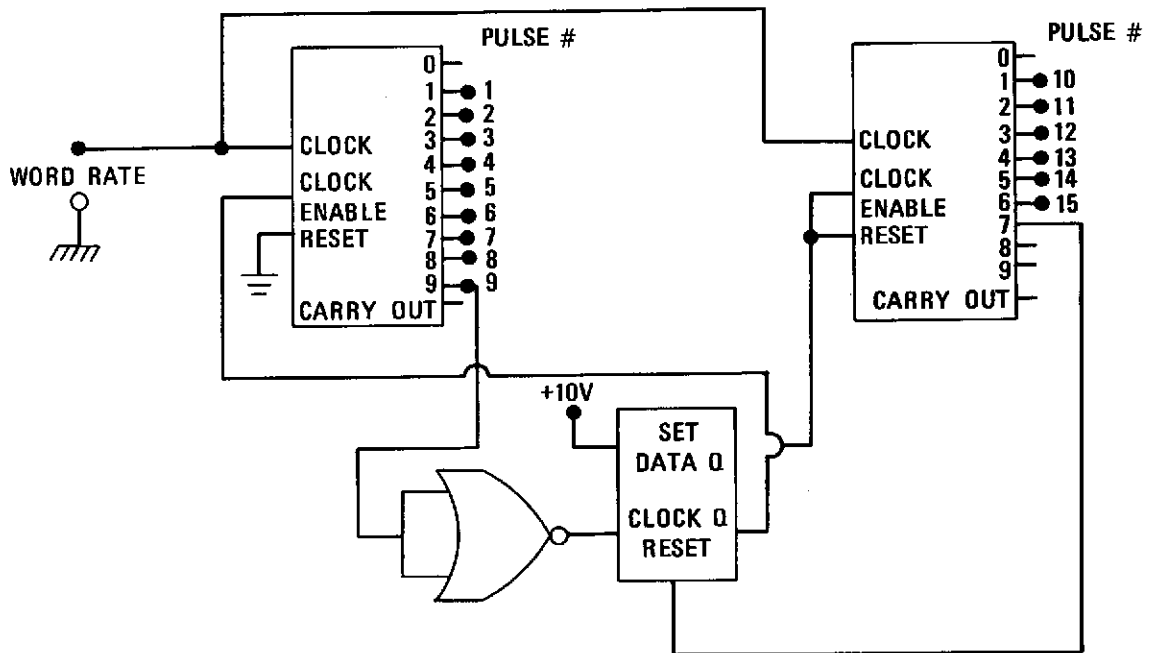
Figure 2-5. Johnson Counter
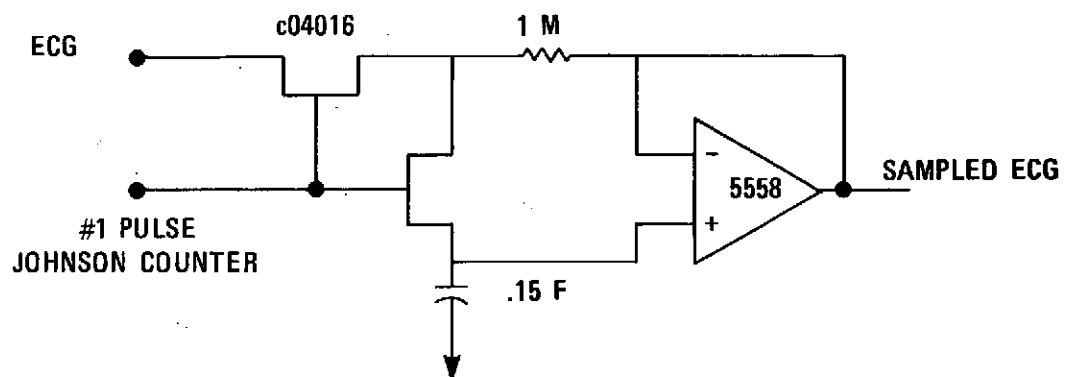
Figure 2-6

By using a polystyrene capacitor (very low leakage) and a smaller value than Oliver suggested, we eliminated the problems of leakage and response time. In the above configuration there was no crosstalk between the switching signal and the input signal.

MULTIPLEXING

After the first control pulse samples the waveform and the sample and hold unit holds this value — the other fourteen control pulses are used to multiplex these analog voltages into the Analog to Digital converter. CMOS switches are used to switch the analog voltages into a serial stream. At this point a Surface Potential Profile is displayed on an oscilloscope. The scope display is not capable of yielding much medical data because there is no way of telling exactly where in the waveform the data was taken. The scope display does tell if all of the electrodes and analog circuitry are working properly.

A/D CONVERTER

The A/D Converter takes the multiplexed analog signal and converts it to a digital word of six bits. The input range of the A/C converter that was available for testing our circuit had an input range of zero to 10 volts. With six bits there are 64 different voltage levels that can be recognized. This circuit can distinguish 15 V.

The A/D Converter that was used was not compatible with the CMOS voltage levels. So 2N2222 transistors were used to increase the output voltage level of the A/D from five to ten volts; also, the input level was cut from ten to five volts by using CMOS CD4010.

Here are the specifications for the proper A/D Converter. It needs six to eight bits, straight binary bits. The input range should be ± 5 volts. It needs at least a 2 k Hz word rate. No input buffer is needed. It must be compatible with CMOS logic. It should have long term stability with regard to time and temperature.

All of the CMOS logic should be run at the same level as the A/D Converter input. So the logic should be run at ± 5 volts.

The A/C Converter sends out parallel digital data from the analog data that was sent in. It does this for each of the fourteen electrodes. The digital data is stored in a shift register and it is clocked out of the shift register at the bit rate. The data now is in a serial stream. So that each of the 14 different electrodes

can be distinguished, some way was needed to signify each start of an 8 milli-second sample. A code word was used to do this. The code word that was de-cided upon was the first six bits of the Barker Code. The code that was used is 101100. This code was chosen because of its correlation function (see Fig-ure 2-7).
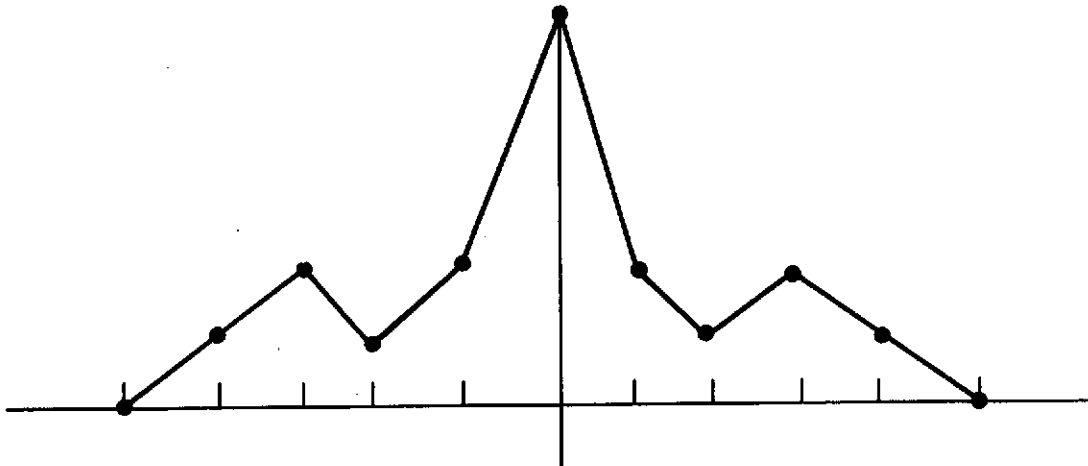
Figure 2-7

This code was generated by loading a shift bit register with the appropriate values, and clocking the values into the serial stream of data while the first con-trol pulse was sampling the waveform and the analog to digital converter had no input.

The serial output is shown below. The code word is the first six bits (see Fig-ure 2-10). After the code word is injected into the digital data stream, there is one further step that must be taken before the tape recorder. NASA engineers have found that when recording digital data on analog tape, it is often hard to pick up the same bits on playback using conventional "1's" and "0's." A technique referred to as split phase has been developed to improve the playback of digital data. The data is coded in the following manner:

Figure 2-8

See Figure 2-9 for schematic and timing diagrams for split phase generator.
See Figure 2-10 for data stream to tape recorder.
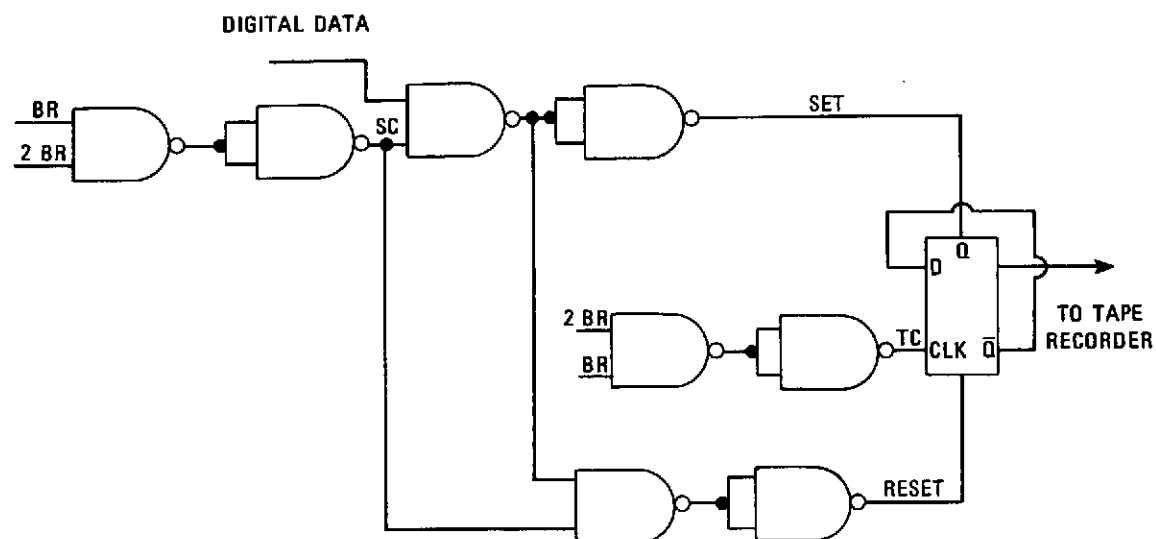
Figure 2-9. Split Phase Generator
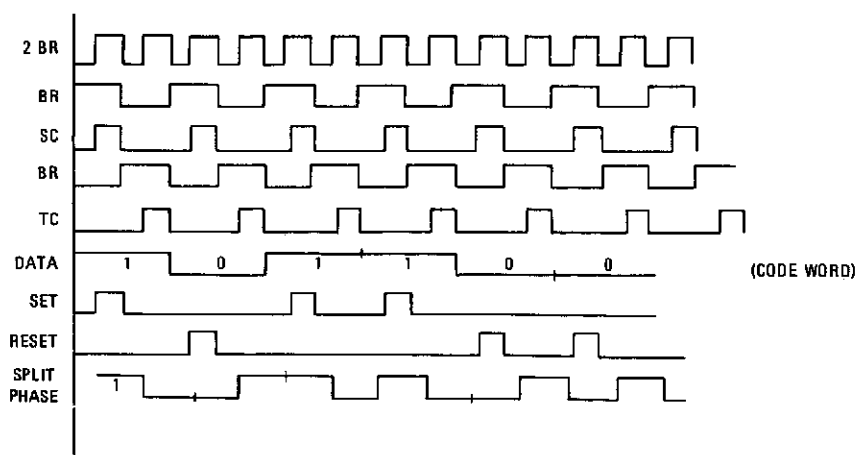
Figure 2-10

COST ESTIMATE

The parts used to build one fourteen channel belt cost $422.00.

Analog Devices	$209.00
A/D Converter	80.00
Digital Devices	59.00
Power Supplies	48.00
Cabinet	26.00
	$422.00

This cost is the cost of parts only. If the prototype device was commercially built it would cost about $6000.00. As more devices are built, the cost would decrease considerably.

SUMMARY

The EKG signal has been processed, digitized and coded for the tape recorder in the work we have done this summer. The flow of the problem is as follows. First there is a tape input. Then the data is demultiplexed. The demultiplexor takes the data out of split phase and puts it in the straight digital bits. Next the code word is recognized and the data is taken out of the serial stream and put into a parallel format where data is then transferred into a memory. It is in the memory that the QRS waveform is detected. The memory is programmed for specific graphs that are to be printed out and at the proper time transmit the digital words to a digital analog converter. The converter converts the digital words to an analog voltage and the surface potential profiles are printed directly on a strip chart recorder.

The actual production of surface potential profiles is some time away. At this point, the curves could be produced, but only if the analog tape could be processed and used as an input to a computer. When the final unit is finished, the time required for producing surface potential profiles will be cut from 4-1/2 hours to approximately 5 minutes. It will be portable and can easily be moved from bed to bed for wide patient application. Without the computer interface, the effective cost per patient will be reduced. A Schematic Diagram of a single channel output is shown in Figure 2-11.
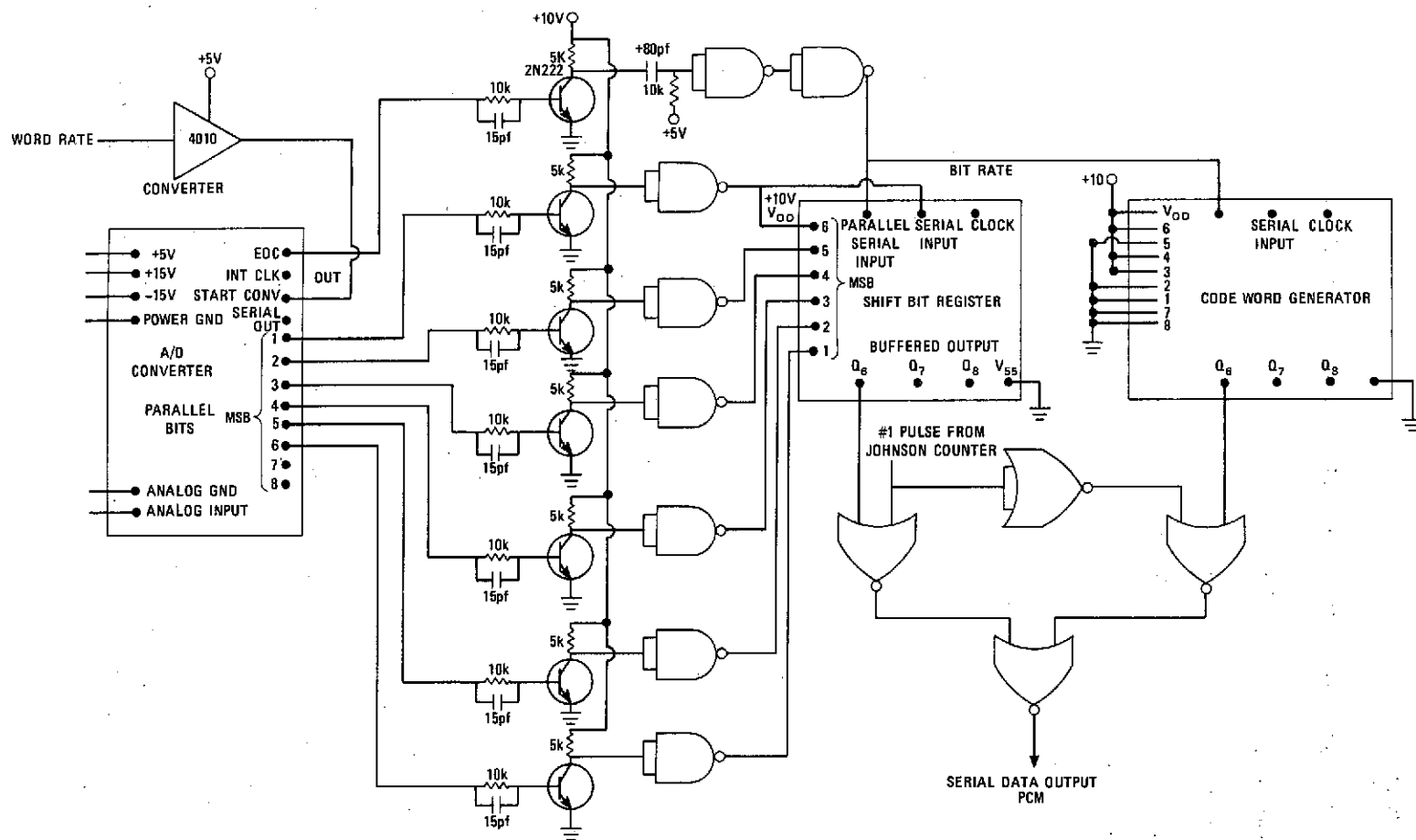
Figure 2-11. Serial Data Output

SECTION 3

THE USE OF SPEECH-MODULATED-WHITE-NOISE

TO DIFFERENTIATE HEARERS AND FEELERS

AMONG THE PROFOUNDLY DEAF

(A Two-Part Report)

PART A

THE DESIGN OF A DEVICE FOR HEARER

AND FEELER DIFFERENTIATION

PART B

THE DESIGN OF AN EXPERIMENT FOR EMPLOYING

THE HEARER-FEELER DIFFERENTIATION DEVICE

Submitted by:

Rodney Creecy

Ronald Betchtel

AUDIO SPECIALIST:

Dr. Henry Tobin

TECHNICAL ADVISOR:

Mr. Roland VanAllen

SECTION 3

PART A

THE DESIGN OF A DEVICE FOR HEARER

AND FEELER DIFFERENTIATION

A SPEECH MODULATED WHITE NOISE DEVICE:
USABLE AS AN AID TO DIFFERENTIATE BETWEEN
HEARERS AND FEELERS AMONG THE PROFOUNDLY DEAF.

