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7/25/68

THE SYNTHESIS OF A MOBILE COMPUTERIZED HEALTH TESTING SYSTEM

A THESIS

Presented to

The Faculty of the Division of Graduate

Studies and Research

by

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

In the School of Industrial and Systems Engineering

Georgia Institute of Technology

June, 1971

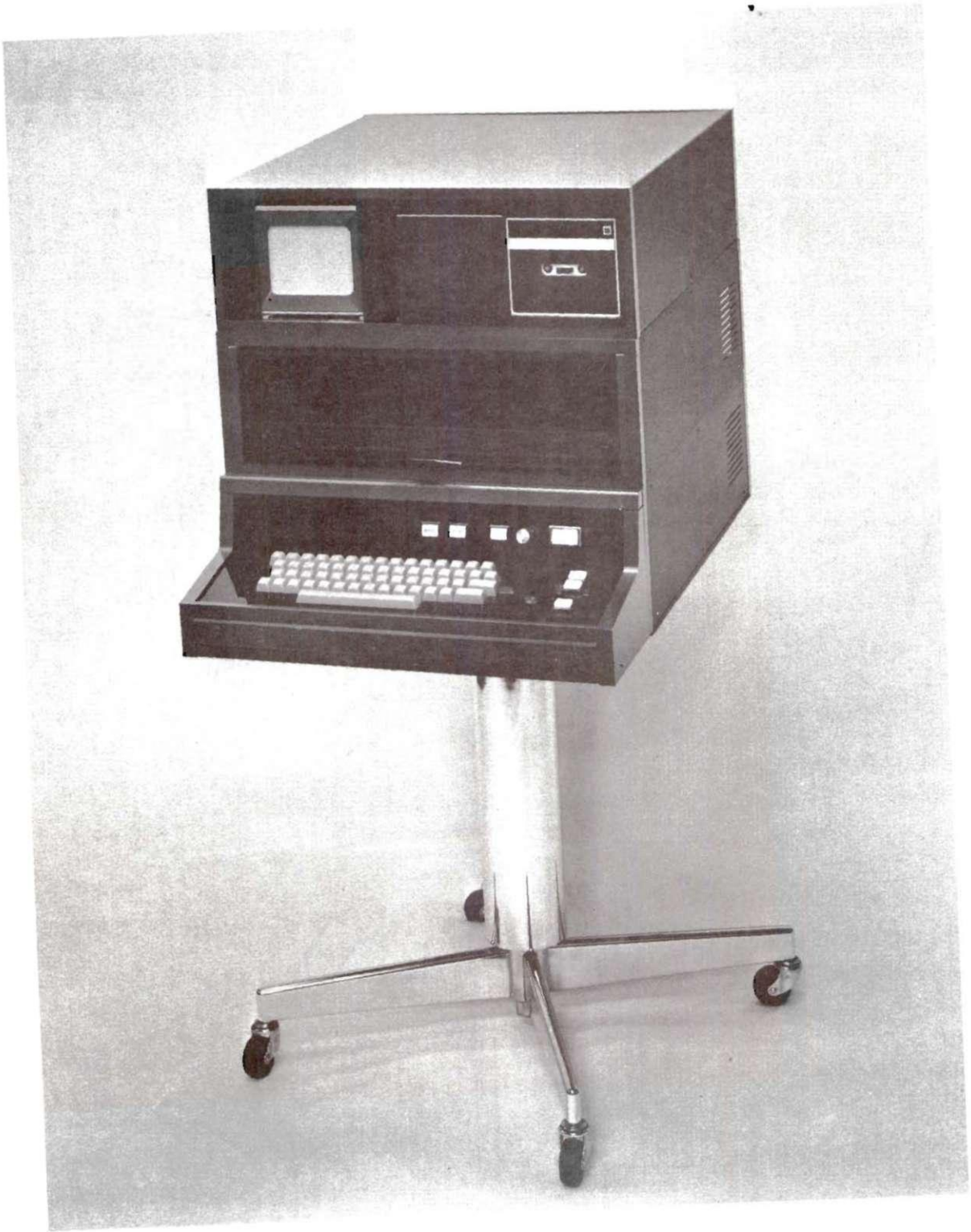
THE SYNTHESIS OF A MOBILE

COMPUTERIZED HEALTH TESTING SYSTEM

Approved:

Chairman

Date approved by Chairman: Aug. 27, 1971



PREFACE

This thesis represents a system design study wherein the auth r had the unique opportunity of not only experiencing, but in being a prime motivational factor and designer for a project from the time of its inception through development and the first engineering prototypes. Though this system is not yet into production, three of these four major hurdles following the conceptual idea have been passed: breadboard, prototype, engineering model, production model. The brochure in Appendix A shows the prototype.

Background

The medical concepts used in the system have been proven and tested over the past six years by the research staff of Dr. Homer R. Warner in the Latter Day Saints Hospital, Salt Lake City, Utah. Their system, called "MEDLAB" for medical laboratory, is centered around two medium sized, time shared computers: a CDC 3200 and a CDC 3300. Each has access to a common set of disks, tapes and a 16 channel analog multiplexor with an analog to digital converter used for real time data sampling. Up to 12 remote stations with CRT displays can operate concurrently. The tests involve pattern recognition, mathematical calculations and data analysis in the areas of pulmonary function tests, ECG interpretation, cardiac catheterization, Intensive Care Unit (ICU) monitoring and clinical lab data collection.

Two major problems arise with the use of the MEDLAB system:

(1) Control. Since the system is considered to exist primarily for the sake of research, a medical researcher debugging from the console can, and does regularly "blow the system" about twice a day. An efficient autoload recovery capability has been built in which brings the monitor back to normal within about 30 seconds, but in the process, it clears out all the application programs currently being run. Medical doctors using the system via a remote terminal in another hospital or distant city are not very understanding of explanations why their active data has been lost.

(2) Cost. The MEDLAB system operating in Salt Lake, and the two similar systems being installed in Washington D. C. and Ann Arbor, Michigan are sponsored by the National Institute of Health research funds. As an independent commercial venture, MEDLAB could not be self-supporting in its present configuration, although a new company was recently formed which hopes to capitalize on the concept through the addition of remote CDC 1700 computers for data collection and terminal control.

Bio-Logics determinded in the spring of 1969 to develop their own equivalent of MEDLAB, utilizing the proven medical techniques, but achieving greater reliability and lower cost. It was decided that a dedicated minicomputer could handle any of the medical subroutines if taken one at a time; the hardware would be under complete control of the user; the system would be priced low enough that even a small hospital or clinic could afford it. With a low cost per system, additional reliability could be obtained by having two or more complete systems in different departments within the same hospital. In the event

of a hardware failure at a critical time, a system from another department could be borrowed and loaded with the appropriate software, reducing the normal delay time for repairs.

Though the project was originally conceived as a commercial, money-making venture for medical applications only, the resulting system is ideally suited for general purpose research in other fields requiring online, realtime data acquisition and analysis. The magnetic tape cassette and CRT output are ideal for one-time programming jobs which occur so frequently during engineering design or "rough approximation" analysis of complex statistical data. Three high level languages are available for this: ALGOL, BASIC and FORTRAN.

Being the first person to start the project, it was the author's responsibility to do a feasibility study, initiate the selection and design of the hardware required, and determine the specifications of the overall system. After these steps were completed, a choice was given to supervise either the hardware or the software development and the latter was chosen. The combined group of design engineers and programmers grew to 13 people.

Because of the indicated interests of the thesis advisory committee and the role fulfilled on the project, the view of the system is slanted more toward the hardware and software development, than toward the medical and mathematical pattern recognition techniques which were developed by others.

Acknowledgement is given to Gale H. Thorne, whose idea sparked the original feasibility study; to Homer R. Warner and the MEDLAB system at LDS Hospital, Salt Lake City, on which the medical

hypotheses were tested; to Warren Johnston, President of Bio-Logics, whose financial and administrative backing made the project possible; to Ron Davies whose ideas helped create an attractive, efficient package; to Dr. David K. Johnston and Richard Rowland who served as project managers; to Dr. W. W. Hines and Dr. Stephen L. Dickerson whose aid in getting financial assistance made attendance at Georgia Tech possible; to all the great professors throughout the different departments at Tech whose innovative ideas gave me the initiative to attempt an interdisciplinary thesis in the first place; to my thesis advisor Dr. Joseph J. Talavage and my thesis committee, Dr. Leslie G. Callahan and Dr. Thomas L. Sadosky. Most important, I wish to thank my wife, Gayla, who served as a sounding board, consultant, typist and editor, all in one sweet package.

Steve Stumph

June 1971

TABLE OF CONTENTS

Chapter

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

Through the limited scope of this project, it is possible for an individual to comprehend a system design in its entirety.

The systems engineering approach is used in examining the trend toward automation in hospitals. Based on the premise that automation can curb the rising cost of personnel in the health care field, an analysis is made of what type of physiological measurements are suitable for linkage with a computer; specifically a minicomputer. Consideration is made of the interdisciplinary aspects required in the development of a marketable system, which serves a needed purpose, and provides a profit to both the seller and the user.

Systems engineering is discussed. This is a loosely defined discipline, and a stand is taken using the methodology described by Arthur D. Hall in his book entitled A Methodology for Systems Engineering. His ideas of systems engineering are discussed in relation to the examination and diagnosis of a patient.

An idea is borrowed from management science and carried throughout as a major theme. In the synthesis of a new system, an analysis of the problem is made first. The system analysis starts with the major system and works down toward smaller and smaller subsystems. The actual construction and synthesis proceeds with an integration of the smallest components into larger and larger subsystems until the final system is complete.

The variations inherent in physiological measurements are discussed along with the general capabilities required of data collection hardware and mathematical analysis algorithms used for medical applications. A step-by-step analysis is made of the hardware components required to make up a subsystem. This is followed by a description of typical problems which occur during integration and synthesis of the larger system. The interdependence of system programs, along with the hardware and the actual health testing application programs, is pointed out. The resultant system presents a simple outward appearance to the operator even though the internal components are quite complex. Considerations are made for such things as human engineering factors in packaging and interactive CRT messages which are self-explanatory. These messages give notice of options for action to be taken next by the computer. Analysis and synthesis techniques similar to those used with the hardware are also used for the software.

The operation of several health testing programs is discussed, including pulmonary (lung) and ECG (heart).

The appendix contains photographs of the prototype hardware and a summary of software programs.

CHAPTER I

OBJECTIVES

1.1 Introduction

This thesis presents a design which was originally conceived at Bio-Logics as an equivalent of MEDLAB*, utilizing the proven medical techniques, but with greater operator control and lower cost than the original. However, the basic components of the system can be used for more than collection and analysis of medical data. The combination of data collection hardware and system software can provide an extremely powerful tool in the hands of a competant researcher or engineer who wants to do interactive data collection and analysis. Someone has suggested the possibility of doing statistical data collection and analysis of psychological experiments. Another possible application of the system is irrigation and crop control. In addition, the system shows promise of filling the gap between the simple problems which can be done on a hand calculator and those which require the high speed and large storage of an all purpose machine such as the Univac 1108 or Burroughs 5500.

Since the medical and mathematical pattern recognition techniques have already been proven, a postmortem analysis will be

*MEDLAB, meaning medical laboratory, collects physiological data and does a partial diagnosis of the irregularities. The system uses a CDC 3200 computer under the direction of Dr. Homer R. Warner, Latter Day Saints Hospital, Salt Lake City, Utah. Further discussion can be found in the preface.

avoided by concentrating on the hardware and software synthesis, pointing out their general applicability.

1.2 Problem Statement

The objective of this thesis was to design a general purpose data collection and analysis system for hospital use. A dedicated minicomputer, is used to detect lung irregularities and perform ECG analysis. The system may also be used for patient monitoring in Intensive Care Units or for automatic data collection in a clinical laboratory.

Part of the thesis research was to examine the available minicomputers and select one which would suit the purposes of this health testing system. Criteria for the selection were cost, instruction capabilities, updating flexibility and "state of the art" hardware. Ancillary equipment selection was also made and included such things as an analog to digital converter, real time clock, keyboard, CRT display, and hard copy output.

A design of system software routines was made; their primary purpose being to simplify the interface of the applications programs and the hardware. The routines provide efficient machine language use of hardware capabilities, yet appear as high level "macro" instructions to the programmer.

The final objective of the system was to provide an easy to use tool with which a physician could apply diagnostic algorithms, such as those used by MEDLAB, to improve the accuracy and speed of his diagnosis.

1.3 Aspects of System Building

The procedure for building a system is: 1) design and build the components, 2) combine the components into a subsystem, 3) synthesize and integrate the smaller subsystems, and 4) synthesize and integrate the larger subsystems. In order to design the system, the designer must first visualize the entire system and analyze the required characteristics to determine the specifications. This in turn defines how the components will be built. As phrased by Dr. Philip Adler (Georgia Tech), "The system is not viable without its components, for without the components, there is no system."

A dichotomy exists in the system design procedure wherein a system must first be analyzed from the top down (in order to determine the interdependency of the components), yet the construction and synthesis of components must be made from the bottom up. One cannot build a house without first building the foundation, but the strength designed into the foundation depends on what kind of house it is to support.

The system design problem is analogous to the one faced by a forester who wishes to plant trees. He must first look at the overall forest (composed of land, water, air, etc.), then analyze what he sees before making a decision of what kind, how many, and where the trees should be planted.

A measuring system must be defined to develop the components used in building the subsystems. This aids in determining the interdependency of the components. The measuring system requires at least two elements: one which is measured, and one which does the measuring.

A standard of performance determines the criteria, parameters and constraints of the system. Recognition of the level of component interaction is vital to the system design, just as a spoke is a subset of a wheel, and not of a chassis.

In this thesis, an attempt is made to coherently present the pieces of the system first, then show how they are combined in a synergistic way to produce a comprehensive whole which is greater than the sum of its parts.*

1.3.1 Interdisciplinary Aspects

Borrowing a concept from management science, a system model can be considered as a inverted "cone of resolution," shown in Fig. 1.1 (1). From the manager's point of view or that of the system designer, the organization or system is viewed from the top down. At each level, greater detail is observed, but the breadth of view is reduced. An analysis of each subsystem (component) is made from the top down. Looking down, a manager or designer can more efficiently develop and relate the components. He performs both vertical analysis and horizontal analysis. After the analysis is made, the development and construction of the system follows from the bottom up.

Since every system can be considered a subsystem of an even greater system, all systems are open-ended. Therefore, there must be other subsystems at the same level. Every system is open except

*Synergy comes from an exceptionally efficient integration of components. Not all systems are synergistic, but occur when the system's components interact in a particular manner to give something greater in value than the normal summation of the parts. This idea of synergy is gleaned from the Management 613 class taught at Georgia Tech, by Philip Adler, in the spring quarter of 1971.

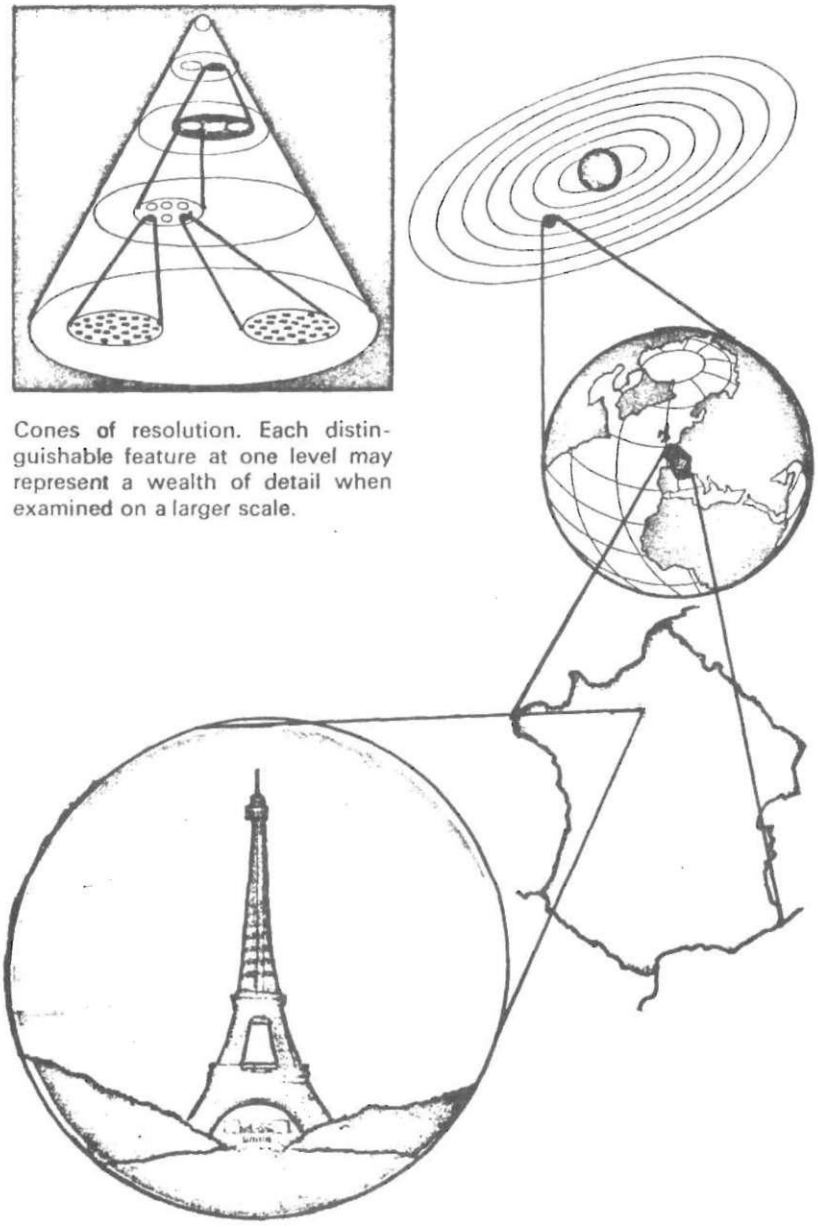


Figure 1.1. Cones of Resolution.
(after Beer)

at infinity. In the systems analysis, the system must be closed for study, high enough to get a handle on what is being studied, yet low enough to be meaningful. Figure 1.2 illustrates the subsystem analysis of the Health Testing System. Interdependent components exist at each subsystem level. The analysis, going down, includes all components shown in Fig. 1.2, but the HTS synthesis goes up, only as far as the computer. The higher level integration is a function of the medical management.

This thesis attempts to use an "inter-disciplinary," as opposed to "multi-disciplinary" approach to the solution of a system design problem. A multi-discipline solution is one in which designers from various disciplines get together momentarily, then each goes back to his own specialty to perform his portion of the task in his own particular way, with little consideration for the interaction with other disciplines. On the other hand, an inter-disciplinary system considers how the various disciplines will interact with each other. It also allows for modification (sub-optimization) of a particular component in order to accommodate a significant improvement in another component. For example, the HTS contains some redundancy in the "Program Selection Switch" functions (engineering hardware) to allow easier system operation for the user (behavioral aspects).

During the integration of components, human factors engineering is used to make the system functional and easy to use. The medical aspects require consideration of patient safety, e.g., electrical shock can be a hazard and must be prevented. Packaging

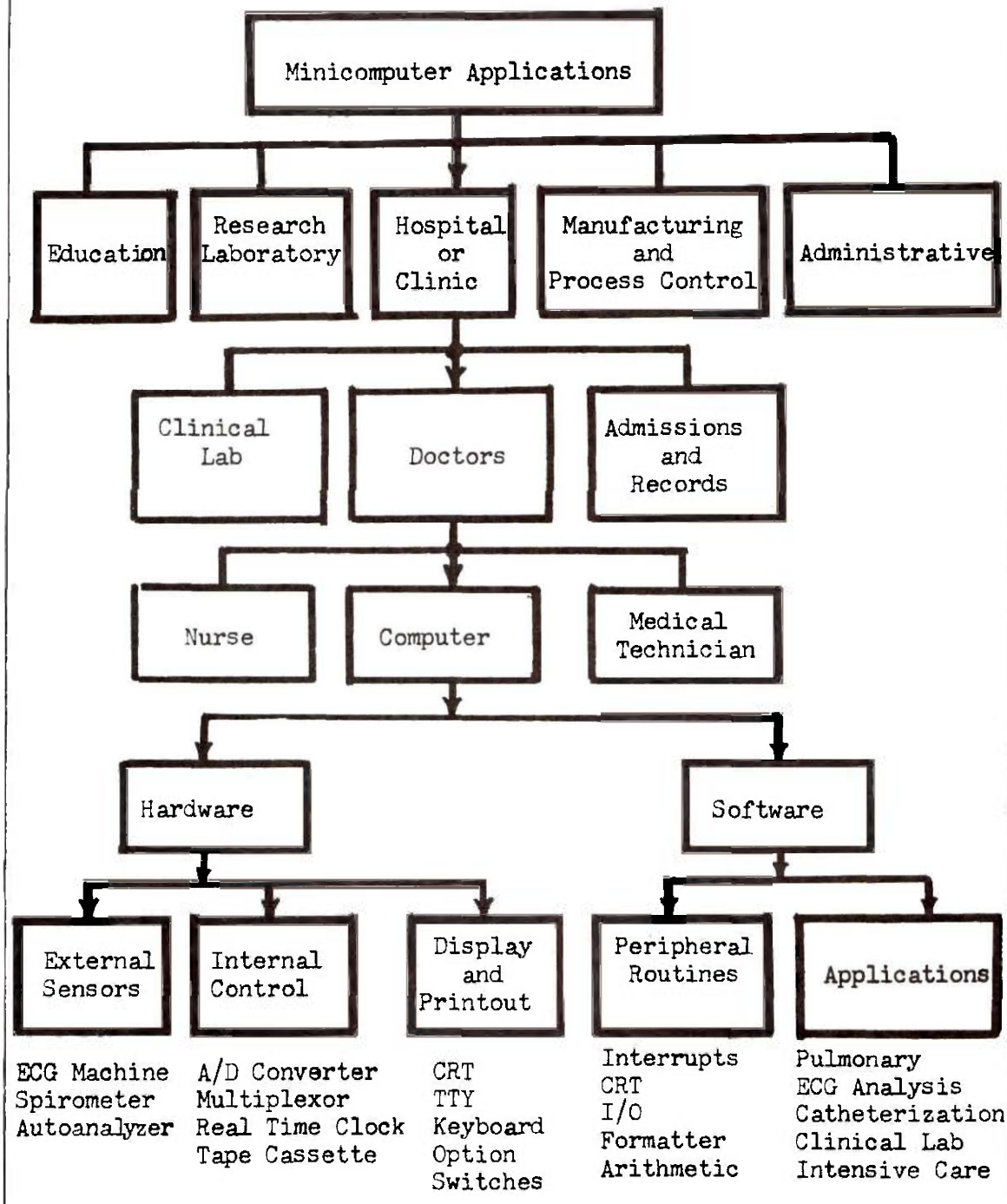


Fig. 1.2. Health Testing System Analysis of Component Levels

must be durable to allow movement over the threshold of elevators and allow for sterilization with harsh chemicals. Hardware design combines both electronic engineering and mechanical engineering. Mathematics and computer science are used for software development. The profit motive of business requires economic and marketing considerations to be made. The linking thread of commonality between disciplines is the industrial and systems engineering approach which ties everything together as illustrated in Fig. 4.1.

1.4 Systems Approach*

Systems Engineering Definition:

> Systems engineering emphasizes the coordination of man and machines in complex arrangements. It is largely a development of the last 25 years and has received impetus from the building of defense systems and the rapid development of other forms of modern technology. Computers and automated equipment play a role in virtually all systems engineering efforts (2).

The systems engineering approach is a step-by-step procedure where a project is designed through its entire life cycle and includes concept formulation, system definition, acquisition, operation and phaseout. Some engineers maintain that this method of project organization is nothing more than good, but ordinary, engineering sense. They're right, up to a point, but a unique characteristic of the prodess is the assignment of numerical values to certain system elements in deciding tradeoffs (3).

---

*Because the "systems approach" to problem solving is a loosely defined discipline, with as many definitions as there are people working in the field, Hall's book entitled A Methodology for Systems Engineering is used as a standard for defining the various steps involved.

1.4.1 Definition of the Problem and Objectives

> The problem definition is isolating, possibly quantifying, and relating that set of factors which will define the system and its environment. Since a problem is an outward expression of an unsatisfied need, the job is to find what the need really is. This means gathering and analyzing data to describe the operational situation, customer requirement, economic considerations, policy, possible system inputs and outputs, etc. (2).

In this particular case, the problem is a shortage of skilled medical personnel and the high cost of diagnosis and treatment of disease.

For years, the answer has been to add more staff assistants and increase the efficiency of the physician by having a number of patients wait in a queue while he visits each one in turn for a short time interval. The medical community has eliminated the traditional house call in an attempt to reduce the wasted travel time of its highly skilled and highly paid physicians.

Unfortunately, the point of diminishing returns is approaching and the medical profession is unable to significantly increase the productivity of a physician by decreasing the time interval spent with each patient. It has become economically desirable to look for an automated or semiautomated procedure which will increase the productivity of physicians. Two areas where this can be beneficial is in the actual measurement of physiological data and in the data analysis which results from a search for probable causes of irregularities.

Measurement of data has been automated in the clinical laboratory for a number of years. Photoelectric chemical measurements produce more accurate and more consistent results of blood tests and

urinalysis than can be done by hand. However, the analysis phase is almost entirely neglected. Until recently, there was neither the necessary computer hardware available, nor the mathematical techniques for reducing the data. Now both are feasible.

> Selecting objectives is the logical end of problem definition. The objectives chosen guide the search for alternatives, imply the types of analyses required of the alternatives, and provide the criteria for selecting the optimum system (2).

This thesis describes a feasible, though not necessarily optimal, system which collects and analyzes physiological data, then generates a report for use by the physician. The methodology for optimal system design of this type is not yet available (4).

1.4.2 Synthesis of Alternatives

> Systems synthesis entails compiling or inventing alternative systems which can satisfy the objectives. Each alternative must be worked out in enough detail to permit its subsequent evaluation with respect to the objectives and to permit a decision as to its relative merits for possible development (2).

Alternatives for medical data collection and analysis.*

1. A physician measures the data, performs the analysis and diagnoses the problem.
2. A technician or nurse measures the data; a physician analyzes and diagnoses the problem.
3. An automated machine measures the data; a physicain analyzes and diagnoses the problem.

*It is assumed that neither the technician nor the machine is sufficiently skilled to completely diagnose or prescribe treatment. Generally, a technician is not as skilled, fast or accurate as a computer in doing data analysis and correlation.

4. A machine measures the data and analyzes it; a physician diagnoses the problem:
   a. The data is collected first, then entered manually into a computer for analysis. This can be done either by batch processing or by time sharing (remote computing).
   b. Data collection instruments are connected directly to the computer. The collection and analysis is done in real time. This can be done either on a time shared system or on a dedicated minicomputer.

1.4.3 Evaluation of Alternatives

> Systems analysis means deducing the consequences of the entire list of hypothetical systems. The deductions relate to system performance, cost, quality, market, etc.
>
> Selecting the best system involves evaluating the analyses and comparing these evaluations with the objectives to select the smallest possible subset of alternative systems which merit further study (2).

The first two alternatives of the previous section represent the traditional, manual methods which are acceptable in a slow moving, low volume environment. The third alternative, using automated measurement and manual analysis represents the current level of automation in most present day hospitals and large clinics. ECG machines, and blood chemistry autoanalyzers are typical.

Considerable research has recently been done in automated data collection and analysis. Dr. Morris F. Collen at Kaiser Permanente Hospital in San Francisco has worked extensively in the area of patient history taking and correlation of disease history. He has designed

and built a large multiphasic screening facility (5). Dr. Homer Warner at the Latter Day Saints (LDS) Hospital in Salt Lake City has developed pattern recognition techniques for lung volume-rate tests and for ECG analysis (6).

1.4.4 Communicating Results

> Communicating results is the final function in this phase. The function may call for a formal report which draws one of three conclusions: 1) that specific development will solve the problem, 2) that exploratory development in the laboratory is needed on particular alternatives before a sound conclusion can be reached, or 3) that no further work is justified at this time (2).

The first conclusion was communicated to management prior to the design which resulted in this thesis. Initial development proved that use of a minicomputer was both feasible and practical. Refinement steps are now being undertaken to prepare the engineering prototype for production. Software development and expansion is expected to continue for the life of the product, which is estimated to be 10 years.

1.5 Significance of the HTS

As mentioned earlier, multiphasic patient screening systems have been developed at various hospitals around the country. The computer approach has been recognized for well over 12 years as offering the ultimate solution to massive data collection, analysis and eventually diagnosis. However, in each of the installations which attempt a complete health care system, the approach has been through the use of large, powerful computers used on a time shared basis. All these systems have in common the inherent problems of

user control and cost which originally motivated the development of this HTS based on the use of a minicomputer.

Two fine examples of minicomputer use in a clinical laboratory interface are found at Boston General Hospital and at Perth Amboy Hospital in New Jersey. A recent minicomputer system which combines the cardio-pulmonary functions can be found at Harbor General Hospital in Torrance, California (7). A new catheterization system has been announced by Hewlett-Packard (8), developed in a joint effort with Stanford University Medical Center, which adds to their already portable ECG family of products which includes the Model 1500A portable electrocardiograph (9).

After a thorough investigation of the literature of the field, including recent sales brochures from manufacturers, it is the author's opinion that this Health Testing System, is the first of its kind which attempts a solution of the complete health care system using a minicomputer. While there are numerous systems which perform one or some of the functions handled by the HTS, they are limited in scope and expansion capabilities. They also lack the mobility characteristic of the HTS which allows use of the basic system in multiple locations, without requiring special electrical wiring in the facilities or moving crews for relocating the equipment.

CHAPTER II

AUTOMATION IN MEDICINE

2.1 Needs of Hospitals, Clinics and Private Practice

> ...It is easy for the man who has never used a motorcar to argue that he does not need one because he never travels more than a few miles. But once he has learned to drive, a new dimension of interest and opportunity is opened up, and so it is with the computer. Just as the most arthritic person who can drive can achieve far greater mobility than the finest athlete who cannot, so the most humble doctor who can 'drive' a computer will achieve far greater mental mobility than his brightest colleague who cannot (10).

It is apparent to both the medical practitioner and layman alike that something must be done about the rising cost of medical care. Medical costs over the past 20 years have risen significantly more than the prices for all other items on the consumer price index. Since 1966, hospital prices have risen at a rate of about 15 per cent per year, and other medical care components have risen about 6 per cent. With reference to the Gross National Product, the proportion spent on health care has gone from 4.6 per cent in 1950 to 6.5 per cent today. That's over a 40 per cent increase, and it is expected to climb (11).

The concern about health care costs is widespread. In the summer of 1969, President Nixon released a "Report on Health Care Needs," in which he forecast a "massive crises" within the next two or three years unless prompt steps were taken. Among the items for which he requested immediate action was the encouragement of "preventative services, to provide incentives to keep people out of hospitals" (11).

Since not everybody who is sick needs to go to the hospital, it is logical to provide more extensive services for outpatient care. Services requiring highly skilled personnel or expensive equipment are often made available only to bed patients. Examples of these are clinical laboratory tests of blood or urine, electrocardiogram (ECG) analysis, and pulmonary function analysis. If more of these tests could be performed outside the hospital, those patients requiring only minor treatment such as a prescription or rest in bed, would not require hospitalization. Another case is when a patient spends several days in the hospital, waiting for a minor operation such as a gall bladder removal. Laboratory tests are required, but otherwise the patient could just as well be "resting in bed" at home, saving himself money and relieving the hospital staff of some of their more mundane duties.

In addition to moving some of the medical services outside the hospital, much of the staff workload can be relieved by automating the routine or repetitious screening and admission tests required. Automation is one way to combat rising personnel costs. Lower skill levels are needed to perform the functions traditionally reserved for a highly skilled and highly paid person.

2.2 Blood Chemistry Analysis

A major step was made in this direction a few years ago when Technicon introduced a 12 channel autoanalyzer for performing blood chemistry tests. Prior to that time, a highly skilled (usually college level) medical technologist was required to perform hundreds

of repetitious chemical analyses each day. Now the autoanalyzer performs 12 tests per minute and requires only that someone keep track of whose test is being plotted on the chart at any particular moment.

2.3 Patient Monitoring

Another area where automation has made its first steps forward is in the area of Intensive Care Unit (ICU) patient monitoring. In the MEDLAB system, the program monitors 10 basic physiologic variables in postoperative cardiac patients. Stroke volume (SV), heart rate (HR), ratio of the time of appearance of maximum pressure to the duration of the heart cycle (TMAX), peripheral resistance (RST), systolic pressure (S.P.) and diastolic pressure (D.P.) are calculated from the time-course of aortic pressure. The average central venous pressure (V.P.), its respiratory excursion (or respiratory amplitude, R.A.), and the respiratory rate (R.R) are calculated using the time-course of central venous pressure. The two signals are the outputs of small pressure transducers which are connected to indwelling arterial and venous catheters. "The system is currently used routinely by the surgeons and nurses for monitoring cardiovascular functions and entering nurses' notes for each patient on the intensive care ward (12)."