By:

Rodney Creecy

ORIGINAL PROBLEM STATEMENT

Written by: Presented by:

   Dr. Henry Tobin, Ph.D.   Eugene M. DeLoatch, Ph.D.

TITLE: THE USE OF SPEECH-MODULATED-WHITE-NOISE TO
         DIFFERENTIATE HEARERS AND FEELERS AMONG THE
         PROFOUNDLY DEAF

STATEMENT OF THE PROBLEM: In 1971 Horii, House and Hughes described
"A Masking Noise with Speech-Envelope Characteristics for Studying Intelligi-
bility" (JASA). Erber (JASA, 1972) used this noise as "... an Acoustic Aid to
Lipreading for Profoundly Deaf Children." He concluded that these children
"perceive mainly time-intensity (envelope) information when they are provided
with an amplified speech signal." This time-intensity analog of the speech signal
is called speech-modulated-white-noise (SMWN).

One of the major unresolved problems in audiology is determining the difference
between hearers and feelers among the profoundly hearing impaired. This dif-
ference influences the formulation of the appropriate audiologic habilitation pro-
gram. The hearer can make use of spectral information and can use a conven-
tional hearing aid. Depending on whether he can hear sound as well as first
formant information, he can be taught to speech-perceive much of the phonemic
and prosodic rules of the language. For the individual who does not really hear,
but rather feels through vibro-tactile sensation, the time-intensity parameters
of speech, the approach is different. Although vibro-tactile information can be
derived from a hearing aid, other devices for teaching language-speech may be
used. These would most likely concentrate on those prosodic features of lan-
guage, such as stress and durational clues, that he can successfully learn.

SCOPE OF THE WORK: The recordings of stimuli that would differ only in
respect to spectral characteristics could be used to differentiate hearers and
feelers among the profoundly hearing impaired. Materials would contain differ-
ent amounts of spectral information. For example, one set of materials would
use a 20 Hz cut-off to avoid the spectral aspects of the speech signal. Other
sets could use higher cut-off points to include some of the spectral information
the speech signal provides. Individual performance on these materials could be
analyzed. If a hearing impaired individual improves his performance with ma-
terials containing speech spectral information, he is a hearer. If no improvement
occurs, the individual may only be responding to vibro-tactile information, and,
therefore, could be considered a feeler.

SUMMARY ABSTRACT

Based on the work done by researchers Horii, House, and Hughes,[1] and another research paper by Norman P. Erber,[2] it has been conclusively shown that the profoundly deaf perceive mainly speech envelope cues, i.e., these cues include rhythm and intensity variations from voiced communications.

With this in mind, a solution to one of the major unresolved problems in the field of audiology was pursued, that of determining the difference between hearers and feelers among the profoundly hearing impaired. This difference influences the formulation of the appropriate audiologic habilitation program. The hearer can make use of spectral information and can use a conventional hearing aid. Depending on whether he can hear sound as well as first formant (first resonant frequency of the human vocal tract, i.e., around 500 Hz) information, he can be taught to speech-perceive much of the phonemic and prosodic rules of the language. For the individual who does not hear, but rather feels the time-intensity parameters of speech through vibro-tactile sensation, the approach is different. Although vibro-tactile information can be derived from a hearing aid, other devices for teaching language-speech may be used. These would most likely concentrate on those prosodic features of language such as stress and durational clues that can be easily learned.

It can be shown that full frequency information only adds to their confusion since the profoundly hearing impaired perceive frequency information usually well below 800 Hertz and down to the sound threshhold of about 40 Hertz; while normal voiced communication extends from the sound threshhold to about 18,000 Hertz. Thus it is clear that the profoundly deaf can only perceive parts of the speech and language information that is communicated to them.

Under the direction of Dr. Henry Tobin, a device was designed and fabricated utilizing Speech Modulated White Noise (SMWN). Our use of SMWN can be defined simply as giving a White noise signal the rhythmic characteristics of a speech signal for the purpose of studying intelligibility. In our device we have eliminated the frequency cues by using White noise as our carrier signal. White noise is a signal composed of random amplitudes and random frequencies likened to the sound of a television set with a "snow" picture. Through our device we use the speech envelope characteristics of rhythm and stresses to modulate this White noise signal. A block diagram of the device may be seen in Figure 3-1.

The SMWN device is designed for four modes of operation. They are the speech mode and three filtering modes. The device operation may be explained simply as follows: There is a speech input device as shown in the diagram followed by a full wave rectifier which alters the signal as shown. The full wave rectified
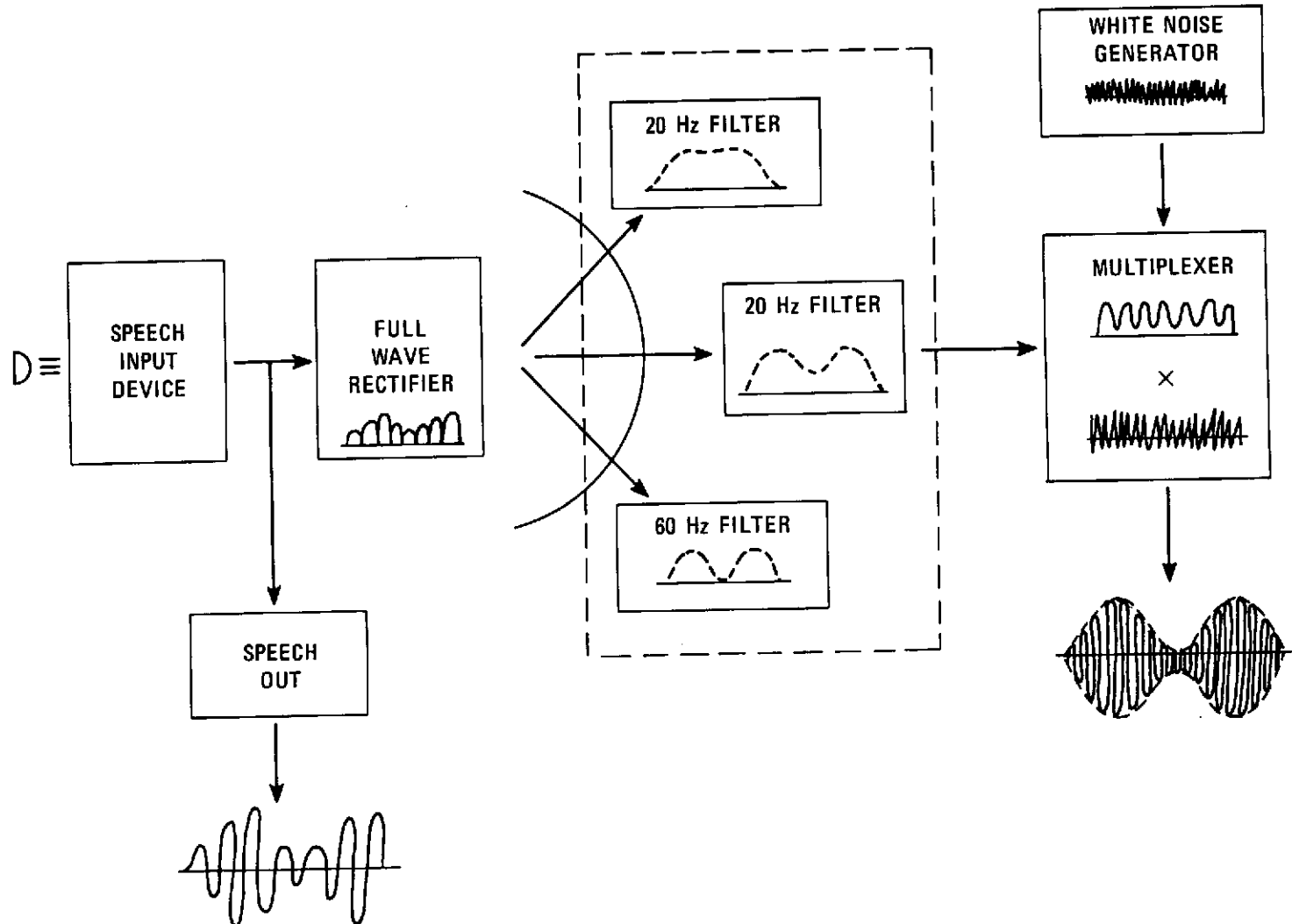
Figure 3-1. Speech Modulated White Noise Device

signal is then passed through a predesignated active linear phase low pass filter as indicated graphically. The White noise signal is passed into a four quadrant multiplier and is in turn modulated by the speech envelope characteristic. This is also displayed graphically.

By using this device a hearing examination can be administered giving stimuli that would differ only in the amount of spectral information provided. This examination would effectively differentiate between hearers and feelers among the profoundly hearing impaired since as more spectral information is provided, the hearer will improve his perception of the speech and language information that is communicated to him. For example, one set of stimuli would use a 20 Hertz cut-off to avoid the spectral aspects that the speech signal provides. Successive filtering modes at 200 Hertz and 600 Hertz would offer more speech spectral information. Individual performance on these sets of stimuli could be analyzed. If a hearing impaired individual improves his performance with stimuli containing speech spectral information, he is a hearer. If no improvement occurs, the individual may only be responding to vibro-tactile information and, therefore, could be considered a feeler.

SPEECH MODULATED WHITE NOISE DEVICE

Based on the work done by the researchers Horii, House, and Hughes,[1] and another research paper by Norman P. Erber,[2] it has been conclusively shown that the profoundly deaf perceive mainly speech-envelope cues i.e., these cues include rhythm and intensity variations from voiced communication. It can also be shown that full frequency information only adds to their confusion since the profoundly deaf perceive frequency information usually well below 800 Hertz and down to sound threshhold of about 40 Hertz; while normal voiced communication extends from the sound threshhold to about 18,000 Hertz. Thus it is clear that the profoundly deaf can only perceive parts of the speech and language information that is communicated to them.

Under the direction of Dr. Henry Tobin, a device was designed and fabricated utilizing Speech Modulated White Noise (SMWN). Our use of SMWN can be defined simply as giving a White noise signal the rhythmic characteristics of a speech signal for the purpose of studying intelligibility. In our device we have eliminated the frequency cues by using White noise as our carrier signal. The White noise signal had a normally distributed characteristic from 5 Hertz to a few Kilohertz. Through our device we use the speech envelope characteristics of rhythm and stresses to modulate this White noise signal. A technically highlighted functional diagram of the SMWN device may be seen in Figure 3-2.

The SMWN device is designed for four modes of operation. They are the speech mode, with linear amplification of the signal and three filtering modes. The three filters are designed to permit certain frequencies to get through the device. The 20 Hertz filter mode is designed to let almost no speech-spectral information pass through, except for clues to the durational pattern. The 200 Hertz filter mode permits speech-spectral information in the region of the male and female fundamental frequencies to get through. The 600 Hertz mode provides frequency information that is within the first formant region of speech. The design and operation of the device is explained in the following subtopics and illustrated in diagram.

INPUT DEVICE

An input device was designed and fabricated using the Sony Electret Condenser Microphone (ECM 16) and a one state amplifier for low gain and increased sensitivity followed by a volume compressor circuit, taken from a design by C. H. Ristad,[3] to provide stability of the input signal to about 3 volts peak to peak maximum over a 50-dB range without distortion. For an explanation see reference 3.

Figure 3-2. A Technically Highlighted Functional Diagram of SMWN Device
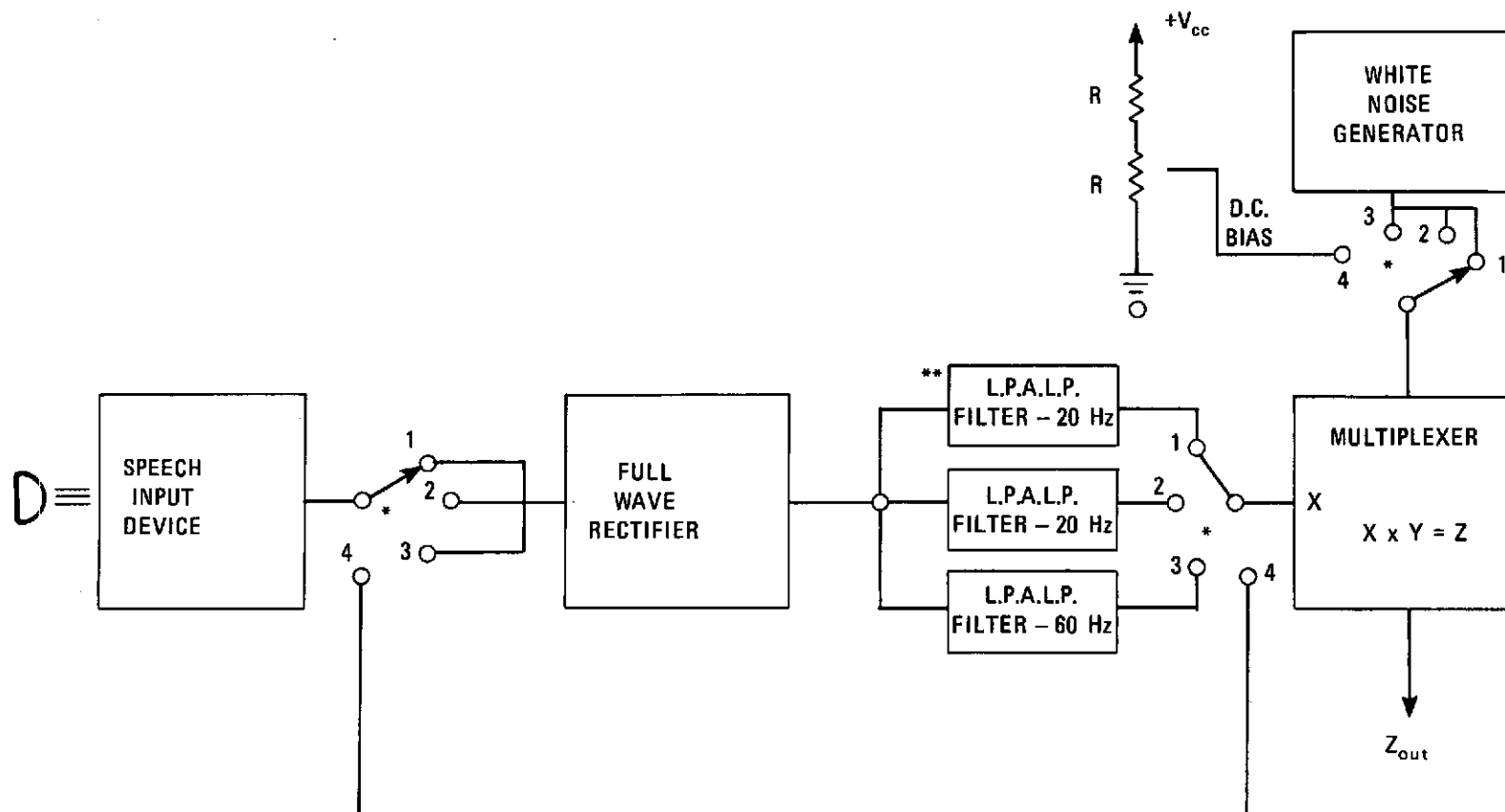
*Three channel 4 position switch
**L.P.A.L.P. Linear Phase Active Low Pass

FULL WAVE RECTIFIER

In mode #1, 2, or 3 of diagram, the speech signal is then input to a full wave rectifier which was built using an RCA 3747T general purpose dual operational amplifier and two 1N126 diodes with the resistors labeled R_2 and R_2^1 (see the schematic diagram) at 1% values for no amplitude distortion of the speech signal. The circuit employs a simple feedback mechanism.