Similar procedures have been initiated for patient screening prior to hospital admittance and for fluorscope analysis of the dye dilution test used in cardiac catheterization (13).

A number of approaches have been used in solving the catheterization problem, but most rely heavily on large scale systems,

often using a small computer such as the PDP-8 or IBM 1800 for such simple tasks as analog to digital conversion and switching of the larger system from control of one piece of equipment to the next (14).

2.4 Computerized Record Keeping

The extensive filing capability of computers is an obvious step toward automation in hospitals. One of the best systems incorporating these capabilities with patient admittance has been installed in the Kaiser Foundation Hospital, San Francisco. The admittance procedure requires a patient to pass through a total of 14 stations, filling out information and submitting to a wide variety of tests such as ECG, visual acuity, hearing, blood chemistry, body measurements, pulmonary function and a medical questionnaire (5).

2.5 Future Developments

In addition to the bedside monitor which now exists for critical patients, new techniques developed by the Apollo space program will allow a basically healthy patient to carry out his everyday tasks with electrodes, either implanted or attached to the skin, monitoring his vital functions. Telemetry equipment might be employed to monitor mobile patients or for research purposes (15). Of course one cannot help but consider the awesome responsibility implied by the possibility of using such implanted devices for the science fiction control of human robots.

Statistical correlation of various symptoms leads one step further toward the day of "computer diagnosis." An information system called MEDATA was developed for this purpose at the Hollywood

Presbyterian Hospital and has been used extensively for the Apollo flight series (16).

The RAND Corporation has done extensive work with mathematical modeling of biological systems (17). They are solving up to 200 simultaneous equations, which was not considered possible prior to 1955. Their work can lead to a better understanding of individual organs, such as the kidney, which can then lead to better kidney machine design and even the development of artificial organs.

CHAPTER III

ENGINEERING CONSIDERATIONS OF PHYSIOLOGICAL MEASUREMENT AND ANALYSIS

3.1 System Considerations

A Health Testing System (HTS) should complement, rather than attempt to replace, the skills of a medical worker, either a doctor, a nurse, or a laboratory technologist. One should therefore consider the kinds of things people can do well and the kinds of things machines do well. Machines are best at performing high speed, repetitious tasks with extremely low error rates compared to their human counterparts. On the other hand, humans do well at analyzing and correcting unexpected or unpredictable one-time situations.

In the first analysis of a potential system, consider a machine which will be used to collect data and perform any required arithmetic operations. A human operator will be used to pass judgement on the validity of tests. The validity will be based, in part, on whether the results look "reasonable" for the particular set of circumstances, and whether the operator judges the equipment and patient to be interacting properly.

Since virtually all physiological measurements made on a human body are of a continuous analog form (with the exception of such things as blood cell count), the instrumentation must accept analog signals. Though other mediums can be used, the signals are most often represented

as electrical signals and may be detected directly, as with ECG and EEG, or converted through the use of an electromechanical transducer. If a digital computer is to be used, some form of analog to digital conversion will have to be made.

An analog computer can provide the necessary precision and does not require conversion to a digital value before performing its calculations. However, it is lacking in the number of sequential tasks it can perform, and it is difficult to change programs. If a graphical output is desired, it is ideal, but most physiological data is more understandable in discrete units, e.g., beats/minute, mm of mercury, per cent, etc. For the extensive calculations to be made during analysis of an ECG, an analog computer would have to be too complex. One might consider a hybrid combination, using an analog computer for such things as peak detection and removal of "baseline drift,"* with the digital computer performing the other calculations. The advantage of this method were not pursued for this HTS, but may provide a significant improvement on a follow-up system.

If the first iteration assumes the system will have a high speed Analog to Digital Converter (ADC) and a digital computer, there are two things that it can do very well. It can convert a voltage from an electrical transducer to a digital value and it can solve the required

*Baseline drift is equivalent to a slowly changing DC bias superimposed upon an AC signal. This often happens with ECG (Electrocardiograph) analysis, since the electrical signals of the body are extremely low (millivolts) and any stray radiation fields, such as from flourescent lights and wiring tends to induce a small static charge on the body. Interference is typically produced at a 60-cycle rate and causes a continuously wandering baseline on the ECG graph. Clever sampling techniques, using a sample rate which is a multiple of 60 Hz (usually 240 samples/sec.), can reduce the effect of this drift.

equations at a high rate, without calculation error.

3.2 Precision vs. Accuracy

Integer numbers are easier for performing arithmetic operations than are fractions. Before using an analog value for calculation, it is usually converted to a decimal value, either mentally or using the computer. One prefers "60 miles per hour" rather than "1/2 full scale;" a voltmeter is read as "115 volts" rather than "3/5 full scale." Fractions are awkward, both for humans and for the digital computer. Likewise, data values which always have the same precision* are preferable to values which vary in the number of significant digits.

In converting from an analog value, one must specify how many digits, or more exactly, how many bits of precision is required after the conversion. The number of bits depends on several factors, the first being the accuracy of the data. Knowing the accuracy of the data, as well as that of the transducers, is important in physiological measurements. Some physiological data sources can change in value by as much as two or three hundred per cent, merely from the insertion of a probe to sample the data. Indeed, this can be compared to an amplified version of Heisenberg's uncertainty principle. A misplaced catheter meant to measure blood pressure within the heart can cause such a radical change in pulse rate. For this reason, a physician desires a

*Precision means "exactly stated," and refers to the number of decimal digits or binary bits used for numeric values in arithmetic calculations within the computer. Accuracy means "free from error," and refers to the measuring instrument capability. For example: 115.500 ($\pm$0.1) volts, has six digits of precision, but only four digits of accuracy. Precision can exceed accuracy, but accuracy can never exceed precision ... 115 ($\pm$0.1) volts actually becomes 115 ($\pm$.5) volts due to roundoff of precision.

real time graphic display of the data, in addition to the calculations presented by the computer.

Even in cases where sampling does not affect the data, the normal values may change radically from day to day. It is wasted effort to measure urea content of blood to three digits accuracy because it may change 30 per cent while the patient is eating. For this data, two digits are sufficient.

Body temperature is more stable. Here is a parameter which is normally read within three decimal digits of accuracy, even with a simple, mercury thermometer. The nurse does not round 98.6 degrees to 99 degrees. However, if the instrumentation is clever, the measuring baseline can be changed from zero degrees (which is an arbitrary value related to the freezing of water), to another arbitrary value more closely related to the temperature of the human body. Then the same accuracy can be obtained with less precision in the sensing instruments: Assume the lowest temperature of a living patient is 96.0 degrees and the highest temperature is 105.9 degrees. Subtract 96.0 degrees from all measurements to obtain a baseline. Convert 98.6 degrees Fahrenheit to 2.6 degrees above baseline. Then the largest measured value will be 9.9 degrees above baseline, and the requirement for three digits is diminished to two.

It takes no brilliant mathematics to deduce the above relationship, but unless one takes an attitude of looking for such characteristics, a great deal of money can be spent for unneeded accuracy in the instrumentation purchased or built. In physiology, relative measurements are usually more significant than absolute values.

3.3 Analog to Digital Conversion

Sometimes three digits must be measured even though only two are needed in the calculations. Consider the lung volume of a large man compared to that of a small child or an infant. If the same spirometer is to be used for both, a large range of measurable values is required. The same number of digits accuracy is desired for one as for the other. However, if this is not practical, it is preferable to throw away the extra accuracy measured on the man, rather than be lacking sufficiently detailed data for the analysis of the child. To meet this requirement, one can choose an arbitrary range of 0-1023 for the Analog to Digital Converter (ADC) and set 1000 equal to the maximum lung volume of the largest man ever expected. For optimum use of the scale, one would use 1023 rather than 1000 for maximum and set the minimum lung volume of the smallest child equal to zero on the ADC. In practice, the child's lung volume is so small that there is little range wasted if the zero value is equated to zero lung volume. The calculations can then be simplified.

Here is how the scale works. A child may have a minimum lung capacity of approximately 0.5 liter, and a very large man a maximum of 10 liters. If 10 liters = 1000 units, then 0.010 liters = 1 unit, and 0.5 liters from the child will give 50 units.

$$0.5 \text{ liter} * \frac{1 \text{ unit}}{0.010 \text{ liter}} = 50 \text{ units}$$

This is sufficient resolution for 2 digit accuracy in the measurements.

The preceding data analysis has shown that the ADC will require

a precision of approximately one part per thousand (three decimal digits or 10 binary bits).

3.4 Data Sampling and Pattern Recognition

One of the objectives of the HTS is to perform real time analysis as the data is being collected. The majority of medical analyses are not based on independent point-by-point calculations, but depend on relative measurements over a span of time. A typical

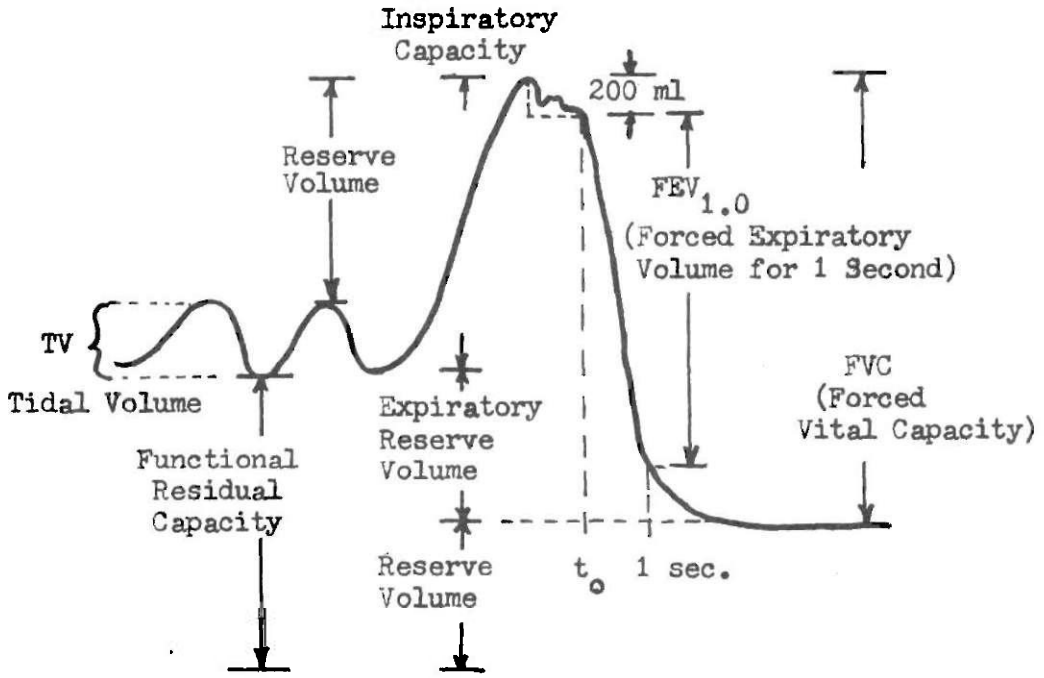


Figure 3.1. Pulmonary Function Tests

example can be seen in Fig. 3.1 where a series of pulmonary function tests are shown. For the forced expiratory volume ($FEV_{1.0}$) test, sampling is begun at the top of the large peak, where the patient has inhaled to maximum lung capacity, and continues for about four seconds

to ensure sufficient data has been taken. The little glitch at the top usually results from the unsteadiness of the patient trying to hold his breath. To eliminate this erratic data, the analysis program must first determine the peak value, subtract 200 ml, find an approximately equal data point at some later time (there may not be an exact digital value from the ADC samples), substitute the exact value of the data point and call it "t_o". The rest is relatively simple. Knowing the number of samples per second which were taken, the program need merely look ahead one second, take the data point, subtract it from the first, and the forced vital capacity has been measured.

Of course, the measured value actually consists of dimensionless, integer numbers between 0 and 1023 from the ADC. That means a lot of scaling and conversion must still be done for even this relatively simple procedure. A simple arithmetic operation like subtracting 200 ml from the peak value can be a major procedure by itself, unless a algorithm such as shown in flowchart form in Fig. 3.2 is used. Note that 200 ml can be converted to approximately 20 units by knowing the conversion factor used in the ADC analysis:

$$0.200 \text{ liter} * \frac{1 \text{ unit}}{0.010 \text{ liter}} = 20 \text{ units}$$

However, this must be corrected by the calibration factors determined by barametric pressure and temperature. Due to the slight oscillations at the top of the peak, care must be taken so that the program does not detect a local peak on one of the oscillations, but will continue looking for an even greater peak if one should occur later.

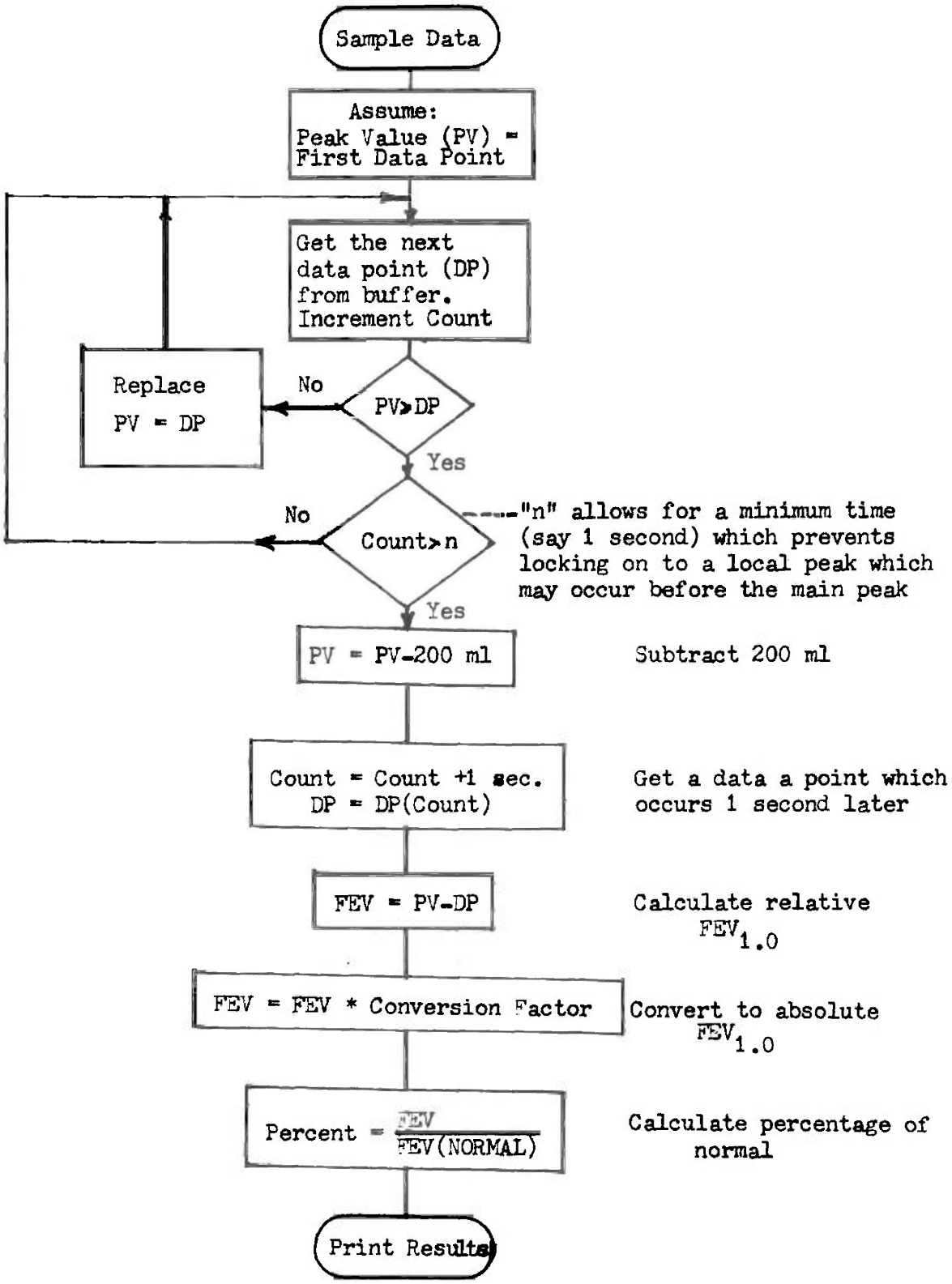


Figure 3.2. Pulmonary Function, $FEV_{1.0}$ Analysis

3.4.1 ECG Analysis

The ECG program has a special case where the first data samples may or may not be valid, depending on what part of the heartbeat cycle the sampling was started. The ECG analysis requires a complete heartbeat pulse of data (about 240 samples x 3 channels) before it can begin the actual analysis. However, it must first detect the "R" peak in the QRS complex (Fig. 3.3) before defining where to start looking at the data for irregularities. After the "R" peak is detected, the algorithm scans backward toward the previous QRS complex; thus requiring the previous data be saved. As will be discussed later in Chapter VI, the analysis requires five sets of data within a 20 second time interval. Drift of the physiology parameters restricts the tests to 20 seconds total.