Mode #4 in diagram bypasses the full wave rectifier circuit and instead uses a D.C. bias through the four quadrant multiplier to produce linearly amplified speech from an in sound field of approximately 25 feet at normal voice levels, i.e., around 70-dB.

FILTER CIRCUIT

The full wave rectified signal is then passed through a predesignated active linear phase low pass filter. The filters all have a "roll-off" slope of 30-dB per octave. It should be noted that with this type of filtering the device does not cut off with respect to information being transmitted in the speech-envelope, but instead indicates a relative level that corresponds to the speech signal. In this sense we actually have "speech-envelope modulated white noise" coming out of the device. We are, in effect, transmitting information about the total speech spectra rather than information limited to the low pass band of frequencies.

WHITE NOISE GENERATOR

The White noise generator employs a simple circuit that utilizes a zener diode operating in its breakdown region. The best configuration for bringing this minute signal (about .04 volts peak to peak) up to a useful level was a modified single stage amplifier using an emitter follower; and a bypassed emitter resistor to reduce a.c. attenuation; and a general purpose operational amplifier. Through experimentation it was found that although the operational amplifier characteristically has a high intrinsic input a.c. impedance, it still required a significant amount of d.c. input bias current, thus the reason for interfacing the one stage amplifier. (This is further explained in reference 4.) As a result of this design effort, we have a "shot" type noise which is normally distributed about the bias point of the transistor.

FOUR QUADRANT MULTIPLIER

The White noise signal is being input to the four quadrant multiplier (Analog Devices #530) and is in turn modulated by the speech-envelope characteristic (see Figure 3-3). A single general purpose operational amplifier is connected at the output for additional gain with volume adjustments for the left and right channels of headphones shown schematically.

OPERATION OF THE SMWN

Using this device a hearing examination could be administered giving stimuli that would differ only in the amount of spectral information provided.* This examination would effectively differentiate between hearers and feelers among the profoundly deaf since as more spectral information is provided, the hearer will improve his perception of the speech and language information that is communicated to him. For example, one set of stimuli would use a 20 Hertz cut-off to avoid the spectral aspects that the speech signal provides. If a profoundly deaf person improves his performance with stimuli containing speech spectral information, he is a hearer. If no improvement occurs, the individual may only be responding to vibro-tactile information, and, therefore, could be considered a feeler.

---

*My research partner, Ronald Betchtel, and Dr. Tobin, our medical advisor, were responsible for devising the protocol for the use of the SMWN device. See reference #5 for more specific details about the testing procedure.

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SECTION 3

PART B

THE DESIGN OF AN EXPERIMENT FOR EMPLOYING

THE HEARER-FEELER DIFFERENTIATION DEVICE

THE USE OF SPEECH-MODULATED-WHITE-NOISE
TO DIFFERENTIATE HEARERS AND FEELERS
AMONG THE PROFOUNDLY DEAF.

By:

Ronald Betchtel

Note: This part of the report is presented in the first person and is
        representative of the presentation made by Ronald Betchtel on
        August 16, 1974. Mr. Betchtel, who presented his work em-
        ploying sign language, was aided by Ms. Betty Butler who
        performed the audible translation.

I will define the profoundly deaf person...

With respect to hearing, we can divide the population into roughly three groups: Normals, who can readily detect sound level from less than 20-60 dB, the hard-of-hearing, whose threshold is from 60-90 dB, and the profoundly deaf whose threshold is greater than 90 dB.

I am going to explain the definition of the difference between hearers and feelers.

HEARER	FEELER
A hearer can perceive tone or tone quality.	A feeler must experience sound by feeling. He cannot perceive tone or tone quality.
A hearer may not use vibro-tactile information and he can learn to use tone information.	A feeler does not feel tone information but he may use this information to extract prosodic information about talking if he has been so trained. He will detect only low-frequency vibration (vibro-tactile information).

I will talk about the experimental protocol used to separate feelers from hearers. There are two objectives in the design hearing test.

First is to establish baseline information about the subject's ability to sense sounds, and second, is to see how well an individual can learn with the kind of signal generated by S.M.W.N. (speech-modulated-white noise).

Now I will explain the Pre-tests listed in the protocol which we employ because:

1. We want to see if the individual can respond to (#1) low frequency pure tone. That will permit us to compare pure tone response with speech modulated-white-noise response as well as #2 (speech awareness threshold). Speech awareness threshold is a clinical procedure that determines at what intensities speech is audible to the subject and is used very often on a profoundly impaired individual as basis for the decision about a proper hearing aid. Yet, many individuals with a given speech awareness threshold score may not really be hearing spectral

CATEGORIZATION BY AUDIOGRAM OF HEARING IMPAIRMENT

Figure: Hearing Loss dB, ISO vs Frequency Hz, showing three sample audiograms labeled I, II, and III.
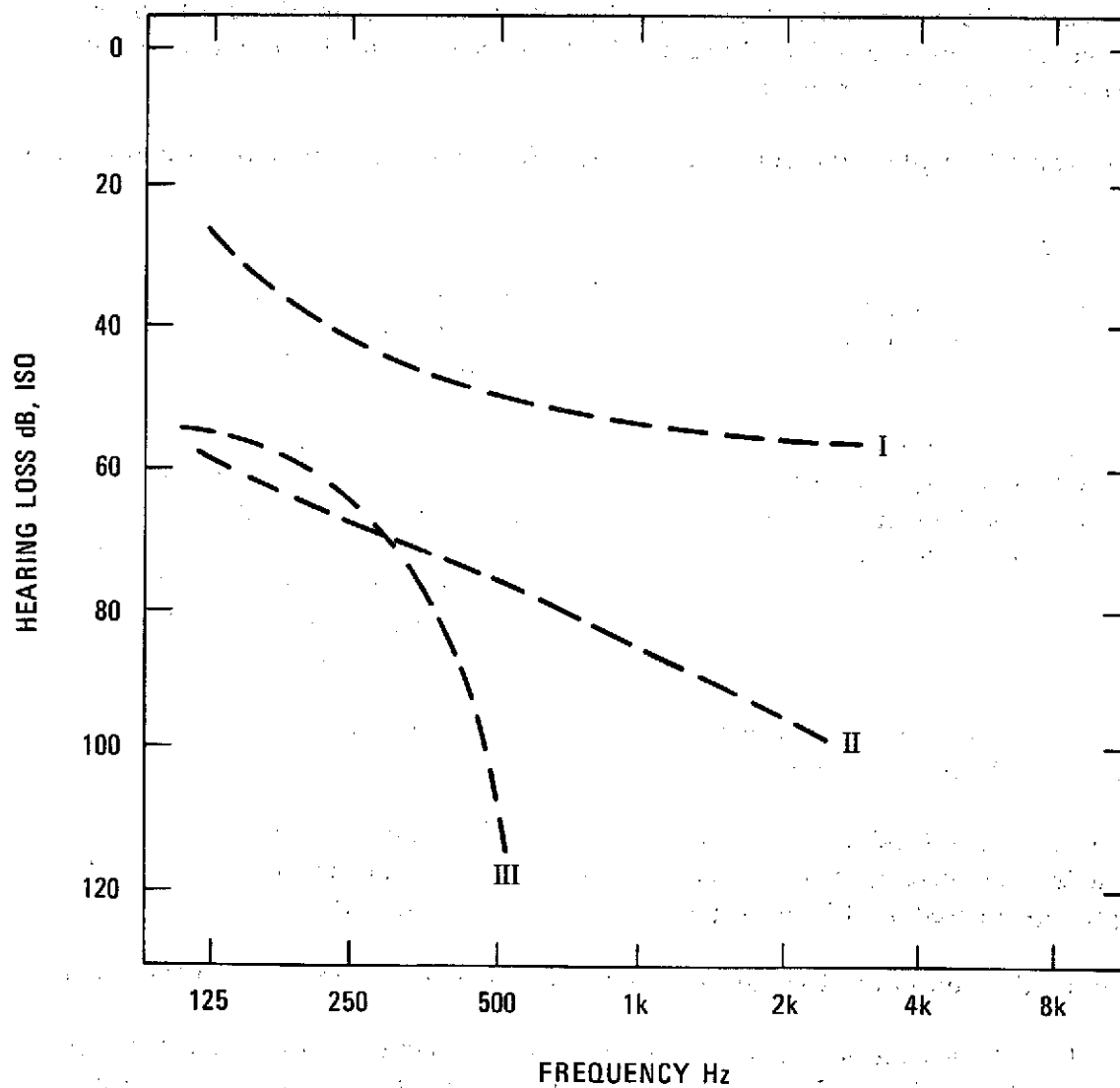
SAMPLE AUDIOGRAMS BY HIRSH OF THREE GROUPS
OF HEARING-IMPAIRED CHILDREN

speech information, they may only be feeling low frequency vibration or prosodic information.

2. The #2 speech awareness threshold will permit us to compare tests #2 and #4 (video tape — look and listen tests with video tape and speech modulated-white-noise hearing aid), as well as tests #1 and #4.

3. Test#3, look and listen test with video taped and linear amplification hearing aid is used when we need to know something about how the person responds with a regular hearing aid or other linear amplification devices.

We need to do #3 with both looking and listening because our subject's have such profound hearing loss that their score might be too low if we only permit them to listen. In order to receive some measure of these individual's speech discrimination ability, we use rhyming words in close response sets that will permit our subjects to make comparisons among a limited number of words. The listing we will be using will have 50 words and the subjects will be required to choose the right word from a listing of six rhyming words in close response sets. This kind of test has been found to be successful with an individual who has profound hearing loss.

4. Test #4, we will test with a similar word listing but now we are using a wearable S.M.W.N. hearing aid. This S.M.W.N. hearing aid has three filters. It is similar to that used in #3 except now we have it in one of three possible speech-modulated-white-noise filter modes.

The three filters are designed to permit certain frequencies to get through the hearing aid. The 20 Hz mode is designed to provide no speech spectral information. The 200 Hz mode permits sound in the region of the male and female fundamental frequency to get through. The 600 Hz mode provides frequencies that are within the first resonant frequency range or formant region of the speech signal.

We are interested in finding out if the individual whose hearing is impaired will respond differently to these filtering conditions.

Word listing similar to those employed in test #3 will be used for this purpose.

5. (Aided threshold in sound field) — We would also like to know what sounds are getting through the hearing aid. It has different modes so we will do what is a behavioral calibration.

6. Training to asymptate — begins the second part of experiment.

The Learning Experiments —

Number 6, we train our subjects with whichever filter condition they do better with in the pre-tests and they continue training until the learning curves show a leveling off or asymptote. Test scores do not get better on repetition.

After that we go to number 7 and retest in a manner similar to that of #3 with linear amplification and #4 with S.M.W.N.

This test design should be useful for distinguishing between hearers and feelers.

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SECTION 4

DESIGN OF AN AUTOMATIC WEIGHT SCALE

FOR AND ISOLETTE

Submitted by:

Robert J. Peterka

William Griffin

MEDICAL ADVISOR:

Dr. Faribarz Rabhar

TECHNICAL ADVISOR:

Mr. Leonard Kleinberg

ORIGINAL PROBLEM STATEMENT

As paraphrased by: Written by:

     Dr. Fariborz Rabhar   Eugene M. DeLoatch, Ph.D.

TITLE: DESIGN OF AN AUTOMATIC WEIGHT SCALE
        FOR AN ISOLETTE

STATEMENT OF THE PROBLEM: It is often necessary for newborn infants
to be maintained in a well-defined environment. The isolette provides tempera-
ture control and isolation from rapid changes in temperature and humidity, and
sources of infection. Unfortunately, the benefits of this isolation are abruptly
ended when the infant must be weighed. The incorporation of means of weighing
the infant without exposing it to the nursery atmosphere is desirable.

SCOPE OF THE WORK: The design of the scale will be such that it will fit in
existing units or it may be part of a new isolette design. A protocol must be
provided so that the measuring technique is standardized. The instrument may
be automated to make the measurement at programmed intervals usually not
more frequently than once every four hours.

It would also be useful to incorporate several other measuring devices in the
same unit: (1) Oxygen concentrations, too low to sustain the infant or high
enough to be harmful, could set off warning devices if they can be included with
the design — apnea monitor. (2) The benefits of a darkroom with special lights
so that the infant's head can be transilluminated without removing it from the
isolette, would be useful. (3) A light (visible and uv) dosimeter giving intensity
of specific wavelengths or ranges of wavelengths and exposure time, or warning
device that is programmable for a certain exposure can be built into the chamber.

DESIGN OF AN AUTOMATIC WEIGHT SCALE
FOR AN ISOLETTE

STATEMENT OF THE PROBLEM

It is often necessary for newborn infants to be maintained in a well-defined
environment. An infant incubator provides a means of controlling temperature,
humidity, and oxygen concentrations and of protecting the infant from sources
of infection. Unfortunately, the benefits of this isolation are abruptly ended
when the infant must be weighed. The incorporation of a means of weighing the
infant without exposing it to the nursery atmosphere is desirable.

SCOPE OF THE WORK

The design of the scale will be such that it will fit in existing units or it may be
part of a new isolette design. A protocol must be provided so that the measuring
technique is standardized. The instrument may be automated to make the mea-
surement at programmed intervals usually not more than once every four hours.

INTRODUCTION

The environment inside an incubator consists of regulated temperature, humidity,
and oxygen concentrations. Premature, underweight, and Caesarian section
babies require the use of this regulated environment. It is possibly dangerous
and certainly undesirable for the newborn to be removed from the protection of
the incubator and placed on a conventional scale. In addition to this, the infant
may have a skin temperature sensor and intravenous tubes attached to him
which may make his removal difficult.

The scale must be designed so that varying temperature, humidity, and oxygen
concentrations do not affect its performance over long periods of time. These
parameters change over the following ranges:

Temperature	80° – 100°F
Relative Humidity	60° – 100°
O_2 Concentrations	20° – 100°

The scale must be able to detect weight changes in the infant as small as 10 grams
since relatively small weight changes are important indicators of a newborn's
state of health.

Finally, the scale must fit in the incubator without interfering with its normal operation. This requires that the scale have a very low profile, its maximum height being only about 1-1/2" (4 cm).

Techniques of Force, Weight Measurement

Several possible ways of weighing the newborn were investigated. These were:

1. Conventional Scales

2. Commercial Load Cells

3. Hydraulic Load Cells

4. Piezoelectric Devices

5. Differential Transformer Transducers

6. Variable Capacitance Transducers

7. Variable Resistance Transducers — Strain Gauges

All of these methods except the last were found to possess drawbacks such as corrosion of sensitive mechanical components, large or inconvenient size, high cost, and inability to accurately measure static loads over long time periods. Strain gauges were chosen as the best force sensitive transducer since they are small in size, low in cost, and have long life expectancies under normal mechanical use.

DESCRIPTION OF SCALE

The scale consists of four stainless steel cantilever beams positioned such that the ends of the beams are situated at the four corners of the scale. The scale platform is supported by four rods which rest on the beams. These four rods provide a means of transforming the diffuse weight of the newborn into point forces applied at known locations in the cantilever beams. On each beam are mounted two strain gauges, one on the upper and one on the lower surfaces. When a weight is placed on the scale platform the beams are deflected and a strain is created along the length of the beam. This strain is detected electronically through the strain gauges and is used as an indicator of the size of the weight placed on the scale. (See Figure 4-1.)

SCALE PLATFORM

SCALE PLATFORM
SUPPORTING ROD

CANTILEVER
BEAM

CANTILEVER BEAM
SUPPORT

STRAIN
GUAGE

BASE PLATE
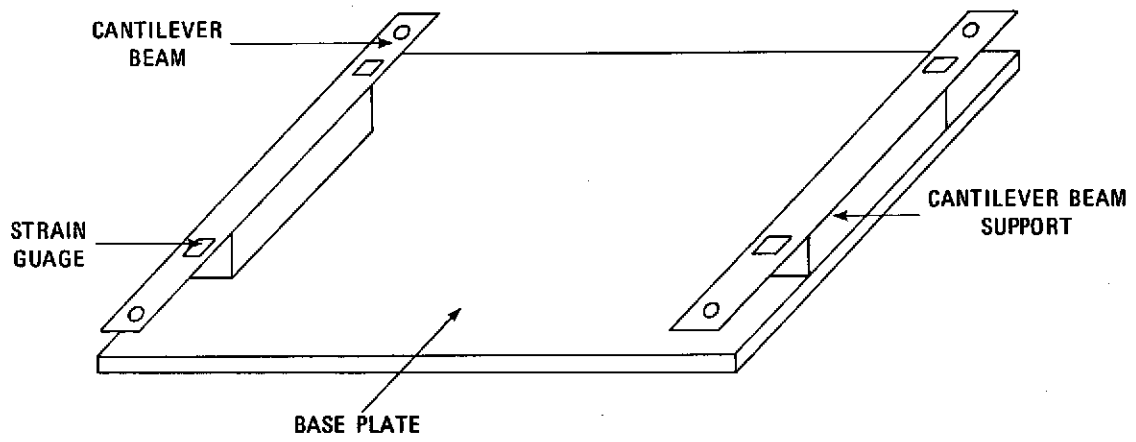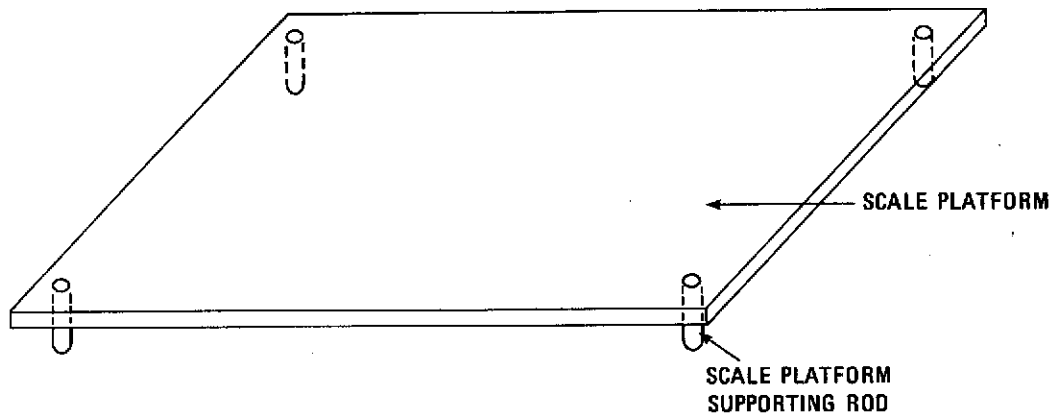
THEORY OF CANTILEVER BEAM SCALE

FORCE

P

1

h

b

$y = \frac{h}{2}$

L
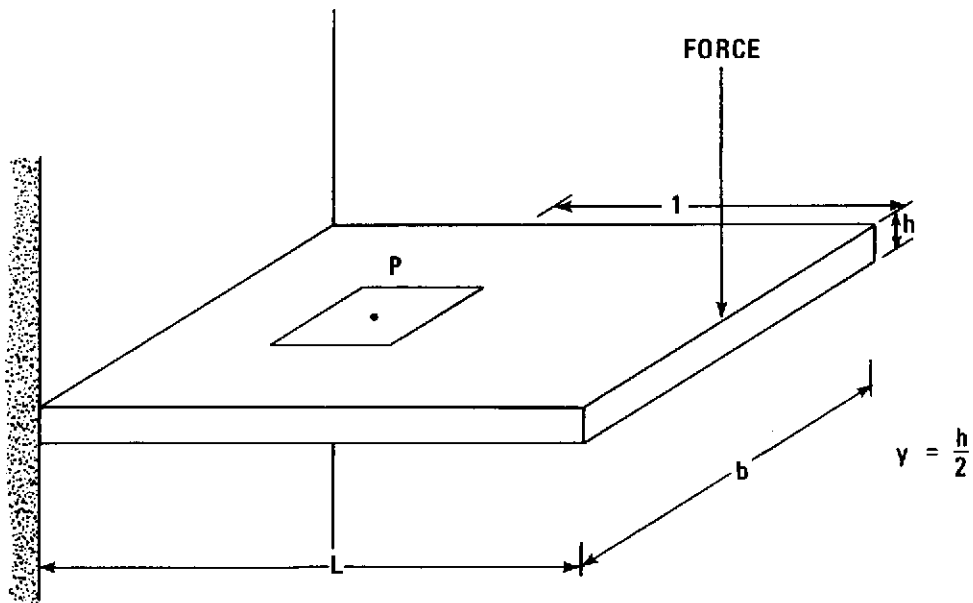
CANTILEVER BEAM WITH STRAIN GUAGE

FORCE

θ

δ_{max}
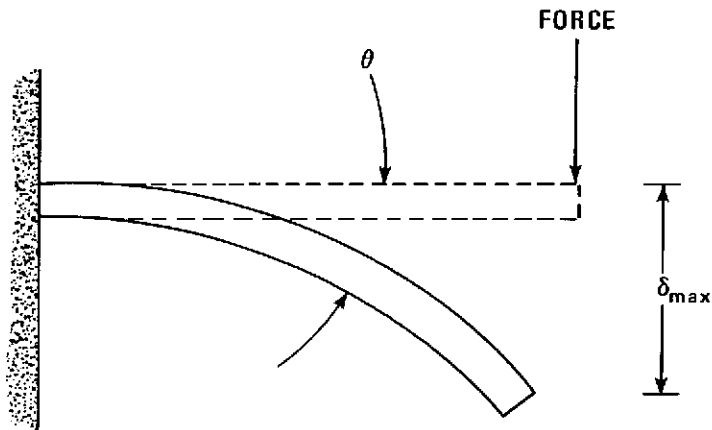
The equations describing a simple cantilever beam when a force, F, is applied at the end will be discussed in this section. Refer to Figure 4-2.

The stress, σ_x, at some point P along the beam is given by the equation:

$$\sigma_x = \frac{F \ell \, y}{I} \tag{1}$$

where

F = Force applied at the end of the beam

ℓ = Length from the end of the beam to point P

y = one half the height, h, of the beam

I = area moment of inertia of the beam

Stress is related to strain by the equation

$$\sigma_x = E \, \epsilon_x \tag{2}$$

where

E = Young's modulus

ϵ_x = Strain at Point P

Also it can be shown that

$$I = \frac{b \, h^3}{12} \tag{3}$$

where

b = width of the beam

h = height of the beam

If equations 1, 2, and 3 are combined it can be seen that:

$$\epsilon_x = \frac{6 \, \ell \, F}{E \, b \, h^2} \tag{4}$$

This equation shows that the strain produced in a beam at some point P is a direct function of the force applied to that beam. Other useful equations are:

$$\delta_{max} = \frac{F\ell^3}{3EI} \qquad \theta = \frac{F\ell^2}{2EI}$$

This analysis can be applied to the proposed scale consisting of four beams. If it is assumed that the four beams have identical dimensions and properties, the force is applied at the same point on each beam, and the strain is observed at the same point on each beam, then the analysis will proceed as follows: The total force, F_{tot}, applied to the beams is equal to the weight of the newborn, W_n, plus the weight of the scale plate, W_p, plus the weight of any additional items placed on the scale such as a mattress or the newborn's diapers, W_a.

$$F_{tot} = W_n + W_p + W_a$$

W_p and W_a should remain constant throughout the weighing period. If the force exerted on beam 1 is defined as F_1, the force exerted on beam 2 is defined as F_2, and so on, then:

$$\sum_{i=1}^{4} F_i = F_{tot}$$

Since strain is a direct function of the force exerted on the beam as shown in equation (4),

$$\epsilon_{tot} = \sum_{i=1}^{4} \epsilon_i = \frac{6\ell}{Ebh^2} \sum_{i=1}^{4} F_i$$

Therefore the total strain is a direct function of the weight placed on the scale no matter what position the weight happens to be in.

ELECTRICAL ASPECTS

Strain Gauges: Strain gauges are variable resistance devices which consist of a metallic wire or foil bonded to a paper or plastic backing. The strain gauges are designed to be bonded to a metal surface such as a cantilever beam. When force is applied to the metal object a strain is created throughout the object and the strain gauge is stretched. This stretching causes a change in the length, cross sectional area, and the specific resistivity of the strain gauge. All of these factors contribute to a small change in resistance of the gauge.

Wheatstone Bridge: A Wheatstone bridge consists of four resistors mounted as shown below. The bridge is said to be balanced when the output voltage, E_{out},
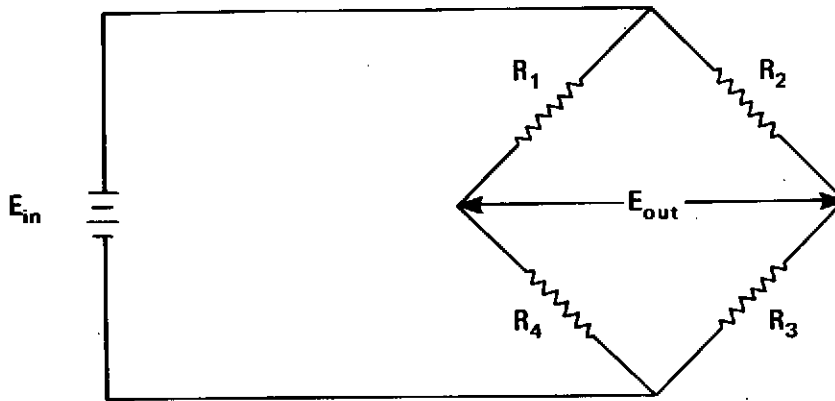
is equal to zero. This is true when the equation

$$\frac{R_1}{R_4} = \frac{R_2}{R_3}$$

is satisfied. One or all of these resistors may be replaced by strain gauges.

The bridge circuit used on the proposed scale is as shown below.
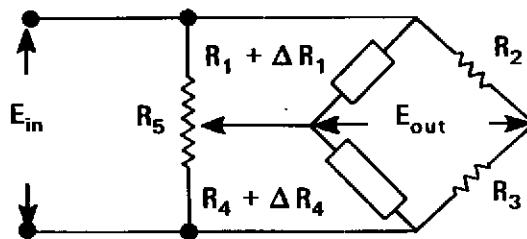
The resistors, R_1 and R_4, are strain gauges mounted on opposite sides of one of the cantilever beams on the scale. Resistors R_2 and R_3 are fixed resistors. R_5 is a variable resistor used to balance the bridge circuit. The equation describing this circuit is to a very close approximation

$$E_{out} = E_{in} \frac{R_1 R_2}{(R_1 + R_2)^2} \left(\frac{\triangle R_1}{R_1} - \frac{\triangle R_4}{R_4} \right)$$

If the strain gauge represented by R_4 is mounted on the underside of the beam then the quantity $\triangle R_4$ is negative since the gauge is in compression with a resulting decrease in resistance. This circuit has the added advantage of temperature compensation. During a temperature change the resistance of each gauge will change in the same direction by the same amount thereby leaving E_{out} unaffected. Since the proposed scale consists of four beams there are four bridge circuits each containing two strain gauges.

DC Differential Amplifier

The output voltage from each bridge circuit was found to be very small, on the order of 1 mV maximum. The signal must therefore be amplified in order to produce a signal of a reasonable magnitude. A DC differential amplifier was chosen to amplify the difference between the voltages across the bridge circuit. The circuit shown below was employed

$$E_o = \frac{-R_o}{R_1} (E_1 - E_2)$$
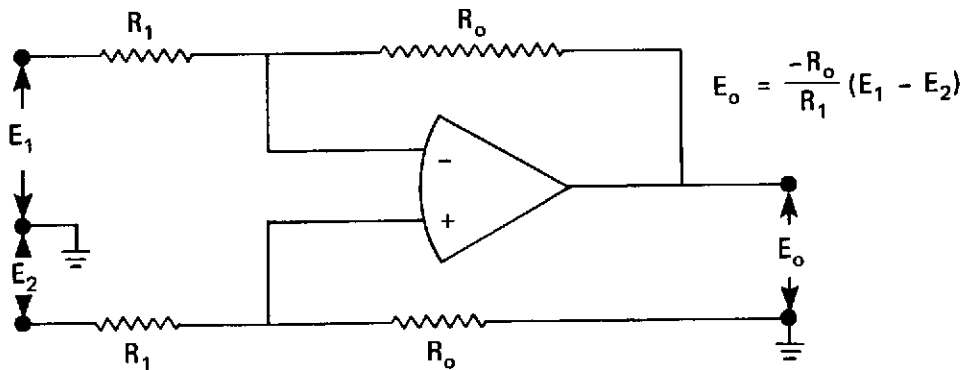
The resistor values are R_0 = 200 kΩ and R_1 = 1 kΩ with a resulting amplifier gain of 200. Four DC differential amplifiers were used to amplify the signal from the four bridge circuits.

Summing Amplifier

The weight of the newborn infant is proportional to the sum of the output voltages produced by the gauges on each beam of the scale. A summing amplifier was used to add the voltage outputs from each of the four DC differential amplifiers. Slight inconsistencies were found to be inherent in the scale possibly due to inexact beam lengths or placement of the gauges. In order to compensate for these inconsistencies a weighted rather than a direct sum is produced in the summing amplifier. This weighted sum is achieved by placing variable resistors as input resistors to the operational amplifier. The circuit is shown below:

$$E_o = -\left[\frac{R_0}{R_1}E_1 + \frac{R_0}{R_2}E_2 + \frac{R_0}{R_3}E_3 + \frac{R_0}{R_4}E_4\right] \qquad R_5 = R_o \| R_1 \| R_2 \| R_3 \| R_4$$
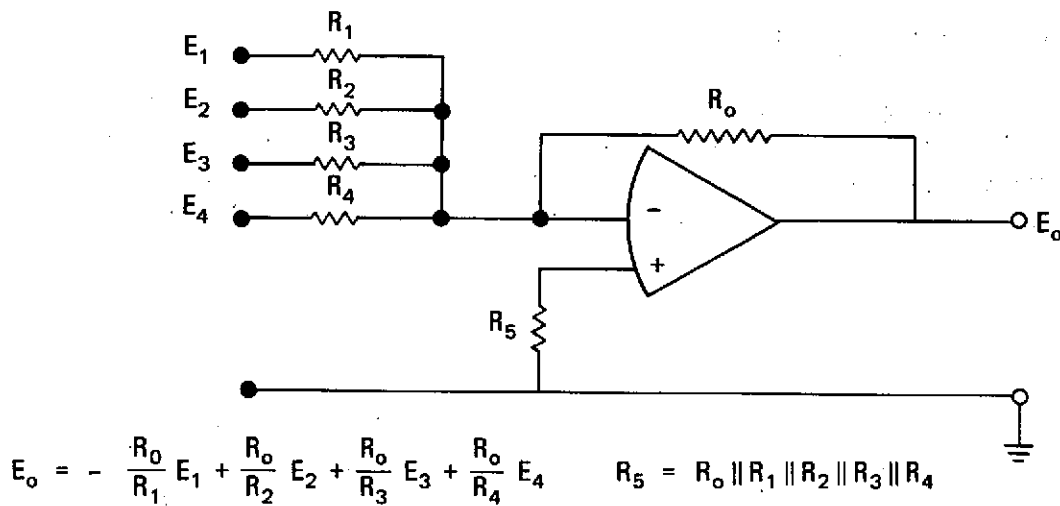
Resistor values of $R_0 = 100\,k$, $R_5 = 2.5\,k$ and R_1 through $R_4 = 10\,k\,\Omega$ potentiometers give a resulting gain in the summing amplifier of about 10. The use of the variable resistors provides a means of adjusting the scale so that an equal weight will produce an equal reading when it is placed at different locations on the scale.