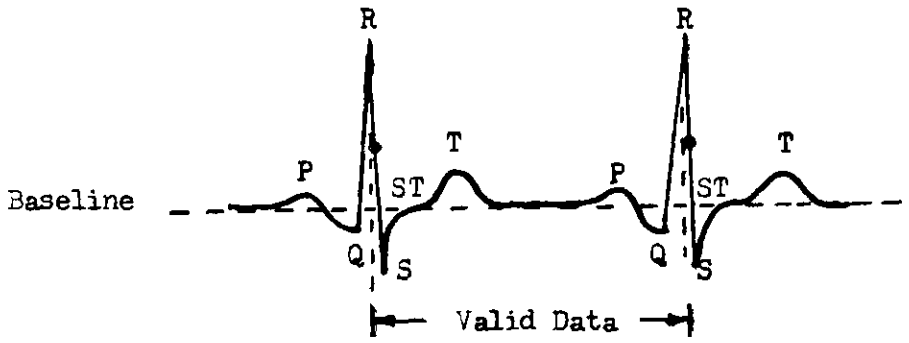


Figure 3.3. ECG Pattern Recognition

CHAPTER IV

HARDWARE CAPABILITIES

4.1 System Analysis

As mentioned in Chapter I, the system analysis is performed from the top down, looking first at the major subsystems and determining their required characteristics. Synthesis and integration of the components is done when the system is actually constructed, going from the bottom up. The total system shown in Fig. 1.2 is opened for examination at the level of the computer as in Fig. 4.5.

Now a more detailed examination of the component subsystems is in order and is shown in Fig. 4.1. It can be seen that several subsystems, such as marketing and production, are beyond the scope of this thesis, but the figure illustrates how the major, interdependent components are linked together. A failure to note this interdependency of major subsystems can cause a less than optimum integration of the system components.

At this point, the system is opened at an even lower level in order to examine the hardware components.

4.2 Component Selection

Since virtually all hardware components of the system must interact with the computer, it is selected first. The computer choice will automatically specify some of the other system components. Such things as the word length (in bits) place limitations

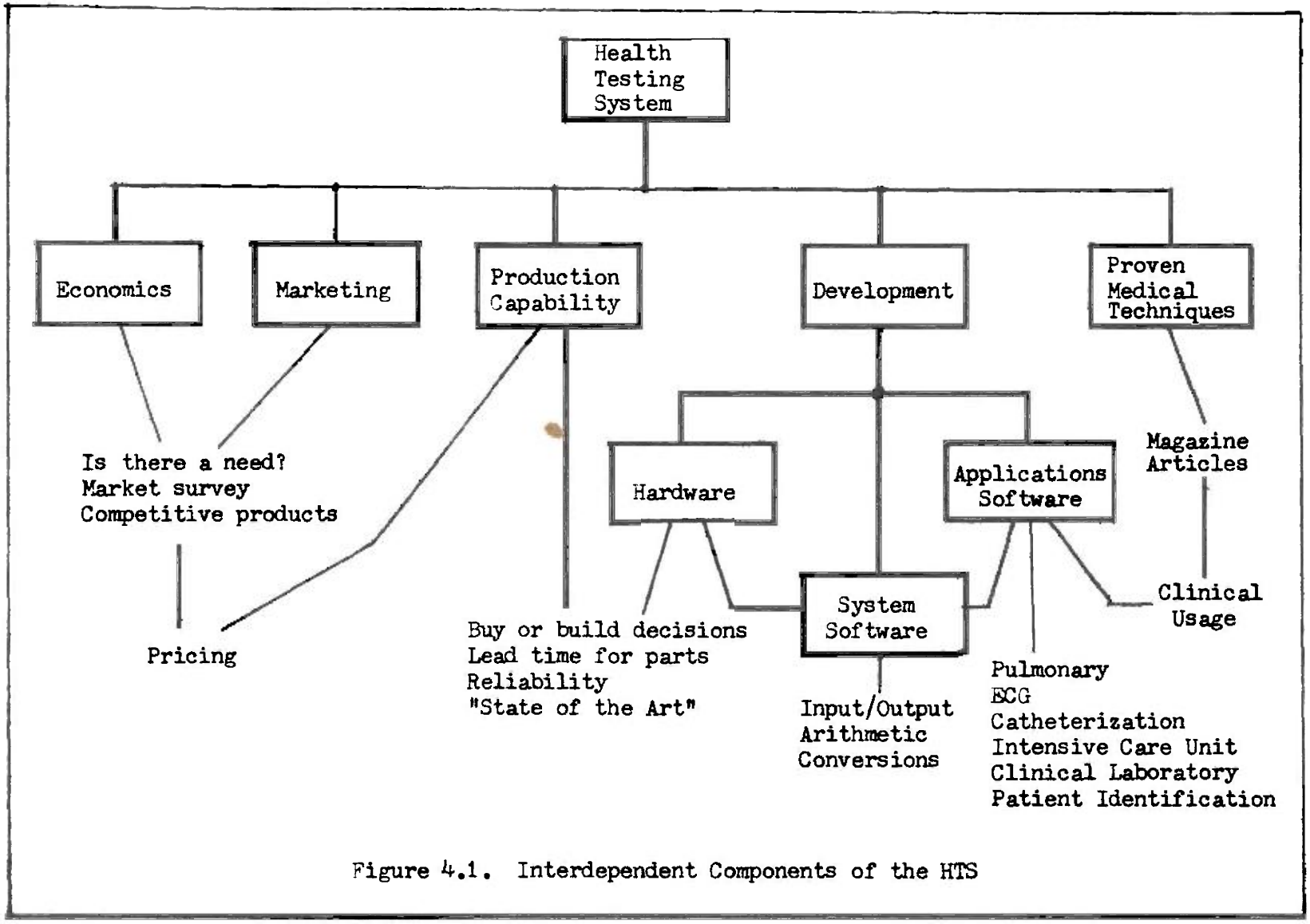


Figure 4.1. Interdependent Components of the HTS

on the precision of the calculations, the flexibility of the instruction set, the maximum amount of memory available and the character packing scheme for messages.

4.2.1 Central Processing Unit (CPU)

The detailed procedure for minicomputer selection will not be discussed here since a great many articles have been written on the subject, including an excellent one by Abhay K. Bhushan (18). The attractive features for which the Data General Nova was selected are as follows:

- Original Equipment Manufacturer (OEM) price: 36 per cent discount.
- Delivery: four weeks.
- Architecture: indexing, relative addressing, multiple operation instructions.
- Speed: Nova is interchangeable with the Super Nova.
- State of the art technology: MSI and Potential for updating to LSI.
- Software capabilities: time shared BASIC, FORTRAN, DOS, TOS.
- Modular core additions: 1K, 2K or 4K increments.
- Features: ROM, memory protect, power fail.
- Heritage: original designers of PDP-8 series.

4.2.2 CRT Display

The initial cathode ray tube (CRT) selection was based on three simple factors: (1) the display unit chosen was the same one designed by the LDS Hospital engineers for use with MEDLAB, and its capability to do the job was a known factor, (2) the unit was

available on a very short time notice (two weeks) from a local supplier, (3) the price was right ($3600) for a one or two quantity purchase.

This "quick and dirty" solution allowed the breadboard model of the system to achieve operational status in a very short time. However, there was a price to be paid when, on subsequent units, it was noted that the quality control was poor and units had to be returned to the manufacturer. An additional drawback was that the memoscope CRT on which the unit was based, has a high price tag (about $1100) and a relatively short lifetime (one year) for continuous operation. In-house development of a refresh display using an ordinary TV set, an integrated circuit character generator and the latest MOS-FET memory was soon started. However, it was over six months before the bugs were out and the unit operational.

The original investment in the quick and dirty method allowed the project to buy time in getting a deliverable system (shown in Appendix A) in less than four months from the date of receiving the first computer. This compares favorably with a "normal" time of one to two years development for a new product. The crash program was one of the system compromises made by suboptimizing one subsystem (development costs) in order to enhance the value of another subsystem (marketing sales). By selling and delivering two systems to a customer before the end of the year, the annual sales (economics) for the subsidiary company, whose R & D efforts were being subsidized by the mother firm, were raised significantly.

4.2.3 Analog to Digital Converter

The selection of an analog to digital converter was based on a more quantitative decision, with four different brands actually being purchased "on approval" and extensively tested prior to placing a firm order for 50 units. The possibility of "in-house" development was briefly considered, then rejected. Rejection of the idea came first because of the time factor and second because of the "art" that goes into developing a really good ADC which will not drift with temperature variations and will perform consistently in a noisy environment over a long period of time.

While investigating the "state of the art" technology in ADC's an integrated circuit model in a 6-lead flat pak was found at the local development laboratory of a major semiconductor manufacturer. Though the unit was operational and worked very well, it had the drawback of offering only 8-bit resolution where 10-bits were required, and it had not yet been released for production.

At the other extreme was a very old design using only discrete components and laid out on two large (6" x 15") printed circuit boards. As one might have guessed from the general appearance, it did not meet the 10-bit accuracy specified. In fact, the non-linearity present over the entire range of 0 to 1023 was so bad that the unit should have been designated as an 8-bit converter.

Surprisingly, both the old and the new technology are about the same price for the same number of bits resolution. The reason for trying to obtain the latest technology with electronic components is that the price is almost guaranteed to be significantly reduced in

coming years as the development costs are paid off and production rates go up.*

1. ADC Selection. Since ADCs are rated in bits and accuracy is determined by decimal digits, Table 4.1 shows the range of unit values which can be represented by different ADCs.

Table 4.1. Analog to Digital Converter Accuracy

No of Bits	Maximum Decimal Value	Commercially Available	Decimal Value Min:Max	Per cent Error	Approx. Cost
4	15				
5	31				
6	63	(6)	0:63	1.6%	
7	127				
8	255	8	0:255	.39%	$ 800 ($99)*
9	511				
10	1023	10	0:1023	.1%	$ 900 ($195)*
11	2047				
12	4095	12	0:4095	.02%	$1000
13	8191	13	0:8191	.012%	$1250
14	16383	14	0:16383	.006%	$1600
15	32767				
16	65535				

As one would expect, the cost of an ADC is proportional to the number of bits converted. However, the relationship is exponential

*Since the time of the original study (September 1969), thin film technology has drastically reduced the price of low resolution ADCs. As of June 1971, an 8-bit converter can be purchased for $99 and a 10-bit converter is $195.

rather than linear. From an economic point of view, it is best to use the minimum number of bits which the level of accuracy requires. This is shown in Fig. 4.2.

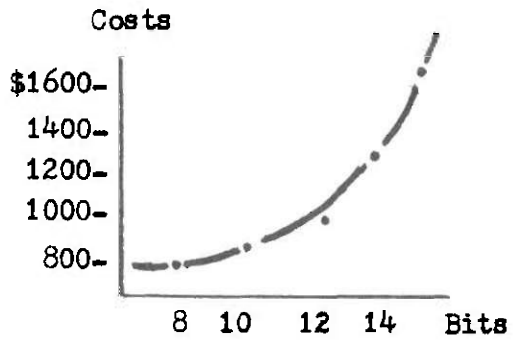


Figure 4.2. ADC Costs

The prices shown represent original equipment manufacturer's (OEM) prices and are about one half the retail price (19).

In addition to accuracy, speed of conversion is a major factor affecting the cost of an ADC. Greater speed results in higher cost. Speed of conversion is important because the analog data is always changing. If the rate of change is relatively slow and the ADC is fast, it can be assumed that during the time a conversion is being made, the data value is constant. A constant value during conversion is important because the ADC does its conversion by a series of successive approximations. When the data is changing rapidly or "simultaneous" measurements are required at several different transducers, as with ECG analysis or clinical laboratory peak detection, "sample and hold" circuits are used to store the analog voltage until the ADC is available for conversion.

Because of the high unit cost, only one ADC per system is used and multiple channels are selected, one at a time, with an analog multiplexor. Until recently, diode or transistor "switches" were used for multiplexing a number of channels. Now 16 channel FET integrated circuits are available. The computer selects which of the multiplex channels is to be sampled, commands the ADC to make a conversion, waits momentarily for the ADC to finish, then reads the digital value from the ADC.

2. Ramp Converter. A ramp converter, generally used in a DC digital voltmeter, is the least expensive method of conversion, but is too slow for computer use, even with the relatively slow changing physiology data. Ramp converters today operate in the range of 2 to 5 microseconds per step, giving a maximum conversion time of 1 to 6 milliseconds for a 10-bit converter (up to 1023 steps). An ECG signal can complete an entire QRS spike in this much time and not even be detected, so this converter is too slow.

3. Continuous Converter. The continuous converter utilizes an up-down counter. The counter moves backward and forward, continuously tracking the analog signal. This can be a fast conversion technique, provided the rate of change of the input signal does not exceed the maximum possible rate of change of the converter. This is a good converter for single channel operation. However, the Health Testing System requires at least 3 channels in the form of multiplexed inputs from the ECG machine. Also, there should be reserve capability for expansion to more channels for a time shared system doing concurrent ECG and pulmonary analysis. ICU monitoring requires

time shared operation of many channels. An N-bit continuous converter may require as many as 2^N steps to catch up after channels are switched.

4. Simultaneous Converter. A simultaneous converter has a separate comparator for each threshold level between the minimum and maximum. It is extremely fast (less than 1 microsecond), but also extremely expensive. A converter with an N-bit resolution would require 2^N comparators (i.e., 1,024 comparators for a 10-bit converter). The present limit is 4 to 5 binary bits (15 to 31 comparators) before the cost and complexity become prohibitive (20).

5. Successive Approximation Converter. The vast majority of computer applications, including the HTS, use a successive approximation converter. The ADC contains a comparator circuit, a digital to analog converter, a digital buffer and a control circuit as shown in Fig. 4.3. The converter operates by trying different numbers. Each trial, or step, determines 1 binary bit and narrows the possible range on the input by one-half.

The lower accuracy converters operate around 1 microsecond per step, giving a typical conversion time of 6 microseconds for a 6-bit converter. Higher-resolution converters require a longer settling time per step, with a conversion time of 28 to 70 microseconds being typical for a 14-bit converter.

Figure 4.4 illustrates how a damped transient would be converted and later reconstructed with (a) a continuous converter, (b) a successive approximation type, and (c) the successive approximation with a sample-and-hold (20).