Low Pass Filter

It was observed that the output signal from the summing amplifier contained a very large noise component on the order of 30 mV peak to peak. It was also observed that the scale itself was sensitive to external mechanical vibrations which produced an additional, lower frequency noise component in a frequency range of 10-20 Hz. Both of these noise components were eliminated by the use of Butterworth low pass filter with a cutoff frequency of 0.1 Hz. The filter circuit design is:
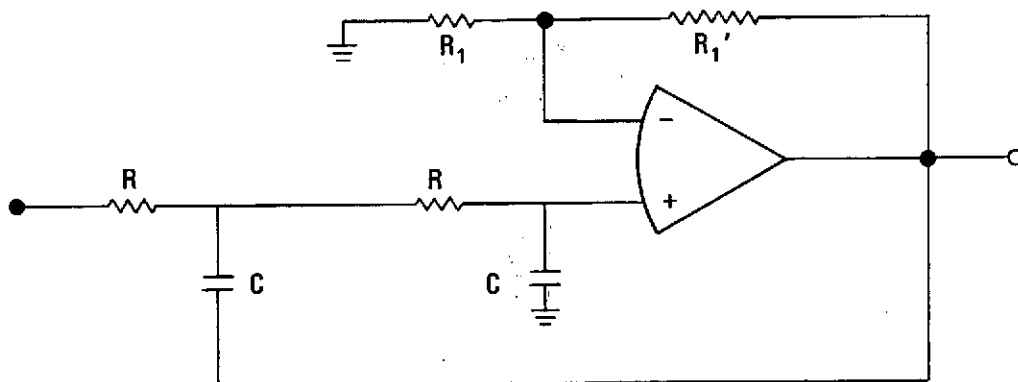
With component values of R = $160\,\mathrm{k}\,\Omega$, C = $10\,\mu\mathrm{F}$, R_1 = $10\,\mathrm{k}\,\Omega$ and R_1' - $14.27\,\mathrm{k}\,\Omega$. The low frequency voltage gain is 1.6 at frequencies above 0.1 Hz. The voltage gain drops at a rate of 12 db per decade of frequency change.

A/D Converter, Digital Display

Once a clear analog signal has been generated it becomes possible to convert this continuously varying signal into a coded digital signal by the use of an A/D Converter. The digital signal can be used to drive an illuminated digital display which would provide a direct weight reading of the newborn. These two components constitute the major cost of the system but with advancements in the electronics industries the costs have been and will continue to decrease to very reasonable levels. At present a reliable A/D Converter and digital display would cost on the order of $100 to $200. Even at this high cost a digital display is the most desirable form of weight readout because of its clarity and ease with which the weight may be recorded. The complete circuit block diagram is the following:

COMPLETE CIRCUIT BLOCK DIAGRAM

SUMMING
AMPLIFIER

LOW
PASS
FILTER

0.1 Hz
CUTOFF

A/D
CONVERTER

DIGITAL
WEIGHT
DISPLAY

4 STRAIN GAUGE   4 DC DIFFERENTIAL
BRIDGE CIRCUITS   AMPLIFIERS
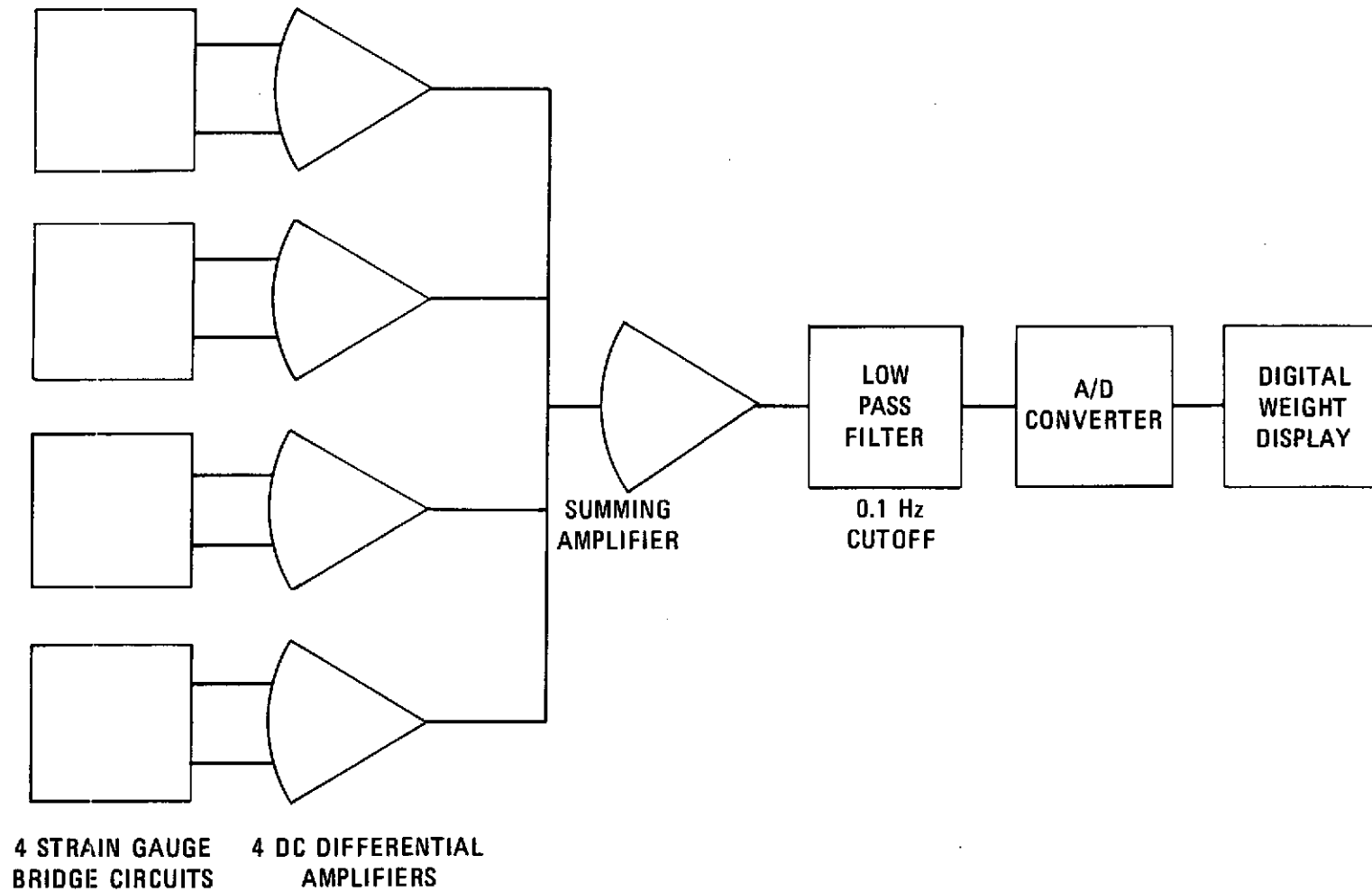
EXPERIMENTAL RESULTS

Tests were performed by placing known weights on the scale and recording the voltage output after the low pass filter. With a bridge supply voltage of 1.50 VDC and an operational amplifier supply voltage of ±15 VDC the following results were obtained:

Wt (grams)	Output Voltage (volts)	$\|E_{out}\|$ = Output - 0.54 VDC
0	0.54	0.00
524.8	0.86	0.32
1069.6	1.20	0.66
1637.9	1.55	1.01
2169.1	1.90	1.36
2893.6	2.37	1.83
3438.4	2.72	2.18
4006.7	3.08	2.54
4537.9	3.42	2.88
5200.6	3.85	3.31
5731.8	4.19	3.65
6367.4	4.60	4.06
6398.6	4.95	4.41

A graph of these results are presented on the following page. The $\|E_{out}\|$ is obviously a linear function with respect to weight. This is a desirable result since a linear voltage response can be easily correlated with weight.

CONCLUSION

At the present time the scale performs to about a ±10 grams accuracy only as a differential weighing device. In other words the scale performs as well as an ordinary scale only for short periods of time. We believe that better components, workmanship, and packaging will result in a final product which is able to satisfy all the requirements for providing a continuous and accurate means of weighing a newborn infant without its removal from the incubator.

OUTPUT VOLTAGE $|E_{out}|$ VS WEIGHT

SLOPE = 0.637 V/1000 g.

E_{out} (volts)

WEIGHT (grams)
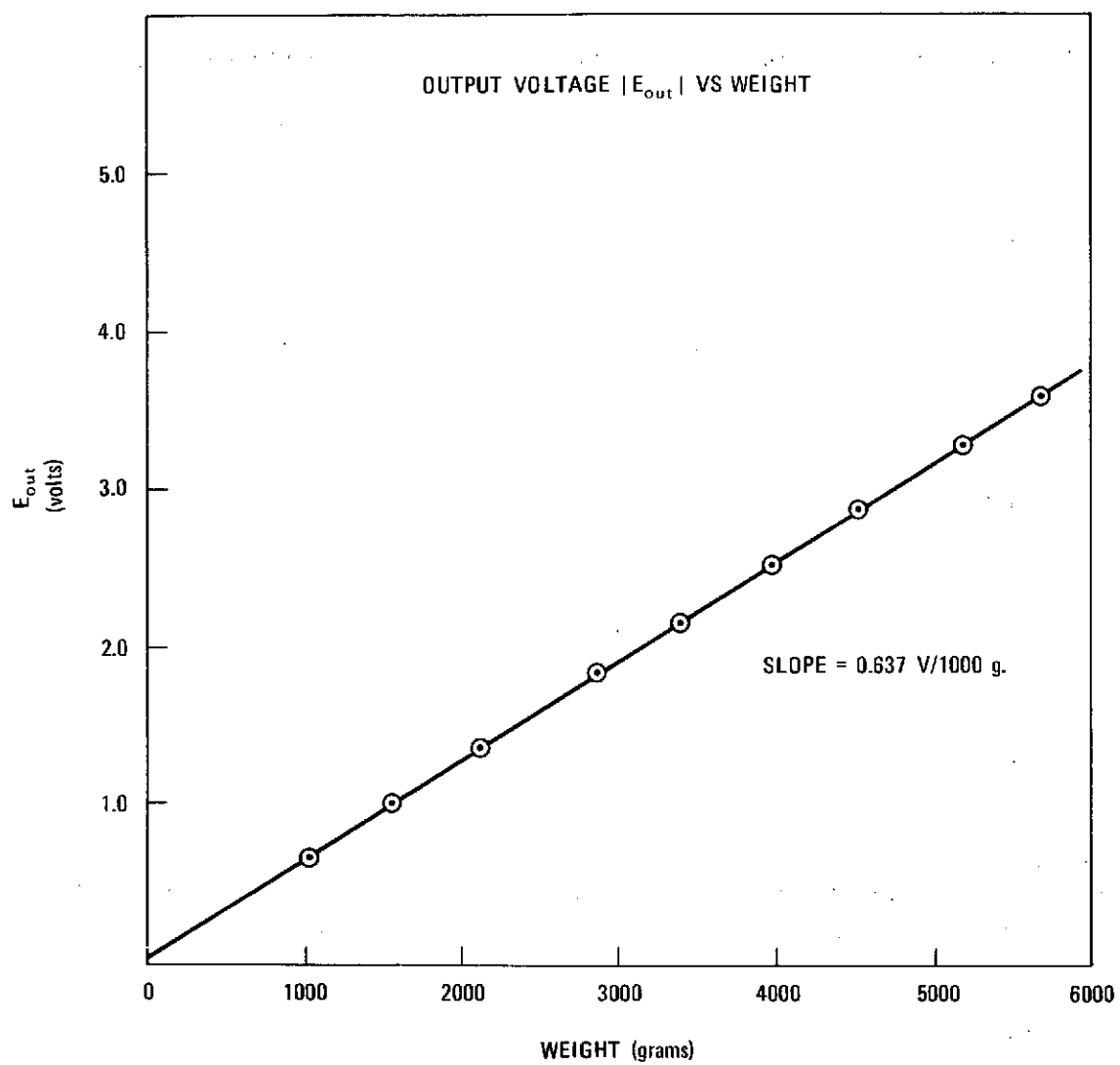
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SECTION 5

INTERNAL TIBIAL TORSION

CORRECTION STUDY

Submitted by:

Juan M. Cantu

Coleen M. Madigan

MEDICAL ADVISOR:

Dr. Charles Epps, Jr.

TECHNICAL ADVISOR:

Mr. Lawrence Kobren

ORIGINAL PROBLEM STATEMENT

Written by: Recorded by:

    Dr. Charles Epps   Eugene M. DeLoatch, Ph.D.

TITLE: INTERNAL TIBIAL TORSION CORRECTION DEVICE

STATEMENT OF THE PROBLEM: Internal tibial torsion is a common clinically recognizable condition, which is very poorly and inadequately measured by either clinical or radiological methods. A direct result of the difficulty in quantifying this disorder is that there is no unanimity among physicians as to indications for treatment. Further, it has been recognized that this condition undergoes spontaneous remission. If the degree of deformity could be measured accurately by a device that could either be simply reproduced and made inexsively, then it would be possible to record a sufficient number of patients and establish the life history of this condition. It would also be possible to measure effectively the results of treatment measures used today which in most centers is the Denis Browne splint. The development of such a device would represent a significant accomplishment by engineering in assisting to solve an interesting as well as critical clinical problem.

SCOPE OF THE WORK: (1) The development of a device is desired which could be employed to determine where correction is obtained in an internally rotated tibia. (2) At present it is not clear to clinicians whether or not the corrective rotation takes place at the epiphyseal plate, that is the junction between the epiphysis and metaphysis or if it occurs at some place along the diaphysis or shaft (see Figure 5-1). (3) It is thought that the new device should apply an external rotation force upon the tibia in a fashion similar to that applied through the Denis Browne splinting method. Via animal experimentation, radiographic evaluation and appropriate histologic studies should be made to determine the site of correction, using the constructed prototype.
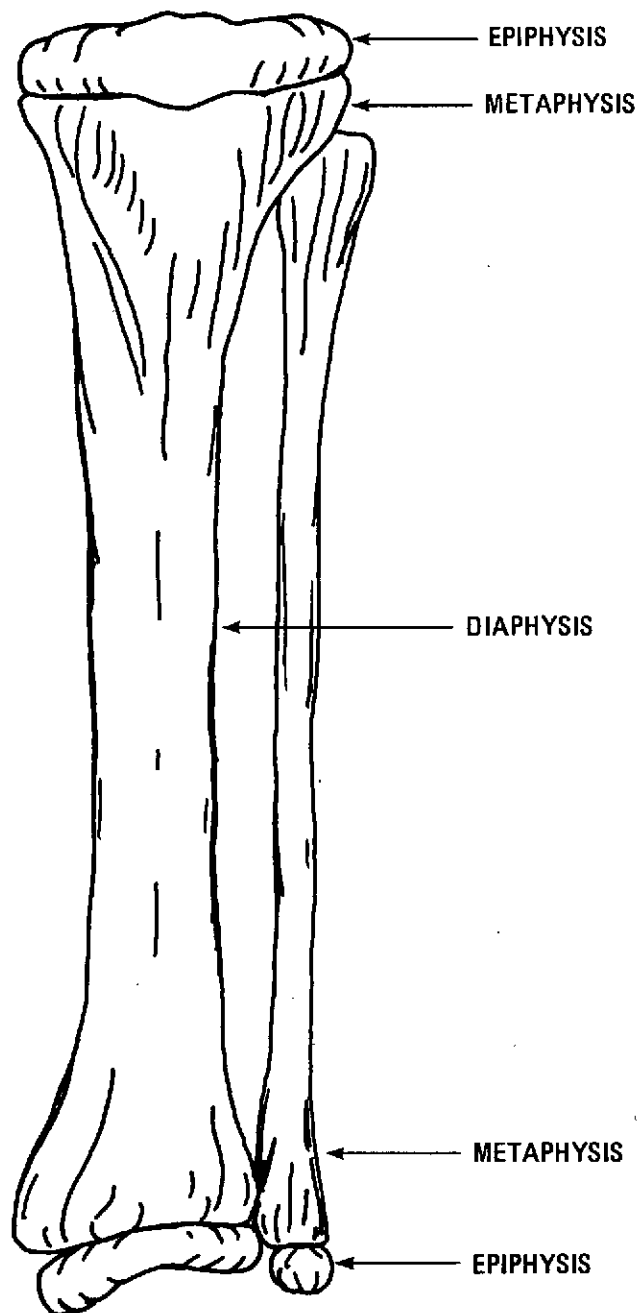
Figure 5-1

INTERNAL TIBIAL TORSION CORRECTION DEVICE

STATEMENT OF THE PROBLEM

Upon reviewing the original statement of the problem and the scope of the work entailed, we concluded that a workable revision of the problem was deemed necessary. We discussed the problem with our medical advisor, Dr. Epps, and determined that the following points form the skeleton of the problem: a) To design a device which accurately measures the external angular deviation exhibited in infants with extensive degrees of toe-in and toe-out, b) to research the sight of maximum twist resulting from the use of the Denis Browne splint through animal experimentation with a technique outlined by our medical advisor: specifically, through implantation of pins in the tibia of a primate and radiological evaluation of pin rotation after application of a Denis Browne type splint.