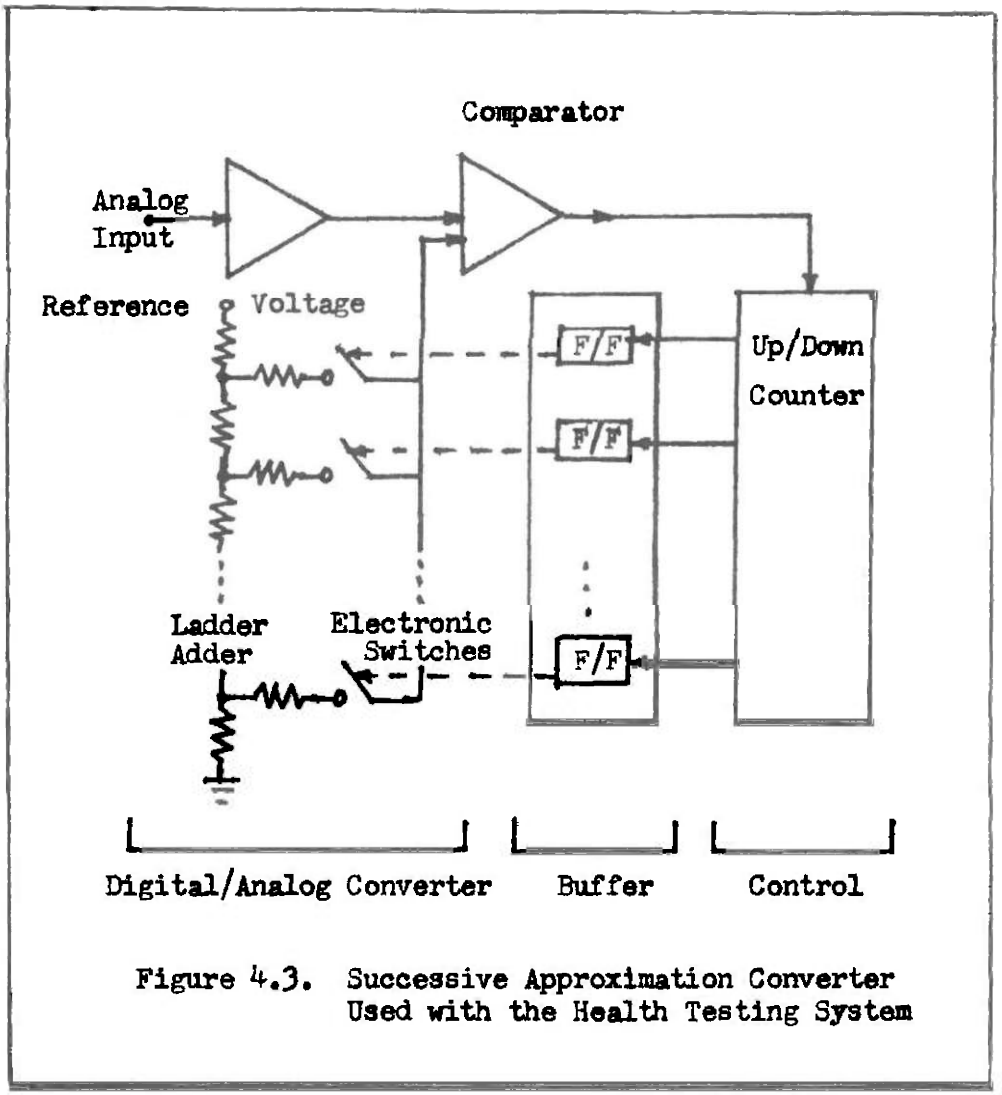


Figure 4.3. Successive Approximation Converter Used with the Health Testing System

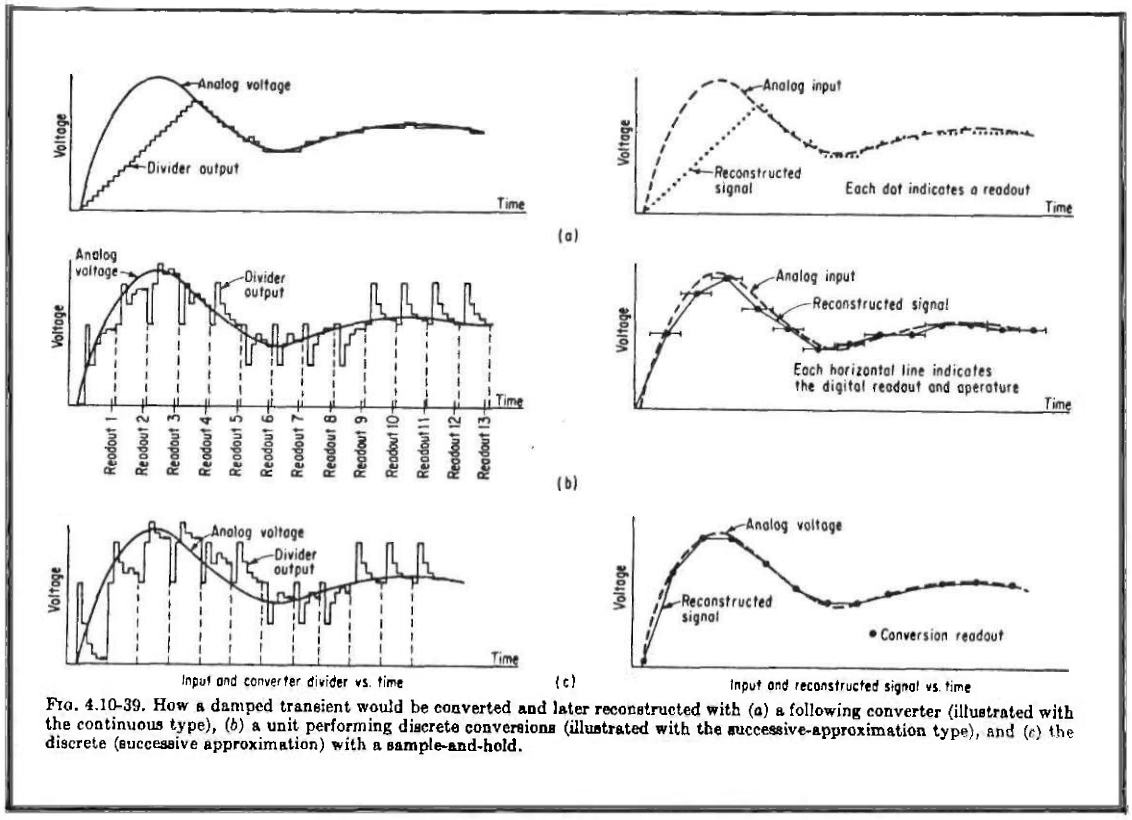


FIG. 4.10-39. How a damped transient would be converted and later reconstructed with (a) a following converter (illustrated with the continuous type), (b) a unit performing discrete conversions (illustrated with the successive-approximation type), and (c) the discrete (successive approximation) with a sample-and-hold.

Figure 4.4. Analog to Digital Conversion (after Klerer).

4.2.4 Keyboard

The keyboard selection proved to be a problem area. After examining the specifications of several manufacturers, a vendor was selected and an order placed for two different keyboards. One was a small 12 key numeric unit with a decimal point and an "ENTER" key. The other was an ASCII keyboard which was, for simplicity of manufacturing, to have the same keys and coding as a standard teletype keyboard.

The long delivery time quoted (six weeks) for a single unit was marginal in the first place, but three months later, after numerous letters and phone calls had not brought delivery, another vendor was

selected and delivery of the first unit made in two weeks. When the original order finally arrived, the first vendor was so apologetic that he made no charge for the units. It was an effort to recover a potential order of 50 keyboards but his lack of systems planning had already cost him the permanent loss of a good customer. Fortunately for the HTS system design, the teletype keyboard could be used for development purposes. This type of problem should be expected, but is very difficult to anticipate in the system design.

4.2.5 Interface

Though much of the interface circuitry could be purchased directly from the computer manufacturer, it was noted that the circuits were high profit items which were used to make up for the low profit margin on the central processor unit. This fact, coupled with in-house design and manufacturing capability made this a "make" rather than "buy" decision. However, the first three systems, used for development, were purchased with as much interface circuitry as was available in order to speed the system design process.

Of the three systems, one was used for hardware development, one for software development, and one for building the prototype model shown in Appendix A.

4.3 System Configuration

The ADC is an integral part of the HTS console, shown in conceptual form in Fig. 4.5. Since the speed of the computer will allow the performance of several simultaneous tests, an analog multiplexor is also contained within the unit. Thanks to the advent of

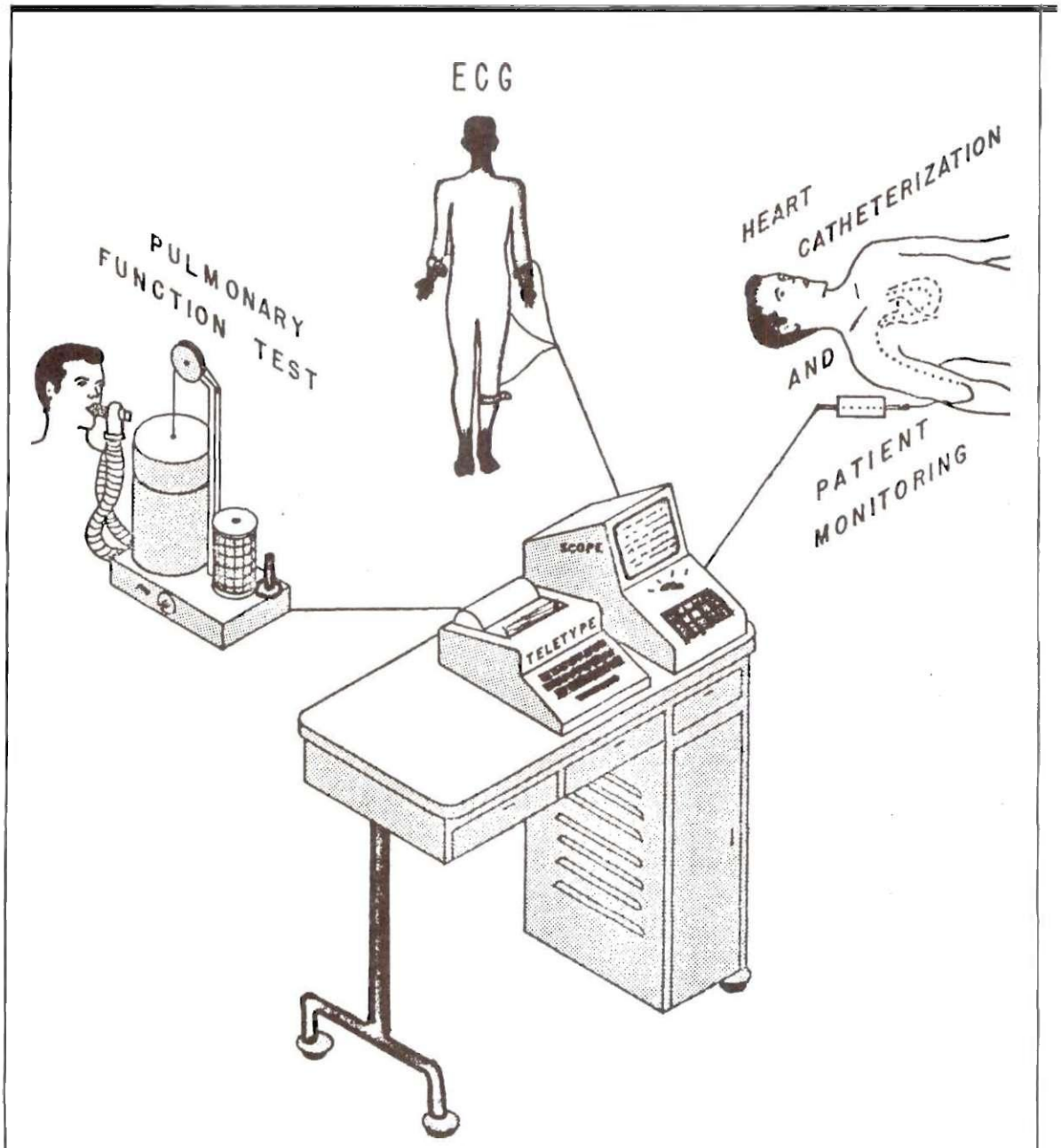


Figure 4.5. Health Testing System Concept.

Designed to aid the clinician in his diagnosis, it is a modular system with the first module performing Pulmonary Function tests and the second assisting in ECG pattern recognition. Other modules are used to assist Heart Catheterization, Patient Monitoring and Patient Screening.

medium scale integration (MSI), the multiplexor can now be purchased as a single, 16 channel integrated circuit for only about 50 dollars.

The "SCOPE" shown on the console in Fig. 4.5 provides messages to the operator and also has graphic capabilities so that a point-by-point plot of the data is made as the sampling proceeds. The keyboard and switch are used by the operator to communicate with the processor (computer). The processor itself is concealed in the panel below. The teletype (TTY) provides a hard copy printout for permanent records.

4.4 Compatibility With Product Lines

The major objective stated in section 1.2 was to design a general purpose data collection and analysis system for hospital use. In meeting this objective, a consideration was made for interfaces with other company product lines. A natural area for product integration could be made by using the fluidics skills of the nebulizer development team for designing a compact flow meter to replace the bulky spirometer presently used in pulmonary function testing.

Another product interface could be made with the automatic urinalysis machine. Urinalysis is now performed entirely by hand and this product has the possibility of being the first automatic machine on the market. A similar interface problem has already been solved in the clinical laboratory where blood samples are analyzed.

Another integration which is starting to develop is in the

area of patient identification and record keeping. The company has patented a patient I.D. tag which is machine readable and reproducible. The tag is worn at all times by the patient and a duplicate is easily made at bedside whenever a blood or urine sample is taken from a patient. Literally millions of samples are taken for analysis in an average sized hospital each year. The number of errors due to mislabeling and lack of labeling is surprisingly high, and is estimated to be as great as 3 per cent.

4.5 Synthesis and Integration

After selection of compatible components, one of the first steps to integration concerns the external packaging design, which in turn determines the layout of the internal components. The necessity of a mobile, compact unit is the primary consideration.

4.5.1 Packaging

The package was designed to be as small as possible for mobility, yet large enough to contain all the hardware components. It has a low center of gravity so it will not tip over when crossing elevator thresholds, yet is high enough for comfortable interaction with a physician standing at bedside in an operating room. A chrome and anodized finish is used so the unit will be attractive, yet durable enough to take continual bumping against tables and fixtures in operating rooms. It also must withstand harsh chemicals used for sterilization when it is to be used in a germ free environment.

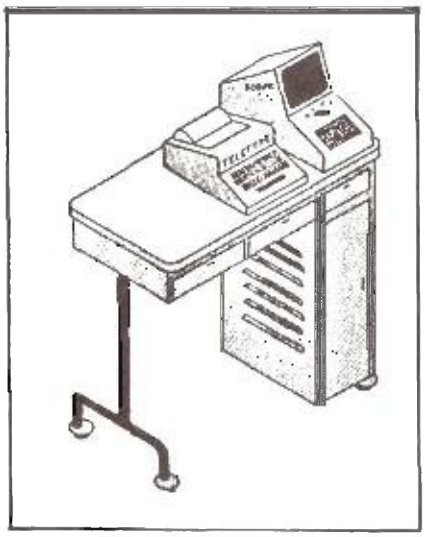
The evolution of the packaging concept, occurred while the prototype was being developed. The final production package is now

being designed by a professional, but the internal dimensions must meet or exceed those of the engineering model because of the hardware thus far developed. Again, the systems approach of considering problems outside the immediate realm of one's responsibilities prevented headaches farther down the line.

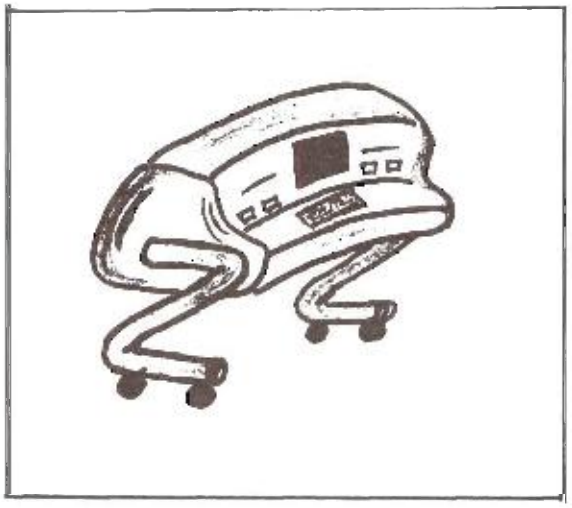
The "first concept" shown in Fig. 4.6, is the same as the system drawing in Fig. 4.5. The second package was an attempt to improve the attractiveness while retaining the functional nature of the unit, but after a clay model was built, it became obvious that the sharp cornered electronic components did not fit well into the curved enclosure. The wasted space required an excessively large unit.

The prototype model is an excellent package from an operational and maintenance point of view. It is compact and constructed with three layers of easily accessible components. The top layer consists of the CRT, character generator and tape cassette. The middle layer is the computer itself, hidden behind a smoked plexiglass lift-up panel. The panel allows easy access for a programmer, and prevents confusion for the operator. The bottom layer has the keyboard and program selection switches on the front panel, with the rest of the bottom layer containing power supplies, interface cards, the ADC and the multiplexor. A swing-out drawer on the right side, bottom layer, simplifies servicing of the printed circuit (PC) cards. Removal of the right panel also permits easy access to the main processor PC boards. Ventilation louvers are made at the rear.