After researching the literature at hand, we discovered a device (orthopedics measurement board for tibial torsion and toe-out) in use which measured the abnormal foot rotation associated with toe-in and toe-out. It appeared this device uses linear measurements which subsequently involved trigonometric calculations. Yet considering the time factor and the use of this device on infants, a better method would be one employing a direct angular measurement of deviation. After locating one of these devices, it was apparent to us that indeed a goniometer was included in the design of the device. At this portion of the problem, we surmised that additional investigation was warranted concerning torsional stress similar to that imposed by the Denis Browne splint. With this in mind, our study was expanded to encompass a quantitative and qualitative analysis of torsion as applied to bones.

In the quantitative aspect of this study, 1) we investigated methods for stress analysis, in particular possible use of ultrasonics to measure stresses in bone, 2) we also conducted some experiments on turkey bones, and 3) finally we ran a theoretical analysis on the bone.

In this study, methods of non-invasively measuring stresses in bones were investigated. Most methods used in industry for stress measurements, however, are not conducted in a non-invasive manner. For example, strain gauges are attached to metals for strain measurements which could be used for stress analysis. There are also photo elastic methods of stress analysis which consist of examining, by polarized light, a model of the structure to be investigated, the material of the model being a transparent plastic having special optical properties. By applying stresses to the model, the model exhibits patterns of fringes, from which the magnitudes and directions of the stresses can be evaluated. Since

the bone is not homogeneous, nor isotropic, a model would be fallible, and the analysis would not be representative of the bone. X-ray analysis has also been used to measure residual stresses using automated diffractometer techniques and computer calculations. Most of the X-ray analysis done, however, is performed on symmetrical bodies, such as sheets of metal; in addition, the mathematical treatment can be very rigorous. Again, metals are homogeneous and bone is not.

For the most part, ultrasound seems to be the most promising. It has been used in the non-medical as well as medical fields. In the non-medical fields, ultrasound has been used to measure residual stress in aluminum. It has also been used in the medical field. For example, there are ultrasonic bone densitometers to measure changes in bone density. Ultrasound has also been used to view internal organs and soft tissue which are invisible to X-rays. Also, ultrasound has been used in the field of orthopedics to detect fractures in bones. Given that ultrasound has been used for stress measurements, and given that it has been used in orthopedics, it seems possible that ultrasound can be used for stress measurements on the bone. We ourselves were unable to obtain the experimental ultrasonic equipment, so we did not do any testing in this field.

After investigating ultrasound, our interest was focused on experimental tests and also on a theoretical analysis on the bone for comparative reasons. All of our experiments were conducted on whole bone, mainly because most tests done on bones are done on bone segments. These results would lead to an invalid analysis of whole bone. The test device employed is shown in Figure 5-2.

Using this device, one end of the bone was clamped while the other was torqued using a lever arm and by adding weights. These tests were conducted to gain insight as to the characteristics and properties of bones under torsion. As we can also see from figure one, strain gauges were mounted on the two ends of the bone and one in the middle or shaft of the bone. The bone was kept as fresh as possible, but the surface needed to be dry and clean to mount strain gauges. Also from figure one we notice a smaller bone which was used in the strain measurements for correction due to temperature changes. These strain gauges measure the amount of deformation (strain = $\Delta L/L$) occurring in the three regions. From these measurements, (as listed in the appendix — data on Bone C), we found that on the average, a bit more strain occurs at the ends of the bone than at the middle or shaft of the bone.

Also an important factor to be considered in the analysis of the bone, is the general shape and dimensions of the cross-sections of the bone along its axis. We used another bone, sliced it, and obtained the necessary measurements, such as the thickness dimension (this can be found with the values of shearing stress
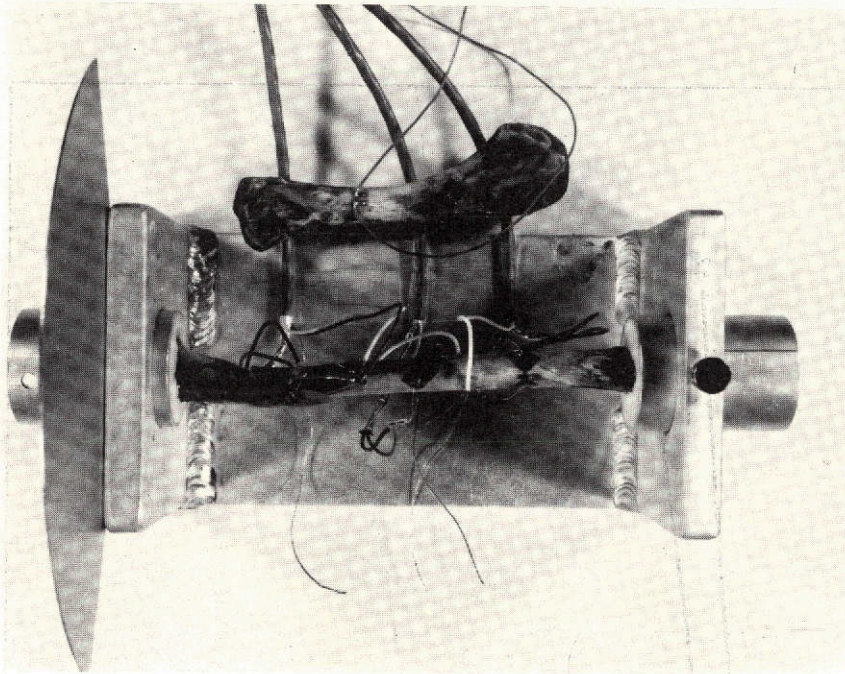
Figure 5-2

and twisting moment). From the strain measurements and from the physical dimensions of the bone, we obtained further information about the bone, namely, about the modulus of rigidity of the bone.

The modulus of rigidity of the bone is a measure of the stiffness of the bone. From Figure 5-3 we can observe that the values of the modulus of rigidity is not the same for all parts of the bone. Curve #1 was calculated in the region where the bone was held, while curve #2 was calculated for the middle or shaft of the bone, while curve #3 was calculated for the skinnier end of the bone which was torqued. Furthermore, as can be seen from the graph, as more torque is applied, the modulus of rigidity decreases, or the bone becomes less stiff. In general for a circular shaft, the modulus of rigidity is given by:

$$G = \frac{S_s}{|\epsilon_1| + |\epsilon_2|}$$

where S_s is the maximum shear stress on the surface. For a circular hollow shaft:
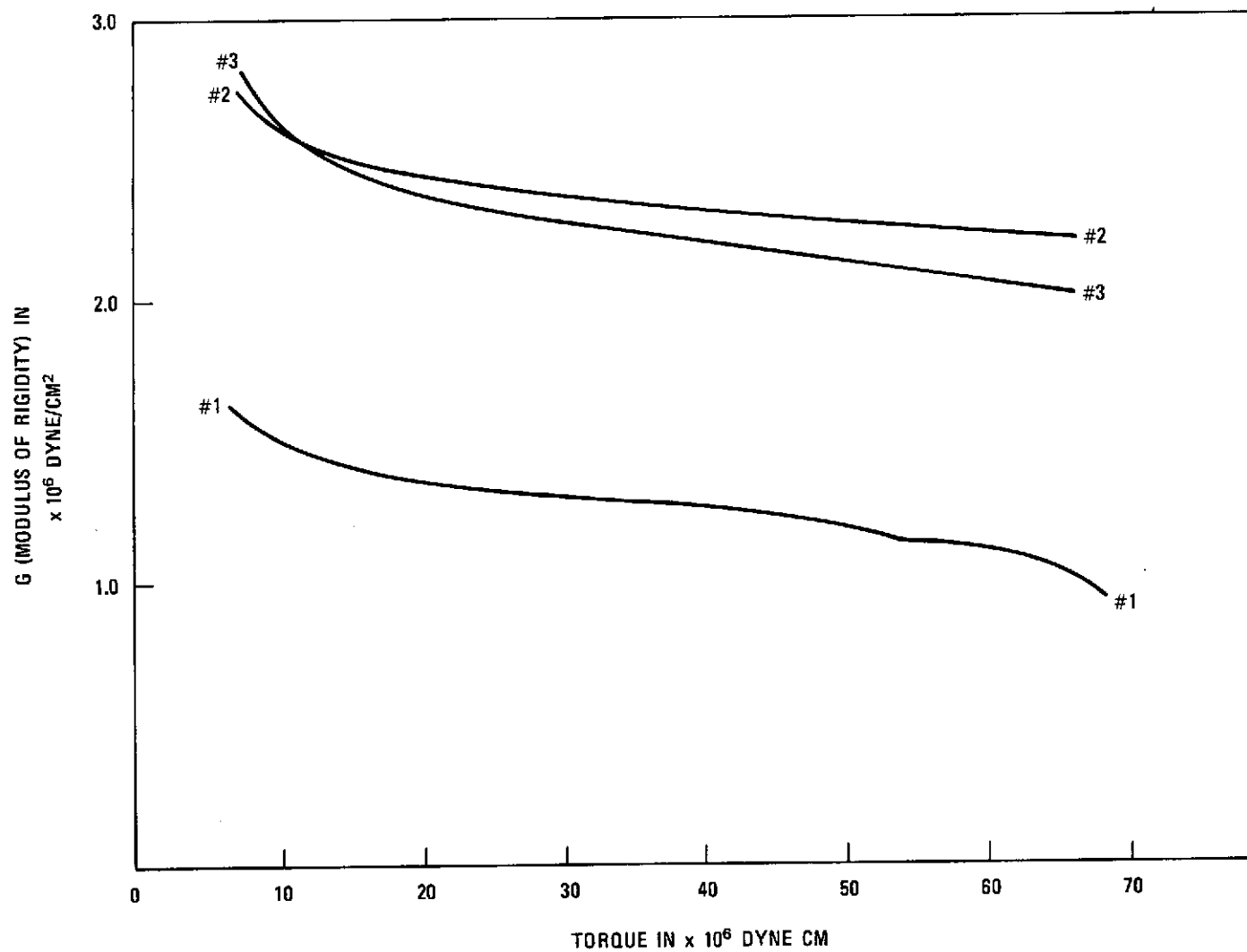
Figure 5-3. Modulus of Rigidity Versus Torque

$$S_s = \frac{T}{2\pi r^2 t}$$

while for an elliptical cross-section

$$S_s = \frac{T}{2\pi b h t}$$
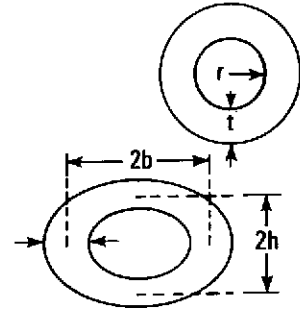
and where ϵ_1 and ϵ_2 are the maximum strain measurements taken along the axis of the shaft. For circular shafts, the maximum strain occurs at a 45° angle to the axis of the shaft. For our calculations, S_s, was determined assuming mainly elli;tical shapes for the cross-sections of the bone, while ϵ_1 and ϵ_2 were the maximum strain measurements using strain gauges mounted also at a 45° angle to the axis of the bone, since the major strain occurs at this angle.

To effect a theoretical analysis of the bone, we programmed NASTRAN, a structural analysis computer system, with the various properties of the bone such as the modulus of rigidity. Histograms of the resultant output are displayed in Figure 5-4 (Stress as a function of Distance) and Figure 5-5 (Angular Rotation as a function of Distance).

It can be seen that the maximum stresses occurred in the region near the torqued end of the bone. Also, most of the twisting occurred in this region where the stresses were a maximum. In general, one would suspect that the bone would fracture where the stresses were a maximum, and indeed this was the case as can be observed in Figure 5-6.

To summarize the quantitative study of torsion in bones, we have found for this experiment, that there was gratifyingly close correlation between our experimental data and the theoretical stress distribution provided by NASTRAN. Again I would like to emphasize that these results were obtained from a study of the entire bone in contrast to analysis of segments of bones as has been traditionally done. Based on these results, we feel that further analysis of skeletal structures using NASTRAN is warranted and would prove to be of great value in the field of orthopedics.
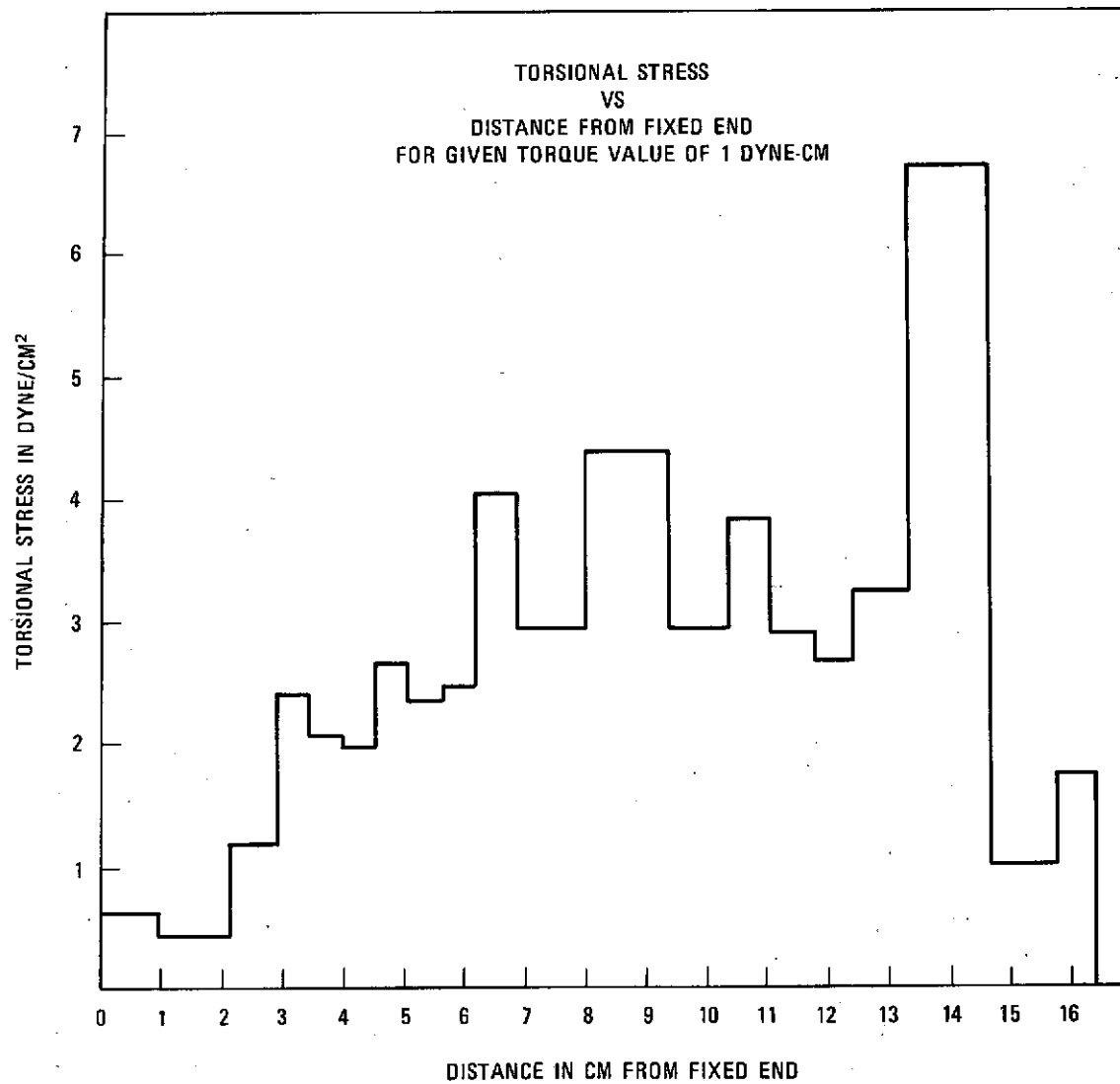
Figure 5-4. NASTRAN Output 1
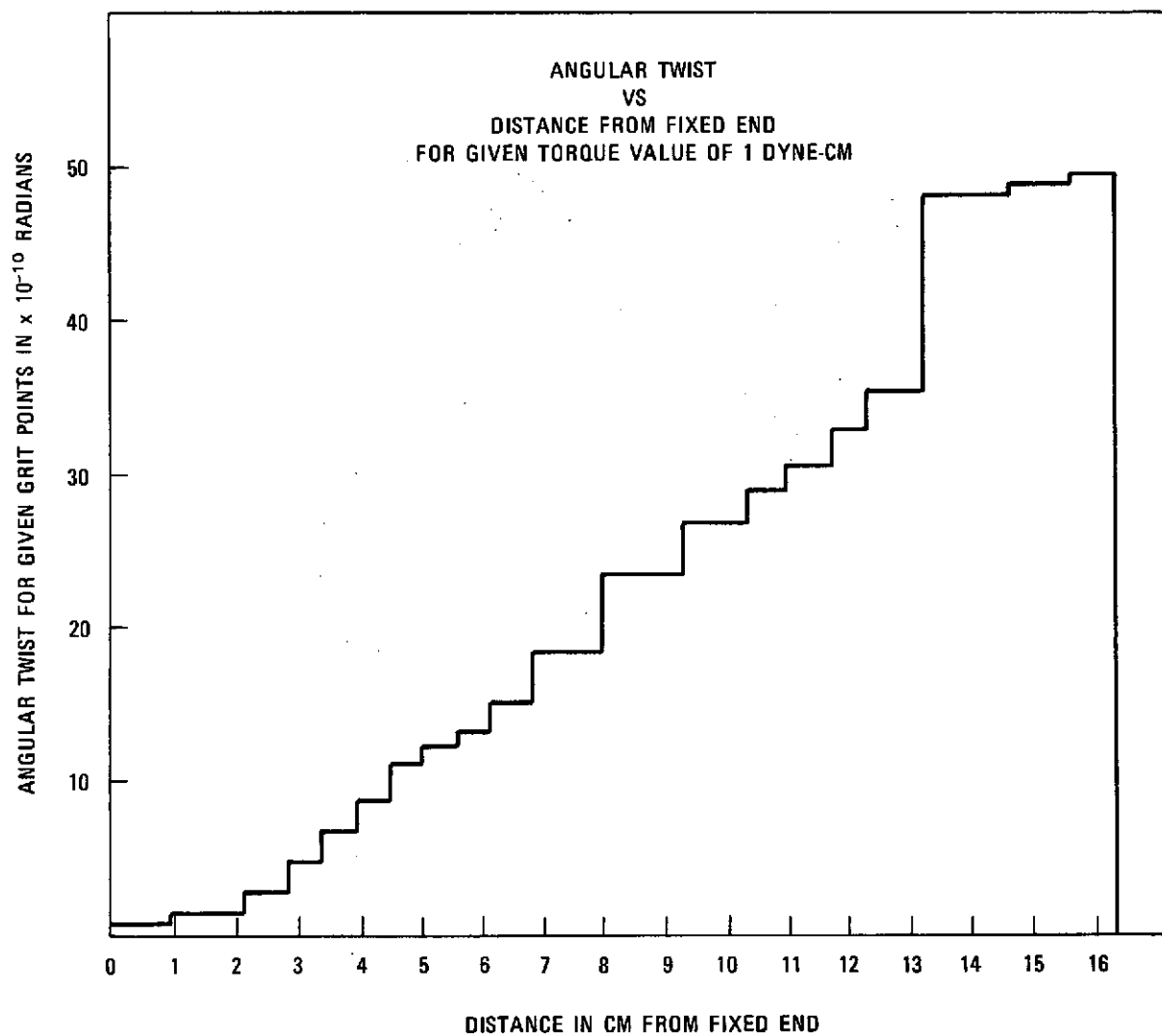
Figure 5-5. NASTRAN Output 2
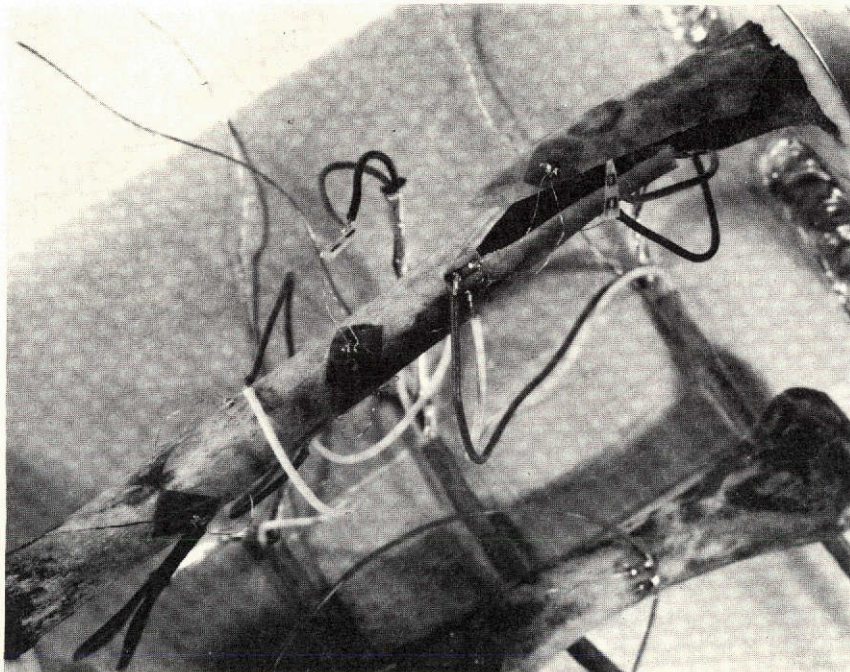
Figure 5-6

SECTION 5

APPENDIX A

DATA — BONE C #1 (Fixed End of Bone)

Weight*	Green and White Gauges		X°	Total Torque	Weight	Red and Black Gauges		X°
	Uncorrected Strain	Corrected Strain				Uncorrected Strain	Corrected Strain	
0	+1001	+591	—		0	−12		—
250	+1592	+591	13.6	7.65	250	−350	−338	13.6
500	+1938	+937	14.6	11.6	500	−591	−579	14.6
750	+2300	+1299	16.3	16.0	750	−879	−867	16.3
1000	+2699	+1698	17.8	20.5	1000	−1187	−1175	17.8
1250	+3119	+2118	19.5	25.2	1250	−1506	−1494	19.8
1500	−1213	—	21.5	—	1500	+1326	−−	21.5
1750	+4120	+3119	23.3	36.0	1750	−2283	−2271	23.3
1850	+4347	+3346	24.4	38.4	1850	−2454	−2442	24.4
1950	+4588	+3587	25.2	40.5	1950	−2644	−2632	25.2
2050	+4850	+3849	26.2	43.0	2050	−2837	−2825	26.2
2150	+5147	+4146	27.0	45.5	2150	−3049	−3037	27.0
2250	+5430	+4429	28.0	48.1	2250	−3250	−3238	28.0
2350	+5764	+4763	29.0	50.7	2350	−3470	−3458	29.0
2450	+6170	+5169	30.1	53.3	2450	−3740	−3728	30.1
2550	+6544	+5543	31.1	56.0	2550	−3980	−3968	31.1
2650	+6956	+5955	32.4	59.1	2650	−4250	−4238	32.4
2750	+7579	+6578	34.0	62.2	2750	−4600	−4588	34.0
2850	+8310	+7309	35.6	65.3	2850	−5050	−5038	35.6
2950	crack		36.7	68.1	2950	−5384	−5372	36.7
gram-wts.	microinch/ inch	microinch/ inch	degrees	× 10⁶ dyne/cm	gram-wts.	microinch/ inch	microinch/ inch	degrees

*This weight does not include the weight of the pin used to hold the weights. It also does not include the weight of the lever arm. Both these quantities were, however, evaluated in the total torque.

DATA — BONE C #2 (Middle of Bone)

Weight	Green and White Gauges		X°	Total Torque	Weight	Red and Black Gauges		X°
	Uncorrected Strain	Corrected Strain				Uncorrected Strain	Corrected Strain	
0	−272		—		0	+931		—
250	+98	370	13.6	7.65	250	+470	−461	13.6
500	+312	584	14.6	11.6	500	+170	−761	14.6
750	+542	814	16.3	16.0	750	−143	−1074	16.3
1000	+797	1069	17.8	20.5	1000	−475	−1406	17.8
1250	+1057	1329	19.5	25.2	1250	−826	−1757	19.5
1500	−1890		21.5		1500	+3658		21.5
1750	+1638	1910	23.3	36.0	1750	−1658	−2589	23.3
1850	+1758	2030	24.4	38.4	1850	−1851	−2782	24.4
1950	+1893	2165	25.2	40.5	1950	−2055	−2986	25.2
2050	+2014	2286	26.2	43.0	2050	−2256	−3187	26.2
2150	+2141	2413	27.0	45.5	2150	−2464	−3395	27.0
2250	+2274	2546	28.0	48.1	2250	−2682	−3613	28.0
2350	+2422	2694	29.0	50.7	2350	−2925	−3856	29.0
2450	+2596	2868	30.1	53.3	2450	−3200	−4131	30.1
2550	+2726	2998	31.1	56.0	2550	−3410	−4341	31.1
2650	+2880	3152	32.4	59.1	2650	−3663	−4594	32.4
2750	+3066	3338	34.0	62.2	2750	−3964	−4895	34.0
2850	+3240	3512	35.6	65.3	2850	−4240	−5171	35.6
2950			36.7	68.1	2950			36.7
gram-wts.	microinch/ inch	microinch/ inch	degrees	× 10^6 dyne/cm	gram-wts.	microinch/ inch	microinch/ inch	degrees

DATA — BONE C #3 (Torques End of Bone)

| Weight | Green and White Gauges | | X° | Total Torque | Weight | Red and Black Gauges | | X° |
	Uncorrected Strain	Corrected Strain				Uncorrected Strain	Corrected Strain	
0	−722				0	+392		
250	−1158	−436	13.6	7.65	250	+762	+370	13.6
500	−1419	−697	14.6	11.6	500	+1030	+638	14.6
750	−1709	−987	16.3	16.0	750	+1318	+926	16.3
1000	−2026	−1304	17.8	20.5	1000	+1640	+1248	17.8
1250	−2346	−1624	19.5	25.2	1250	+1968	+1576	19.5
1500	−2713	−1991	21.5		1500	+2346	+1954	21.5
1750	−3116	−2394	23.3	36.0	1750	+2744	+2352	23.3
1850	−3298	−2576	24.4	38.4	1850	+2913	+2521	24.4
1950	−3483	−2761	25.2	40.5	1950	+3088	+2696	25.2
2050	−3691	−2969	26.2	43.0	2050	+3271	+2879	26.2
2150	−3887	−3165	27.0	45.5	2150	+3448	+3056	27.0
2250	−4083	−3361	28.0	48.1	2250	+3641	+3249	28.0
2350	−4322	−3600	29.0	50.7	2350	+3864	+3472	29.0
2450	−4552	−3830	30.1	53.3	2450	+4101	+3709	30.1
2550	−4776	−4054	31.1	56.0	2550	+4327	+3935	31.1
2650	−5004	−4282	32.4	59.1	2650	+4552	+4160	32.4
2750	−5277	−4555	34.0	62.2	2750	+4807	+4415	34.0
2850	−5551	−4829	35.6	65.3	2850	+5084	+4692	35.6
2950			36.7	68.1	2950			36.7
gram-wts.	microinch/ inch	microinch/ inch	degrees	$\times 10^6$ dyne/cm	gram-wts.	microinch/ inch	microinch/ inch	degrees
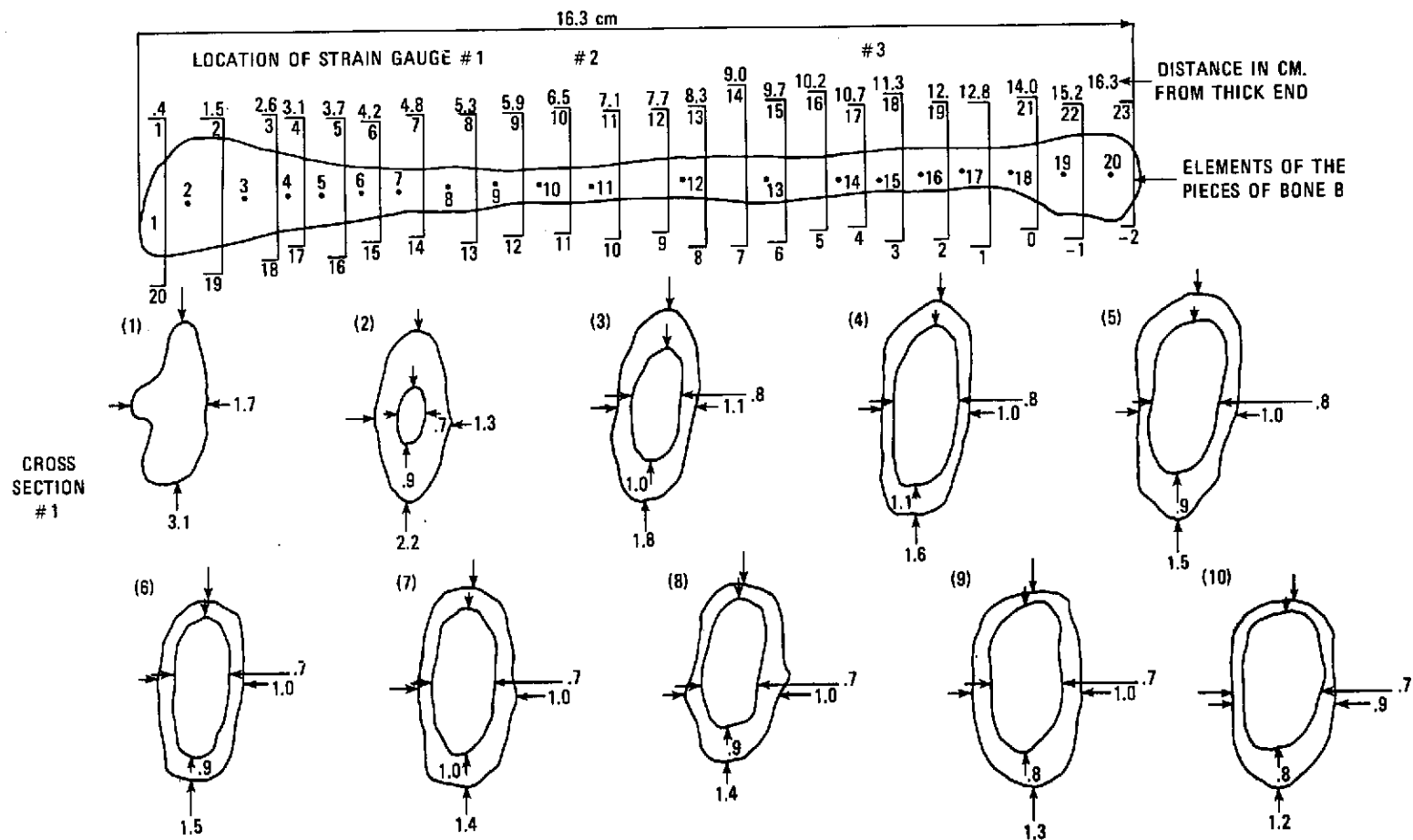
FIGURATIVE DATA ASSEMBLY FOR NASTRAN PROGRAM
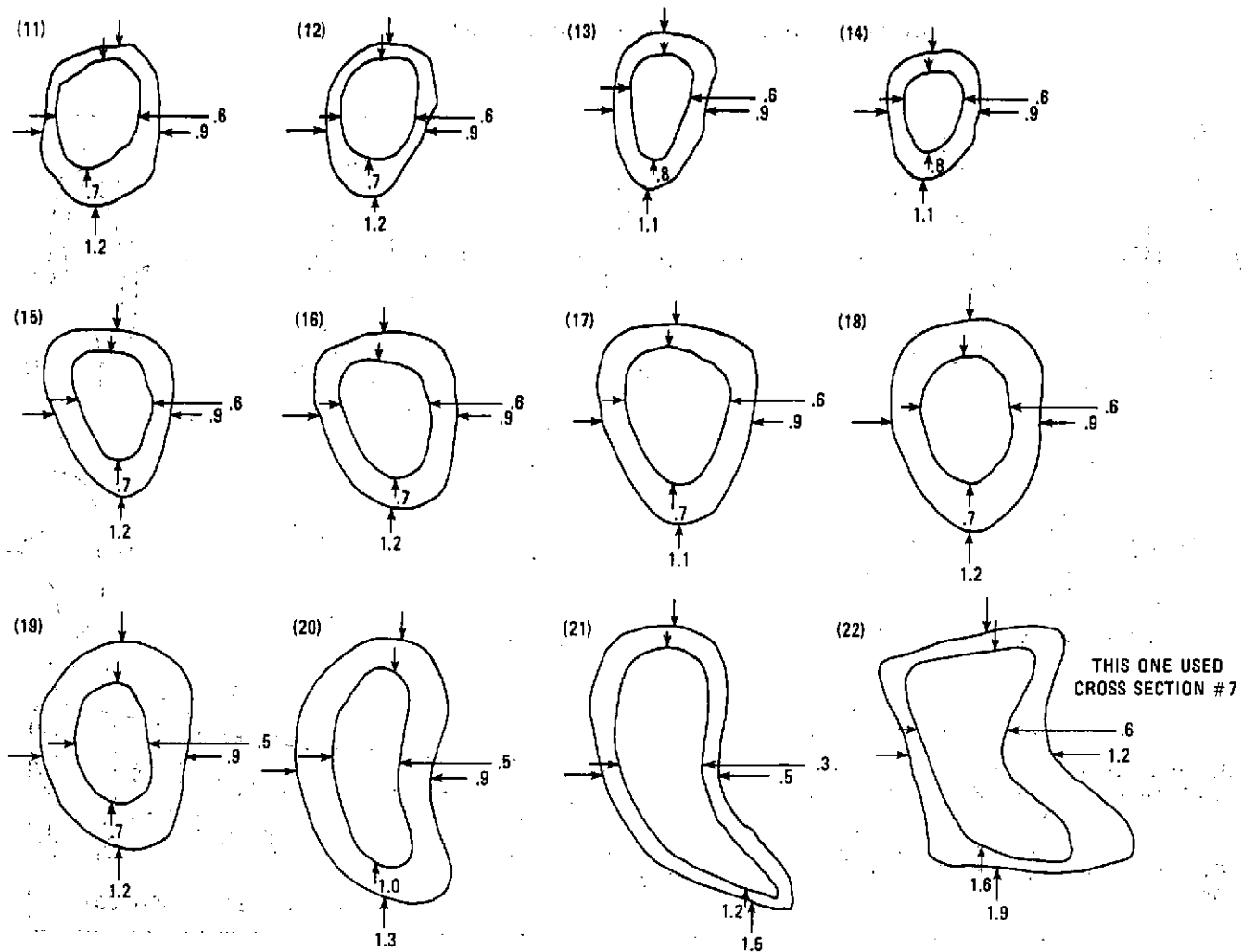
FIGURATIVE DATA ASSEMBLY FOR NASTRAN PROGRAM (Continued)