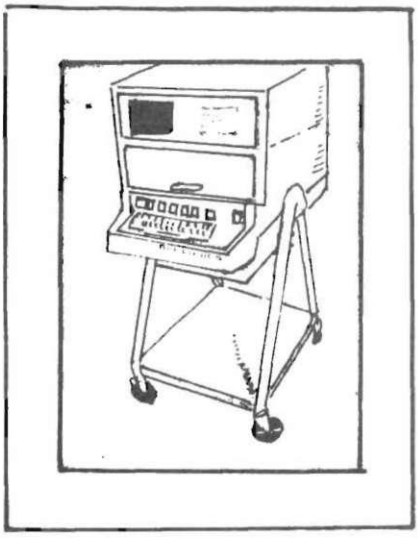
The engineering model has a specially built table which replaces the oscilloscope cart used on the prototype. Otherwise



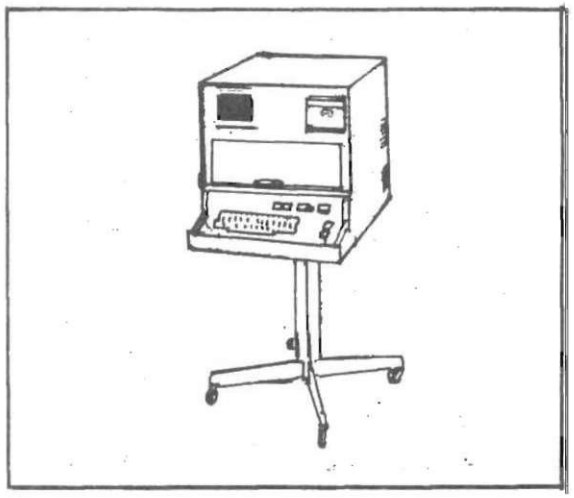
First Concept



Clay Model



Plastic Model
and Prototype



Engineering Model

Figure 4.6. Evolution of HTS Packaging.

it is the same. An external CRT, keyboard and interface package are being designed for a time shared system.

4.4.2 Component Interfacing

The major internal components of the HTS are shown in Fig. 4.7. For the first time, the synthesis of the total system becomes apparent. Each of the devices shown in the dashed outline is contained within the main package of the HTS.

The pulmonary function test is done in conjunction with a spirometer (shown on the left in Fig. 4.5), which has an electrical readout. A potentiometer is connected to the pulley, over which rides the cable leading to the strip chart recorder on its right. Below the pulley are two nested cylinders, the top one inside, acting like an inverted bucket. A small amount of water between the two cylinders allows a loose fit which will give low sliding friction and yet be air tight. As the patient breathes in and out of the attached hose, the top cylinder goes down and up. A nose clip is used to ensure that there is no leakage of air.

Each of the ECG leads requires a signal conditioning amplifier to help filter the 60 cycle noise and to boost the signal from millivolt level to a maximum of +10 volts for the ADC. All other devices operate from digital signals of either 0 volts or +5 volts.

The details of the component interfacing are too extensive for this thesis, but can be found in a term paper presented in Information and Computer Science 632 at Georgia Tech, by the author, May 1971.

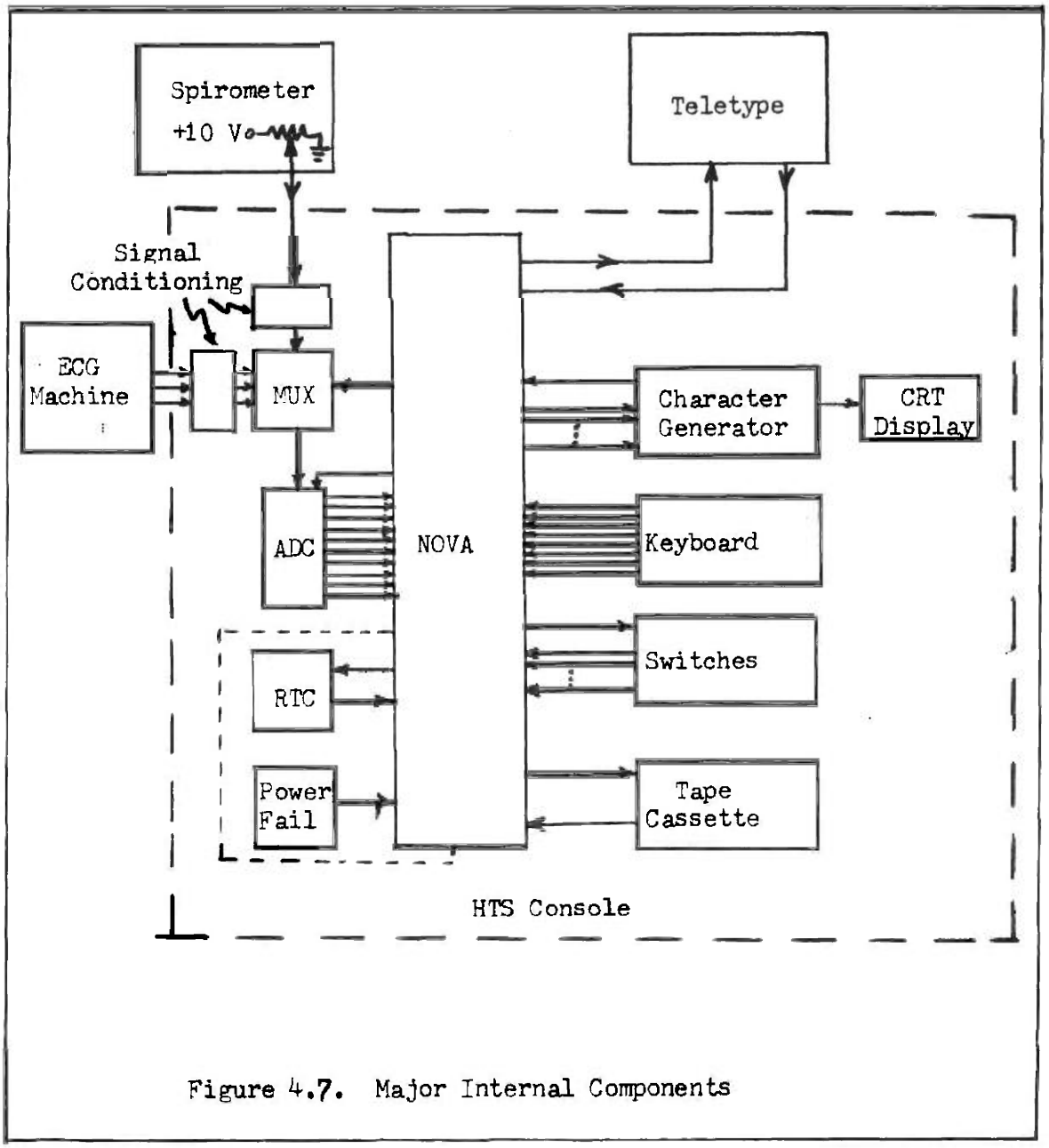


Figure 4.7. Major Internal Components

4.4.3 Electrical Safety

An electrical accident can occur whenever a patient becomes a conductor of alternating current. Common causes of accidents occur from such things as a floor polisher, electric bed, television or overbed light. The nature of the HTS measurements require that particular cautions be taken in grounding and in using current limiting circuits for instruments connected directly to the patient. As little as 100 milliamperes can cause ventricular fibrillation.

> The danger of electrocution is far more serious in procedures and techniques in which catheters and electrodes are placed in the major blood vessels or in the chambers or the muscle of the heart, because the human heart can be induced to fibrillate by extremely small amounts of current--fractions of the amount that is hazardous if the current pathway is not directly through the heart (21).

In order to alleviate the problem, a ground loop circuit has been employed to warn of impending danger. The incoming AC power, consisting of a twin conductor cable, passes through a ferromagnetic torroid. Normally, the current in one of the cable wires is always equal and opposite to that in the other. If there is a current leakage path from either of the conductors to ground, a current imbalance will result. If the two currents differ by more than 100 milliamperes, a "crowbar circuit" will detect the difference and force the main power circuit breaker to open, thus rendering the HTS safe, but inoperative. A current difference between 1 and 100 milliamperes causes a "ground" light on the front console panel to light up.

CHAPTER V

SYSTEM SOFTWARE PROGRAMS

5.1 General Purpose Service Routines

All programming for the Health Testing System is done in assembly language. Though time is not critical for most programs, the cost of core ($3650 for each block of 4096 words) places a premium on having small programs. Even so, the large data arrays required by the ECG programs make an 8K (8192 words) memory necessary.

The primary purpose of the system programs is twofold: 1) prevent often utilized procedures from taking up redundant blocks of core memory and 2) save programming effort by merely having to pass parameters to perform common functions.

As shown in the analysis diagram of Fig. 1.1, there is a natural breakdown between hardware and software functions. Likewise, there is a natural breakdown between system software which interacts only with hardware, that which interacts with both hardware and application programs, and that which interacts only with the application programs.

The "hardware only" programs handle such things as automatic data sampling and analog to digital conversion (ATD). The application programs then need to merely specify the sample rate (samples per second), and which data channel is to be sampled. The ATD program will fill a predefined memory buffer, using the Real Time Clock to

interrupt the processor each time a new data sample is required. The time between samples (about four milliseconds) is available for processing the data.

The data buffer in memory is setup to operate as though it were a continuous circle. By keeping track of where the last data sample was stored and where the last sample was removed for processing, the computer can sample and process concurrently. This technique is especially useful for ECG analysis where the first data samples may not be valid and can be discarded. In this case, a wrap around "circular buffer" is used which writes over itself and samples continuously until the ECG program gives a stop command.

While it is true that the program performs real time data analysis, it is somewhat after the fact since the analysis must be performed in a reverse time sequence. Two seconds of data are taken first in the circular buffer to ensure that two complete QRS complexes (Fig. 3.3) are available following the basic calculations, such as the peak values and the time interval between pulses. Then the first of the five samples, consisting of 1.2 to 1.5 seconds each, is taken. Separating the samples, rather than taking one massive set of data before analysis, saves on the amount of core storage required. The processor is fast enough to perform the pattern recognition analysis and discard the excess raw data for a total of six sequences during the 20 second time allowed. The last five data sequences are saved for extensive diagnosis analysis.

In addition to the ATD program, the "hardware only" programs handle all interrupt service. The interrupt service routines are

discussed in greater detail in section 5.3. The "hardware and applications" programs handle all the routine input and output functions which require interaction with the operator. No peripheral hardware interaction takes place in the "applications only" routines. These routines handle such things as floating point arithmetic, number base conversions and scaling the data to fit the CRT graph area. The Nova has hardware instructions for normal binary addition and subtraction. However, multiplication and division require special purpose software programs which handle the iterative sequence necessary for the multiply and divide algorithms.

Floating point arithmetic is so extensive that a special "Interpreter" is required. The interpreter is a manufacturer supplied software package which is approximately 800 words long. Because of its length, a programmer can save core storage space by using only integer arithmetic.

5.2 System Routines

Each of the program names in Appendix B calls a system subroutine. The name is stored in the "Bio-Logics Assembler" symbol table and is converted with a ".DUSR" command to an indirect jump, "JSR @XXX". The "XXX" is a page zero address which contains the starting address of the subroutine. This permits the actual address to vary without affecting application program assemblys. The only time it is necessary to reassemble an application program is when a major change is made to the "Bio-Logics Assembler." This has happened only once.

There are two types of subroutines in the system:

1. The simple to use, general purpose routines. These have a name with no "." at the end. To use these, a programmer merely enters the name in his program, with successive lines containing the arguments for calling that routine. Except for AC3 (Accumulator #3), which is destroyed by the "JSR" used to call the subroutine, all other accumulators and the carry bit are unchanged after the return from the system routine.

2. The special purpose routines are meant primarily for use by the Bio-Logics programmers. These names end with a "." and do not save any accumulators. It is up to the user to prepare any needed accumulator values required by these routines. This alternative is available for a programmer who wants to save the (approximately) 100 micro-seconds extra overhead required to save and restore the accumulators.

Within the system routines assembly listing, a general rule has been to begin the name of an entry point label with a ".". For example, the routine called by the name "KEY.", would actually be named ".KEY". By using two similar, but different names, the same assembler can be used for both the application program using the routine (KEY.) and the assembly of the system routine itself (.KEY). Similar names are used for calling and entry whenever possible.

All names used for calling system routines are reserved words, and cannot be used by an application programmer. In addition, there are a number of commonly used constants which have their names contained within the "Bio-Logics Assembler" and their values stored

in page zero when the system routines are present. A list of reserved names (system routines) and a list of page zero constants are shown in Appendix B. The appendix also has a brief description for operation of the routines.

As can be seen in Fig. 5.1, there are several levels of programs. The application programs call the main system routines. In some cases, such as "ERASE" the CRT, there is only a single level of system routine. After the function is performed, control is returned to the calling (application) program. In other cases, such as "MESI" message insertion, several program levels are required. The multiple levels help prevent redundant code in the system routines themselves, by allowing several main routines to use a single minor routine such as "KEY." (get a character from the keyboard).

5.3 Hardware Routines

When the "hardware only" routines are analyzed, it is clear that an intimate knowledge of both hardware operation and software capabilities is required. The hardware action can be initiated by the operator simply pressing a button as indicated in the flowchart on the left of Fig. 5.2. Depending on which button was pressed and what program status presently exists, the system software will branch to the appropriate service routine. In the case of multiple interrupts occurring simultaneously, the computer selects the highest priority device, indicated by the interrupt priority sequence in the center. The various hardware interrupts are discussed below.