Section	b cm	h cm	t cm	J_s $r = 1$ $2\pi b h t$ cm^3	$\sqrt{z\,(b^2 + h^2)}$ cm	$J_\theta =$ $\dfrac{4\pi b^2 h^2 t}{\sqrt{2\,(b^2 + h^2)}}$ cm^4	Set R $=$ $\dfrac{J_\theta}{J_s}$ cm
2	1.1	.65	.47	2.12	1.807	1.67	.79
3	.9	.55	.27	.84	1.492	.557	.66
4	.8	.5	.17	.42	1.334	.256	.61
5	.75	.5	.20	.48	1.275	.277	.58
6	.75	.5	.22	.52	1.275	.305	.59
7	.7	.5	.17	.38	1.217	.215	.57
8	.7	.5	.20	.44	1.217	.253	.58
9	.65	.5	.2	.41	1.16	.229	.56
10	.6	.45	.15	.25	1.061	.129	.52
11	.6	.45	.20	.34	1.061	.173	.51
12	.6	.45	.2	.34	1.061	.173	.51
13	.55	.45	.15	.23	1.005	.1148	.50
14	.55	.45	.15	.23	1.005	.1148	.50
15	.6	.45	.2	.34	1.061	.1726	.51
16	.6	.45	.2	.34	1.061	.1726	.51
17	.55	.45	.17	.26	1.005	.130	.5
18	.6	.45	.2	.34	1.061	.173	.51
19	.6	.45	.22	.37	1.061	.190	.51
20	.65	.45	.17	.31	1.118	.163	.53
21	.75	.25	.125	.15	1.118	.049	.33
1				1.558	1.969		1.26
22				1.0032	.7378		.74

TABLE OF RIGIDITY MODULI NEEDED
TO COMPLETE NASTRAN ANALYSIS

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RADIOGRAPHIC STUDY

After investigating the various aforementioned methods of analyzing torsion applied to bones, radiography was focused upon for study for two basic reasons: It is a non-invasive method and it is used in diagnostic medicine. Radiography as an application to this study could offer possible quantitative analysis, but preferably, it would yield a more appreciably accurate qualitative study.

The basic radiographic method in common use is medical X-ray. In researching various areas, the suggestion of investigating a relatively new radiographic method was made. This method is called Xeroradiography. Essentially, diagnostic X-rays are X-ray absorption patterns through a material as displayed on photographic film.

"When the useful beam of an X-ray tube is projected through an anatomical or other structure, many and sometimes most, of the photons which comprise the beam are absorbed. A few, however, pass through the structure to emerge on the other side. If these are allowed to fall on a flourescent screen, some are absorbed and their energy converted into light.

"If all of the anatomical tissues absorb X-ray photons equally, the number which fall on the flouroscopic screen is uniform from one portion of the screen to another, and hence the light generated by the screen exhibits no image pattern. If, on the other hand, some tissues absorb more X-ray photons than others, the brightness of the screen is not constant from one point to another, but instead, varies in accordance with the configurations of the anatomical structures through which the radiation passes; that is, the screen bears an image pattern. Although many tissues absorb X-rays nearly equally, others, because of differences in density and/or atomic number, do not. Therefore, the images of many anatomical components may be recorded flouroscopically and radiographically." [1]

Xeroradiographs are patterns of electrostatic charge distribution caused by the effect of normal X-rays on a p-charged Selenium-coated glass plate rather than the customary radiographic film. The same X-ray equipment used to photograph conventional medical X-rays is employed with additional Xerox equipment. This equipment includes a conditioner to store and charge the plates and a processor to develop the exposed charged plate. In addition are the selenium coated "re-usable" glass plates in cassette cartridges. To photograph a Xeroradiographic image, a cassette is placed into the conditioner (which also stores extra plates) and is returned, charged, to the technician. The photograph is taken with X-ray apparatus and followed by development in the processor.

"All photographic applications of Xerography depend on the physical phenomenon of photoconductivity, the phenomenon exhibited by some materials in which their electrical conductivity is changed when they are illuminated. In the best-known application of Xerography, an electrical potential is applied across a layer of a highly insulating photoconductor and the film is then exposed to a light image, as it would be in the back of a conventional camera. Where light strikes the surface, the electrical potential decays, leaving a distribution of electrostatic charge corresponding to the dark areas of the projected image. This electro-static latent image can be made visible by development with a suitable powder."[2]

X-rays have long been used in medicine to exhibit ossified tissue while Xero-radiography is still being developed. Xeroradiographs do display ossified tissue as well as normal medical X-rays when the correct exposure conditions are used, yet they also delineate soft tissue much better than conventional X-rays. X-rays show slight density changes more clearly than Xerographs, but sharp density differences are more definitive on the Xeroradiographs. To date, Xero-radiography mainly has been used in mammography because they can show sharp density differences of calcified matter, which may accompany the early stages of breast carcinoma and are not yet palpable, to the surrounding soft breast tissue. Bone analysis by this method is currently under experimentation and reduction of radiation dosage seems to be advised; Xeroradiography requires higher exposure parameters than conventional X-rays. In the long run, Xero-graphic images may prove quicker and easier to process.

Based on the fact that limb bones of infants are only partially ossified tissue, Xerography appeared applicable to this study. Specifically, the shaft of the tibia is rigid yet the ends are soft-cartilaginous-like material. In Figure 5-1 the diaphysis and metaphysis of an infant are for the most part ossified, yet the epiphyses are still undergoing gradual calcification. In the normal growth process calcification occurs along lines of stress and as children grow, placing weight on their legs, their bones ossify both radially and longitudinally. If an external torque were placed on the legs of these infants, it is believed that cal-cification may follow a distinctly different pattern.

With this idea in mind, definitive stress lines or resultant calcification along those stress lines might be recognized as varying from the norm. To visualize these patterns, the soft tissue might act as a contrast to the ossified tissue in premature bones.

EXPERIMENTATION

Animal experimentation was performed for two reasons: To use an X-ray analysis to locate the origin of the maximum twist resultant from use of the

Dennis Browne-type splint and to apply Xeroradiography in detecting stress or calcification patterns resultant from use of that orthopedic device.

A 2-month old Stumptail Macaque was obtained for experimentation. This particular monkey was the best to use because it is comparable to a 6-month old human infant (the age group in which there is extensive use of the Denis Browne splint for correction of toe-in or toe-out.) Five pins were surgically inserted in both legs along the tibia by Dr. Charles Epps. Aiming for implantation perpendicular to the longitudinal axis of the bone, he placed the pins in each of five areas as illustrated in diagram. The monkey wore a Denis Browne-type splint 20 hours a day, 7 days a week with the right foot rotated 60° and the left foot held in a neutral position.

X-rays were taken before surgery, after implantation, and a final X-ray after 33 days. The original plans were to compare the first X-ray at implantation to the final X-ray to observe a deviation in the arrangement of the pins: thereby, locating the origin of the maximum twist. Unfortunately, the difficulty in duplicating the exact positioning of the monkey was not anticipated. In essence, because of the difficulty in handling the monkey and the flexibility of the muscles and bones, photographs of the identical view were unable to be taken consistently. This resulted in radiographic obliques, which reduce the validity of comparison of the pins. During the 5 weeks of the monkey experimentation, Xeroradiographs were photographed at interims, in hopes of seeing stress lines, definitive calcification patterns, and to reconfirm the other conventional X-ray data. In the former two searches for stress or calcification lines, Xerography proved unsuccessful for 3 possible reasons: (1) The monkey's bones were small and therefore offered vague information upon radiographic examination. (2) The process of calcification was more advanced than was anticipated in the limb bones of the infant monkey. (3) Concerning the latter search, reconfirmation of the X-ray data, difficulty was encountered again in attempting to duplicate positional views that were extremely variable and virtually impossible to copy.

After each set of Xerographs were photographed (several shots were taken each time) a geometric analysis of the angles and lengths of the pins was made to identify an established pattern of angular deviation by differences in the angle sizes correlated to the lengths. After examination of the angles, there appeared to be a pattern evolving. Unfortunately, because the photographic angle was not fixed, the pattern which was contingent on the differences in the identical pins could have been the result of either the rotational forces or the position from which the photographic shot was taken. This difficulty is inherent in projecting a 3-dimensional rotation on a 2-dimensional plane. Also, in analyzing the positioning of the pins in growing bones, standardization of the pins is necessary to account for the differential deviation resultant not only from the imposed torque,

but also from marked elongative and radial growth forces. Adhering to a specific anatomic exposure view would eliminate these discrepancies.

CONCLUSIONS

With further research and development, Xeroradiography seems most applicable to studying stresses in bones; particularly because of its ability to delineate soft tissue and fine bone detail well. It also is a non-invasive method requiring equipment currently used in the medical field and additional equipment which can be leased from Xerox corporation. The only apparent difficulty with Xerography is the high radiation dosages it requires.

COSTS

    Xeroradiographs = X-ray   @$10-$15 per shot

    Xeroradiographic equipment
    rental (includes 100 images
    at @$.68 per image) $475 per month

RECOMMENDATIONS

(1) Follow-up studies on the Dennis Browne-type splints for investigation of the changes in the natural compressive properties of the bone due to the application of an abnormal correctional torque and to note possible long range effects on bone stability after use of this correctional device during infancy.

(2) Experimentation similar to that performed, establishing a control position, preferably by device, to photograph both the X-rays and the Xeroradiographs if taken.

(3) Investigation into Xeroradiography for bone studies, especially in infants: X-rays are useless in early infancy because of the (unossified) soft-cartilaginous-like material. The correction of congenital abnormalities is a possible application.

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THE FOLLOW-UP EFFORT

The problem entitled "Surface Potential Profiles" has benefited from an intensive follow-up effort and is beginning to assume very encouraging direction. The funds and guidance needed to carry out this follow-up are being provided by Dr. Eugene Fischman. A proposal to continue this problem, with NASA's active and financial support, was submitted in early fall, 1973, and it is apparent that the requested level of funding will be forthcoming.

The other four (4) problem studies were initiated in the Summer Institute without the benefit of preliminary funding or readily available funds for desired follow-up studies. For these reasons, along with a lack of properly trained personnel to carry out the activities, continuity on these problems was lost. Discussions are in progress with the Technology Utilization Officers at Goddard to determine what we might do to reactivate the studies and to circumvent this matter in any future Institute.

COMMENTS

There is little doubt that the concept of this Institute is unique and interesting. To date we (the Howard University - NASA program) have afforded twenty young engineering/science students the opportunity to enter into some exciting and novel research. The comments by these students have, for the most part, been very favorable. In several cases this experience has served to enhance the students employability or aided in their admission to graduate, and medical study programs. Educationally, therefore, we have undoubtably performed an extremely valuable service.

The idea of the Summer Institute was put forth to some of the fifteen hundred conferees at the 26th Annual Conference on Engineering in Medicine and Biology, in a paper[1] delivered at one of the sessions. The Institute, its structure and its solid potential as a mechanism for educating were well received by those in attendance. This served to reinforce the belief that the two program objectives (see page 2), relating to the novel research opportunity afforded students along with the provision of a means for encouraging cooperative efforts between engineering and medical persons, have been adequately met.

The questions raised by the remaining objectives, namely (a) does there exist a way to significantly reduce the time delay between the delivery of clinically testable prototypes, following the original concept and (b) is it feasible to efficiently transfer space technology, via NASA-based knowledge, to problems in medicine and related areas, have yet to be answered. Although the reasons for non-conclusive answers are diverse it is possible that one can be pinpointed. This reason is central to the age old problem of the commitment of funds.

As mentioned previously, discussions on how to most effectively affect the follow-up effort are in progress. The keys to this effort are thought to be money and personnel. Although we have not settled on the measure to be attributed to each of these factors, in assessing the success of our program, we feel certain these parameters are critical.

As to the roles of the participating organizations, it is felt that each occupies a unique position and must play equally unique roles in the Institute future efforts. One must keep the goals of the Institute in mind and call on each member of the partnership (NASA and Howard) to maximize their contribution as each is best suited to do.

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[1]DeLoatch, E. M.; "The Investigation of An Aspect of the Medical - Technical Interface Employing An Interdisciplinary Model Team Approach," Proc. of the 26th ACEMB, Minneapolis, Minn., 1973.

The University in keeping with its function should be able to identify the personnel needed to study the problems initiated in the Institute. Following the identification of this personnel type and the assessment that the studies to be effected are significant and in harmony with the University's mission, every effort to accommodate this program must be made. In this light much has been accomplished. The medical doctors who have worked with us have displayed a complete willingness to cooperate, and a sincere desire to provide the information needed for success by their technical counterparts.

It needs to be recognized that with all the cooperation of the medical doctors, there is a place where their contribution to technical-based problem solutions must necessarily become minimal. It is at this point that engineers and their technicians must take over. Along these lines, when we have lost our summer engineering students, we have, for the most part, lost continuity in the problems being studied. To date the engineering personnel available at the University has not been adequate to fill this void. This situation must be remedied, in the future, if valuable time is to be saved in the development of clinically testable medical device and system prototypes, and if supportive arguments are to be made relative to engineering ability to contribute to reducing the nation's crisis in health care delivery.

The National Aeronautics and Space Administration has been very instrumental in providing the initial funding and facilities for beginning studies under this program. Without their support we could not be at this point in our discussion with substantive data concerning engineering's potential to provide feasible solutions to problems found in the medical environment. At the same time we see that the point at which we should cease soliciting NASA's aid is not yet near while our present needs are much in excess of the funding being afforded for the three month Institute. The technical advisors, the laboratory facilities and the administrative suggestions afforded by the NASA effort are indeed valuable to this effort. However, the future of our efforts are in line for serious questioning if an improved mechanism for additional funding is not developed.

The most critical area of support for additional funding are (a) the salaries and wages of technical (engineering) personnel as identified by the University and (b) the monies for laboratory materials, supplies and fabrication costs to assemble and test clinically applicable prototypes. Without continuity in these areas of funding momentum is lost, and the continued cooperation of participating medical personnel is seriously jeopardized. We must not underestimate the potential risks involved in this latter statement.

In summary, it is felt that the program of the Summer Institute, whose success depends on serious cooperation between the medical and technical communities,

has come to a serious crossroad. What was started as a modest venture has the potential to provide some critical answers to pressing problems concerning our nation's health care services. We are most desirous of providing those answers and we can do so only if the participating members (NASA - Howard) in this venture decide to make a firm commitment to this endeavor. This commitment will be best manifested by a supporting role consistent with the character of each participating organization to the maximum level at which the Institute can practically transform these inputs into significant and meaningful results.