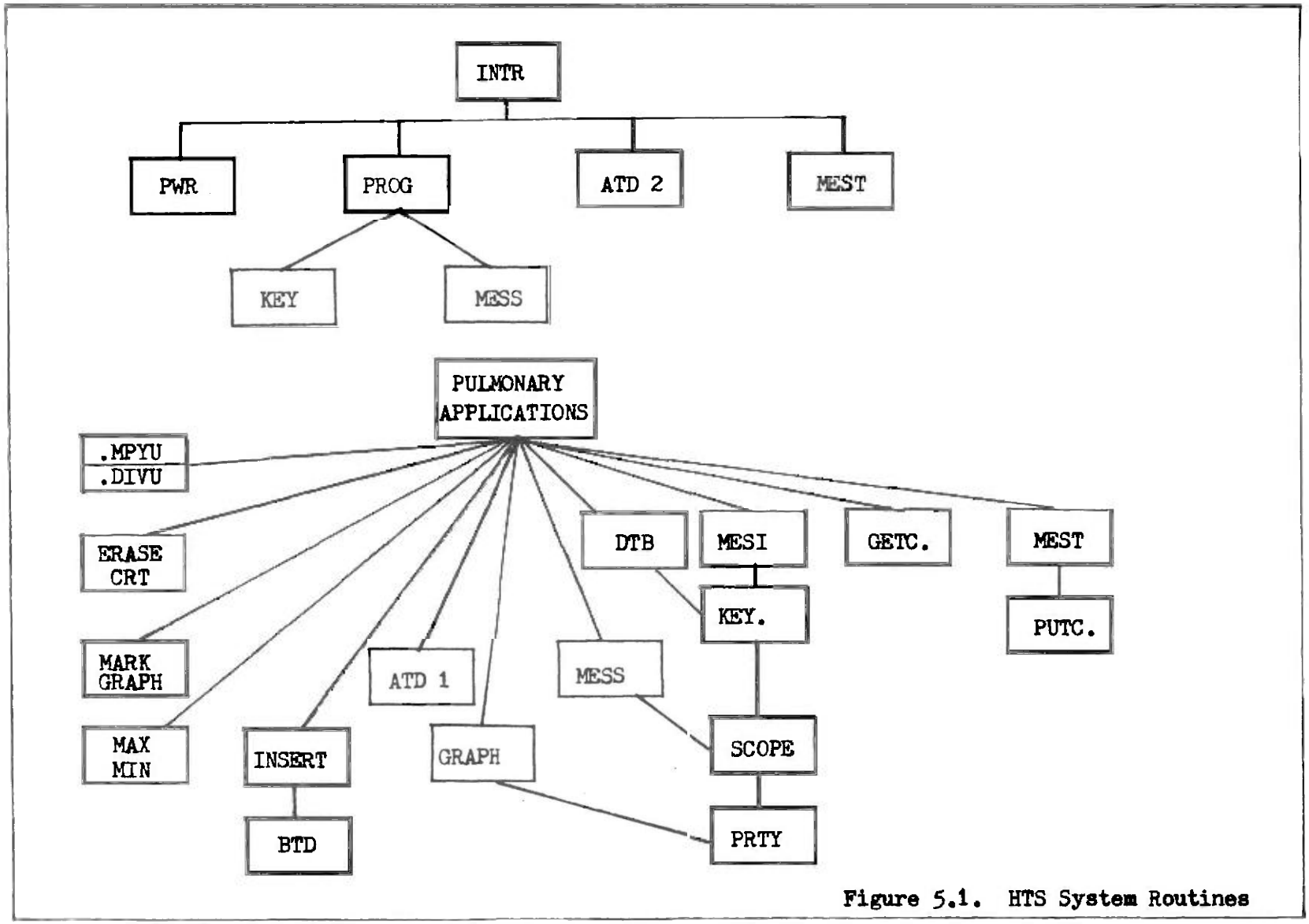


Figure 5.1. HTS System Routines

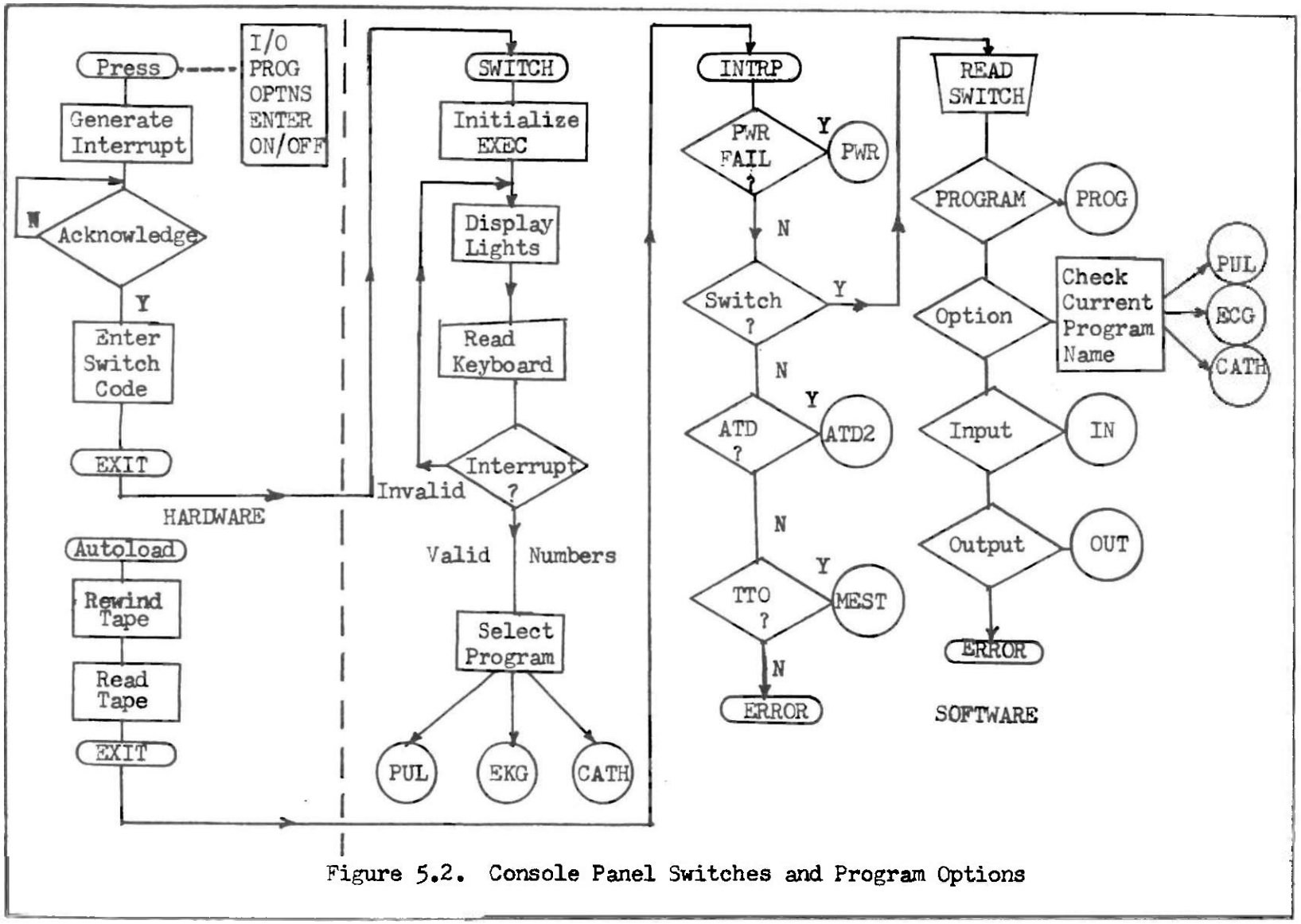


Figure 5.2. Console Panel Switches and Program Options

5.3.1 Power Fail

The power fail circuit generates an interrupt whenever the AC line voltage falls below 105 volts and places its device code on the DATA lines. The capacitors in the processor power supply will maintain operating voltage for approximately 1 to 2 milliseconds, during which time the power fail (PWR) program saves all the active registers and halts itself. "In so doing, the processor always completes a memory cycle and sequences power off so the contents of memory are unaffected" (22). The action taken by the processor when an adequate power level is restored depends on the position of the power switch. If the switch is ON, power comes back on with the machine stopped. If the switch is in the LOCK position, then 200 ms after power comes back on, the processor executes a jump to location $\emptyset$, which causes it to begin executing instructions in normal sequence. Location $\emptyset$ will contain a jump indirect through location 377, which returns control to the recovery section of PWR.

A 30 second software delay allows for warmup of the CRT, then a message, "POWER FAIL RECOVERY," is displayed for the operator. All data is retained and the previous program status is restored. If the program was in the middle of a time dependent data sampling sequence, the operator will want to repeat the test.

5.3.2 Console Panel Switches

The program select switches (SW) are assigned device code 22 (octal), with each switch having an individual bit on the DATA line interface register. The "ON/OFF" switch is a self-lighting "press ON/press OFF" type which operates a relay, controlling power to the

processor, to the ADC, CRT display, keyboard, TTy, and all interface power supplies contained in the HTS mainframe. The "STOP" and "START" momentary contact switches are used for program control, and perform such functions as temporarily halting the execution of a test sequence while repositioning the ECG leads on a patient. The "OPTION" switch generates a branching condition within the application program, while the "PROGRAM" switch returns control to the executive monitor. The "INPUT" and "OUTPUT" switches are for selecting the I/O device (i.e., disk, tape or TTY). The processor controls the lighting of each switch with a latch circuit, indicating the current machine status to the operator.

5.3.3 Recovery from Catastrophic Software Failure

Stored within readonly memory (ROM) is a short "RESTART" program to be used in the unlikely (but probable) event that some stray noise spike will alter the contents of a critical memory location in the dynamic core area of the executive monitor, making normal operation impossible. The RESTART program is used to reload the monitor and automatically starts executing as though control had just been returned from a major application program.

5.3.4 Real Time Clock

The real time clock (RTC) is an optional hardware item that is purchased with the computer and mounted on the TTY interface board. It is not actually a "real time" clock, but rather an interval timer. It is not normally used for time of day readings as with larger machines, but is used to generate equally spaced interrupts for data collection. The interrupt frequency is under computer control and

can be set to 60 cycle (AC line frequency), 10 Hz or 1000 Hz.

The clock is used primarily for low resolution timing (compared to processor speed), but it has high long-term accuracy. Initial power turnon or recovery from a power failure resets the clock to the line frequency.

5.3.5 Analog to Digital Converter

There are two modes of operation of the analog to digital converter (ADC) software. The first requires the application program to specify such things as the sample rate, which multiplex channel is to be sampled first and the number of channels to be sampled for each clock interrupt.

The second mode of operation controls the actual starting and stopping of the sampling. The start command normally is generated by a signal from the "ENTER" key of the sonsole keyboard. Either a sample count or time interval determines when the sampling stops.

5.4 Synthesis and Integration

While the system subroutines diagram of Fig. 5.1 illustrates a first level of program integration, it was found after writing several application programs that one higher level of integration was required. Here again, the systems engineering approach allowed a compromise of the "system routines" optimization, in order to achieve greater programming efficiency in the "application programs." The result was an overall improvement of the system integration.

The application programmers made a request for a "FORTRAN like" formatter program which could be used to simplify message

handling and report writing. The following objectives were specified:

1. A,F,I,X format capabilities similar to FORTRAN IV.
2. Minimize core requirements for the formatter. Use only a minimum of error detection, but avoid catastrophic user errors.
3. Avoid any changes to the Nova assembler.

A generalized flowchart of the resulting formatter program is illustrated in Fig. 5.3. The "READ" and "WRITE" commands are illustrated in Fig. 5.4 and a sample printout is shown in Fig. 5.5.

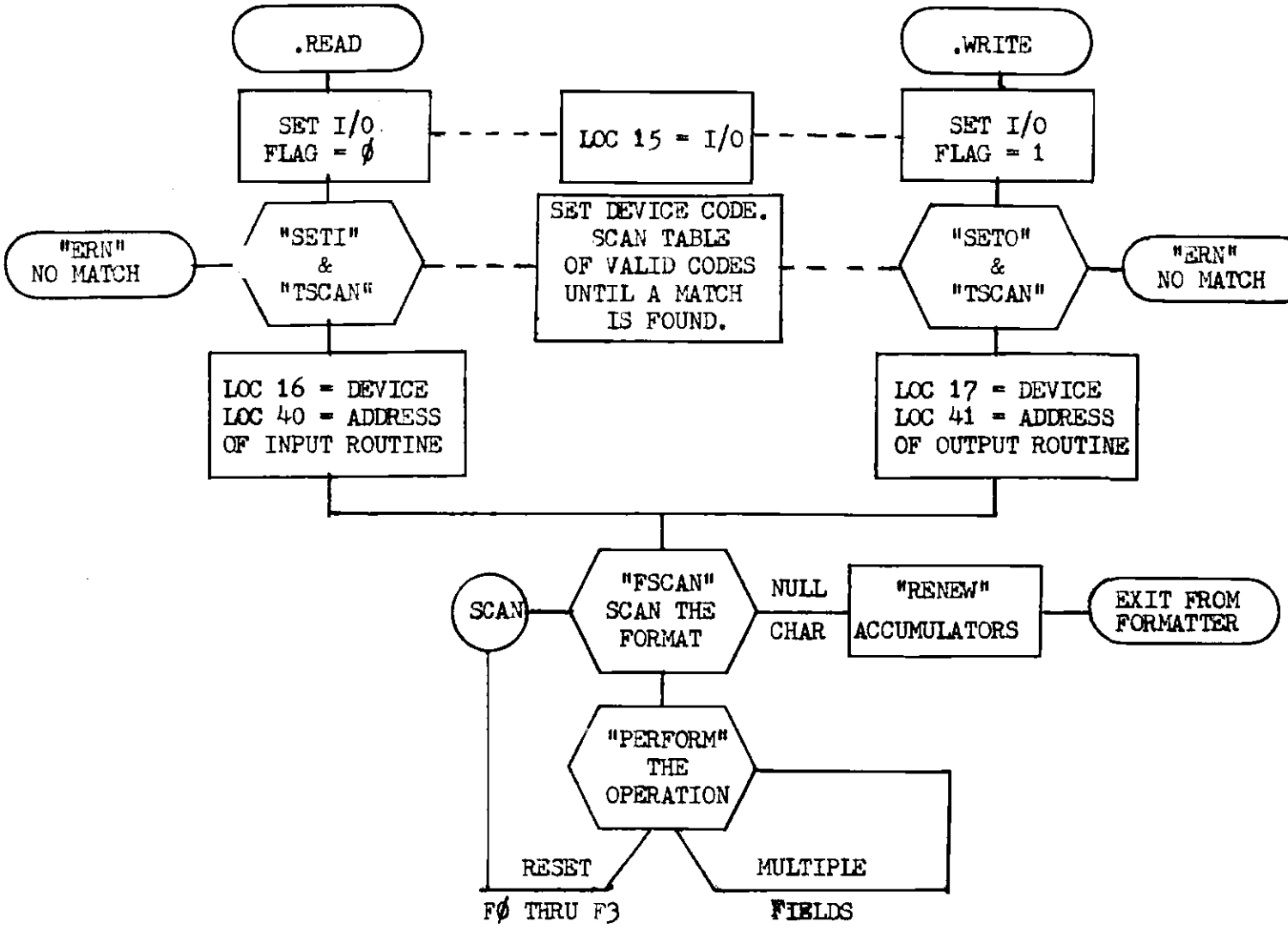


Figure 5.3. Formatter Flowchart

```
; AUG 27 '70

READ    FORMATTED INPUT
----
CALLING SEQUENCE:
        READ
        KY      ;DEVICE CODE
        FIO1    ;FORMAT STATEMENT ADDRESS
        ALPHA   ;ALPHA VARIABLE NAME
        FLOAT   ;FLOATING POINT VARIABLE
        INT     ;INTEGER VARIABLE
        ....    ;RETURN

OTHER:  READ
        DFL     ;SPECIAL CASE REQUIRING DOUBLE ARGUMENTS
        FIO1    ;FORMAT STATEMENT ADDRESS
        ALPHA   ;ALPHA VARIABLE NAME
        ASCII*2 ;CHAR ADDRESS OF ASCII INPUT FROM CORE
        FLOAT   ;FLOATING POINT VARIABLE
        ASCI2*2 ;CHAR ADDRESS OF ASCII INPUT FROM CORE
        INT     ;INTEGER VARIABLE
        ASCI3*2 ;CHAR ADDRESS OF ASCII INPUT FROM CORE
        ....    ;RETURN
        ....
        ....
        JMP XXX

ALPHA:  .BLK 19 ; -OCTAL- CAN BE LONGER THAN ACTUAL INPUT
FLOAT:  0       ;MUST BE 2 WORDS
        0
INT:    0       ;SINGLE WORD

FIO1:   .TXT(A19,F10.2,I7(    ; -DECIMAL-

ASCII:  .TXT"STEVE'S FOLLY "
ASCI2:  .TXT"123.45"
ASCI3:  .TXT"6789"


ASSUMPTIONS:
        'A' FORMAT SPECIFIES AN EXACT INPUT LENGTH.  EXTRA CHARACTERS
        ARE TRUNCATED; FEWER CHARACTERS ARE PADDED WITH BLANK SPACES.
        A CARRIAGE RETURN MUST FOLLOW EACH ENTRY.  A NULL CHAR WILL
        REPLACE THE CR IN CORE.

        'F' FORMAT IS FREE FORMAT INPUT WITH UP TO 7 DIGITS FOLLOWED
        BY A CR.  FEWER DIGITS CAUSE NO PROBLEMS, BUT MORE DIGITS WILL
        RESULT IN AN ERRONEOUS CONVERSION.

        'I' FORMAT IS FREE FORMAT INPUT WITH UP TO 5 DIGITS FOLLOWED
        BY A CR.  FEWER DIGITS CAUSE NO PROBLEMS, BUT MORE DIGITS WILL
        RESULT IN AN ERRONEOUS CONVERSION.

        'X' FORMAT AND LITERALS ARE ILLEGAL INPUTS.
```

Figure 5.4. Formatter Calling Sequence

```
; AUG 27 '70

WRITE   FORMATTED OUTPUT
-----
CALLING SEQUENCE:
        WRITE
        DVT     ;DEVICE CODE
        FIO2    ;FORMAT STATEMENT ADDRESS
        ALPHA   ;ALPHA VARIABLE NAME
        FLOAT   ;FLOATING POINT VARIABLE
        INT     ;INTEGER VARIABLE
        ....    ;RETURN

OPLOT:  WRITE
        DF      ;SPECIAL CASE REQUIRING DOUBLE ARGUMENTS
        FIO2    ;'X', 'A' FOR LITERALS - ILLEGAL
        ALPHA   ;ALPHA VARIABLE NAME
        ASCII*2 ;CHAR ADDRESS OF ASCII OUTPUT TO CORE
        FLOAT   ;FLOATING POINT VARIABLE
        DIGIT*2 ;CHAR ADDRESS OF ASCII OUTPUT TO CORE
        INT     ;INTEGER VARIABLE
        DIGIT*2+4+12    ;CHAR ADDRESS OF ASCII OUTPUT TO CORE
        ....    ;RETURN
        . .
        . .
        JMP XXX

ALPHA:  .TXT"STEVES FOLLY NO."
FLOAT:  123456
        876543
INT:    3662

FIO2:   .TXT(A16,4X,F10.2,/,18X,'TODAY IS AUG. 26,',I4(
FIO3:   .TXT(A16,F10.2,I9(

                ; -DECIMAL- FORMAT SIZES
ASCII:  .BLK 28 ; -OCTAL- BLOCK SIZE
ASCI2:  .BLK 20
ASCI3:  .BLK 20


ASSUMPTIONS:
        'A' FORMAT SPECIFIES AN EXACT OUTPUT LENGTH.  EXTRA CHARACTERS
        ARE TRUNCATED; FEWER CHARACTERS ARE PADDED WITH BLANK SPACES.
        &PORT MESSAGES MUST HAVE A NULL AT THE END.

        'F' FORMAT IS FIXED FORMAT OUTPUT WITH ANY LENGTH SPECIFIED.
        FEWER DIGITS WILL BE PADDED TO THE LEFT WITH BLANK SPACES AND
        TO THE RIGHT WITH ZEROS.  MORE DIGITS WILL BE TRUNCATED TO THE
        LEFT OR RIGHT, DEPENDING ON THE POSITION OF THE DECIMAL POINT.


        'I' FORMAT IS FIXED FORMAT OUTPUT WITH ANY LENGTH SPECIFIED.
        THE NUMBER WILL ALWAYS BE RIGHT JUSTIFIED, WITH FEWER DIGITS
        BEING PADDED TO THE LEFT WITH BLANK SPACES, AND MORE DIGITS
        BEING TRUNCATED TO THE LEFT (SIGN FIRST).

        'X' FORMAT, '/' AND LITERALS CAN BE INSERTED ANYWHERE WITHIN
        A FORMAT STATEMENT AS LONG AS THE DEVICE CODE IS NOT 'CR'.
```

RESPIRATORY TEST REPORT
MT. STAKE PENINSULA HOSPITAL
PULMONARY FUNCTION LABORATORY

NEWMAN, ALFRED E. 30 FEB. 1984 10:00 A.M.

CASE # 6969 38 YEARS MALE 202 CM 293 KILOGRAMS

DR. SPIRO T. DOCTOR

(ALL VOLUMES BTPS)

	MEASURED	PREDICTED	% PREDICTED	UNITS
A. MECHANICS				
FVC	5519	4941	111	ML
TIME TO COMPLETE FVC	.3	184	172	SECONDS
MVV	72	-	-	L/MIN
FEF (200-1200 ML)	698	414	169	L/MIN
FEF (25-75%)	354	144	247	L/MIN
FEF (1.0)	4731	4015	118	ML
FEF (2.0)	5407	-	-	ML
FEF (3.0)	5519	-	-	ML
B. VENTILATION				
MINUTE VOLUME	97.3	86.0 - 118.0	-	L
RESPIRATORY RATE	14	8 - 20	-	B/MIN
AVG TIDAL VOLUME	644	300 - 600	-	ML
BASELINE SHIFT	0		-	ML
C. LUNG VOLUMES				
VITAL CAPACITY	5768	5029	115	ML
INSPIRATORY CAPACITY	2105	3021	70	ML
EXPIR RESERVE VOLUME	2084	1267	173	ML

D. COMMENTS

STUDY IS AFTER BRONCHODILATOR TREATMENT.
PATIENT PERFORMANCE WAS SATISFACTORY.
SLIGHT INDICATION OF CRUNCH.

E. INTERPRETATIONS

THIS SURE IS A TEDIOUS WAY TO MAKE A LIVING !

Figure 5.5. Formatter Printout

CHAPTER VI

SYSTEM OPERATION

6.1 Operation

Programs are called by pressing the "PROGRAM" button which is above the keyboard. The major program options are listed on the CRT screen and the operator may choose which one he wants to run. The program selected will be read from the tape cassette or disk and its subroutine options will be displayed. Normally, the sequence will start with patient history and the program will automatically increment to the next subroutine as the previous routine is finished. The "OPTION" button allows any of the subroutines to be repeated and will overlay any erroneous data previously entered. It is assumed that people will make errors, so a simple correction procedure is provided. The OPTION button is one level lower in hierarchy than the PROGRAM button. It causes a list of the sections of the program chosen to be displayed, from which the operator chooses the optional entry point. Using this button, the operator can perform any or all tests in any order he wishes.

The "YES" and "NO" keys are used by the operator to respond to branching decision questions asked by the program. The "ENTER" key is used when finishing a communication to the machine. It can be recognized as a carriage return when typing patient information or as an indication to begin sampling data at the beginning of a

maneuver involving the patient testing equipment. After completion of all tests, the user can type comments which will be printed on the hard copy report following the test results. The final report is printed out on the teletype. A sample report was shown in the previous discussion of the formatter system routine in Fig. 5.5.

6.2 Patient Screening

The term "screening" refers to the performance of a test with a sufficiently high likelihood of detecting a disease, if present, to separate out persons who probably have the disease from those who probably do not. A popular term recently circulated among medical journals is "multiphasic screening," meaning the combination of multiple tests to screen for a number of diseases. "Automated multiphasic screening" is the expanded concept of utilizing automated or semiautomated electronic and machanical equipment to determine whether the likelihood of disease presence is sufficient to warrant further specific diagnostic testing.

> The recent advent of electonics, computers, and automation, into medicine offers the opportunity to improve and augment screening techniques and instrumentation, so that not only more tests but more accurate and quantitative measurements can be performed. Since diagnosis is defined as the identification of a specific disease, then as screening becomes more comprehensive, precise, and quantitative, disease detection approximates disease diagnosis and automated multiphasic screening approaches automated diagnosis. (23).

The patient screening system is a special embodiment of the basic HTS with a spirometer, ECG machine and login station. It is designed to be a free standing, mobile unit which can be quickly moved to any area of the hospital. For mass community health testing

and screening, the unit is small enough to be transported in a panel truck or station wagon for on site testing. The compactness, the use of standard 115 VAC outlets and the ability to operate wihout air conditioning makes the unit ideal for these circumstances.

The brochure in Appendix A shows how the login station has been incorporated into the HTS package and how the spirometer is an independent unit. This modularity allows various types of spirometers and ECG machines to be interfaced with the basic HTS.

6.3 Pulmonary Function Testing

Pulmonary malfunction is the fastest growing disease state in the country. There are more patient treatments for respiratory ailments than for any other medical problem. As the rate of the problem increases, so does the need for diagnosis.

While pulmonary function testing is not a new technology, it does require a significant amount of calculations, so has not been attempted by the general practitioner and internist. Rather, it has been left generally to the pulmonary physiologist. With the HTS computer program, pulmonary function testing can easily be done in the general practitioner's office, with calculations done on-line.

The HTS pulmonary program provides the direct and immediate presentation of results of pulmonary function testing by means of the CRT screen. As a person enters this station, the technician inputs his I.D. number from the keyboard. With a disk system, this number would be displayed back to the operator, along with his full name, for positive identification.

After verification of name and I.D. number, a message is generated, instructing the technician to enter the sex, weight, height, and age of the person. Other manually taken information such as skin-fold thickness, blood pressure, ocular tension, and audiometry results may also be entered into the record at this point. As the values are entered, they are echoed back on the screen for positive verification.

The pulmonary function measurement is made with a 13 liter Collins Spirometer or equivalent, with electrical readout. A typical test is made when the person is instructed to perform a Forced Vital Capacity (FVC) maneuver. The computer samples the potentiometer output of this maneuver and computes FVC, $FEV_{1.0}$, $FEF_{200-1200}$, and $FEF_{25-75\%}$.

These values, along with the person's predicted per cent of normal as determined by his age, sex and height, are presented to the technician on the CRT display. If the measured values are low (usually less than 80% of predicted), the test is repeated. Repeating the test is often necessary because there is a certain amount of learning required before a FVC maneuver is performed properly. When the technician is satisfied the person has performed the maneuver adequately, the results, consisting of the best values for the four tests and the per cent of predicted, are stored in the person's file for the final report.

Normal spirometric standards for the four pulmonary function parameters are currently known and available for all ages, from children in kindergarten on up.

When the pulmonary program is called via the PROGRAM button, a list of program sections is displayed on the screen for selection. The operator need only follow the instructions displayed for him. The OPTION button is used to alter normal program flow, which is similar to the order in which the sections are explained below.

6.3.1 Calibration

One of the exceptions to normal program flow occurs at the beginning of each working day or whenever the pulmonary program is loaded into the machine with the PROGRAM button. Calibration provides the necessary compensation "constants" used to convert the pure numbers from the spirometer and ADC to volume representations which are meaningful in the computer calculations. This section need not be re-entered for each patient unless there has been a change in barametric pressure or temperature.

As this section is entered, the operator is asked whether he desires to run the calibration subroutine. He will respond by pressing either the YES or No key. An answer of YES assumes that a recent calibration has been made and is unnecessary. The program will jump to the next subroutine, leaving the calibration constants undisturbed. An answer of YES must be entered when the program is initiated at the beginning of the day. When the program has just been reloaded, a YES answer is automatically assumed and the program goes directly into the calibration routine. A general flowchart is shown in Fig. 6.1.

6.3.2 Patient Information

This is an optional section which may be selected at operator discretion. It allows the operator to input information identifying

the patient, his doctor, and the patients vital statistics. The patient's age, height, weight and sex are required in order for the per cent prediction calculations to be performed. The default option will assume "0" for all these values and the per cent prediction will not be calculated in later tests.

On the expanded system, the patient history is pre-recorded on the patient disk file. When a new patient first visits a physician, a voluminous history questionnaire usually is completed prior to his seeing the doctor. The physician must visually scan the entire questionnaire to isolate, and then synthesize the pertinent facts. By computerization of that history, the HTS condenses the pertinent data to capsule form, and relates that information to the patient's health condition by probability diagnosis.

6.3.3 Tidal Volume

This section measures the patient's normal, average breathing habits. The measuring takes place for a length of time (e.g., 15 seconds) at the end of which the following results are displayed:

TV	Tidal volume in milliliters
RR	Respiratory rate in breaths per minute
MV	Minute volume in liters per minute
BLS	Base line shift in milliliters

Also the question "ACCEPTABLE?" is asked with an answer of NO leading back to the start of tidal volume for repeating the test, and an answer of YES leading to the vital capacity analysis section.

6.3.4 Vital Capacity

Vital capacity measures the maximum volume a patient can exhale

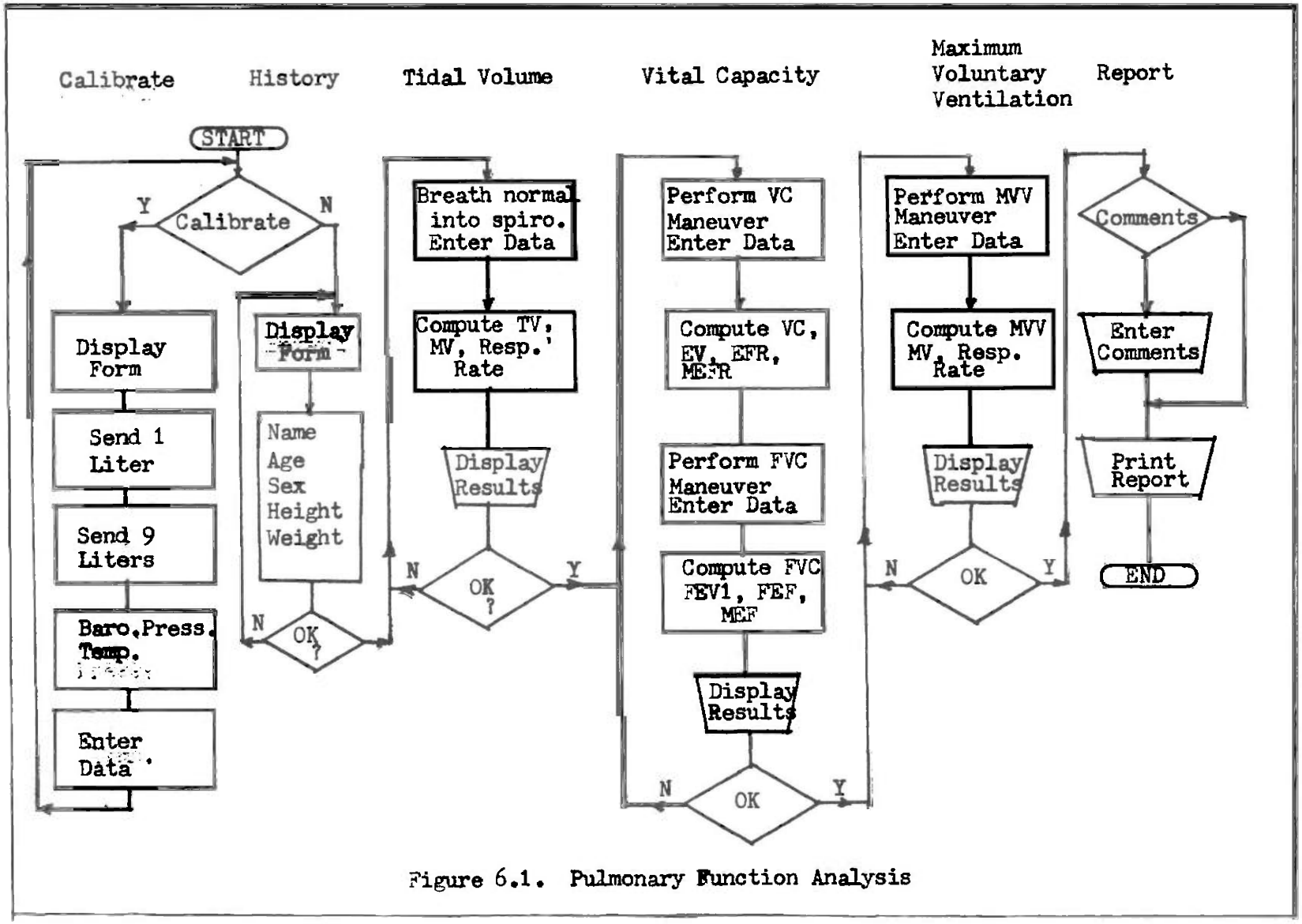


Figure 6.1. Pulmonary Function Analysis

in an unforced manner; i.e., the patient exhales at a normal rate. With the mouthpiece in place, the patient should be asked to inhale to maximum, then exhale as much as possible. During inhalation, the operator should push ENTER and watch the screen for abnormalities in the data pattern which would cause misleading or incorrect analysis. The following results are displayed:

VC	Vital capacity in milliliters
TIME	Time between maximum and minimum volume in seconds
EV	Expiratory volume for one second after 200 milliliters below maximum in milliters per second
EFR	Expiratory flow rate from 200 milliliters Below maximum until 1200 milliliters Below maximum in milliters per second
MEFR	Mid expiratory flow rate from 25% volume exhaled to 75% volume exhaled in milliters per second.

The operator must enter NO to repeat the test, or YES to continue to the forced vital capacity section.

6.3.5 Forced Vital Capacity

This section measures the maximum volume a patient can exhale as rapidly and forcefully as he can. The patient should be asked to inhale to maximum then exhale as hard and fast as possible. During inhalation, the operator should push ENTER and watch the screen for abnormalities in the data pattern which would result in incorrect or misleading results. The following results are displayed:

FVC	Forced vital capacity in milliliters
TIME	Time between maximum and minimum volumes in sec.

$FEV_{1.0}$ Forced expiratory volume exhaled for one second after 200 ml's below maximum in milliliters

$FEF_{200-1200}$ Forced expiratory flow rate from 200 ml's below maximum to 1200 ml's below maximum in milliliters per second

$MEF_{25-75\%}$ Mid forced expiratoy flow rate from 25% volume exhaled to 75% volume exhaled in milliliters per second.

This section usually must be repeated since a patient is not used to exhaling rapidly.

6.3.6 Maximum Voluntary Ventilation

This routine measures the patient's forced breathing capability. The patient should be asked to breath as deeply, as rapidly and as forcefully as possible. After he begins and the operator is sure the patient is putting forth his best effort, the operator should push ENTER. The operator should watch the data pattern for abnormalities which would result in misleading or incorrect results. The test continues for a time period (e.g., 15 seconds) then the following results are displayed:

MVV Maximal voluntary ventilation in milliliters

RR Respiratory rate during this period in breaths per min.

MV Minute volume in liters per minute

BLS Base line shift in milliliters

This test is performed last since it is the most tiring for the patient. It is not at all unusual to see a decaying sine wave plot on the graphic CRT display as the patient gets tired and the lungs

get saturated with oxygen. This is an important test because an extremely rapid decay (3 or 4 seconds) indicates a strong likelihood of emphysema.

6.3.7 Written Report

The operator may type up to four lines of comments (up to 26 characters each) which are pertinent to the tests just completed. Perhaps a patient's nervousness or inability to comply with instructions might be in the comments. If there are no typing errors, the operator selects YES for a typewritten report of all the patient information and calculated results. On a disk system, the information is sent to the patient's file to be accessed via demand mode or a batch output of all reports at the end of the day.

A detailed description of the calculations can be seen in Appendix C.

6.4 ECG Interpretation

The HTS electrocardiogram (ECG) provides an automated means for detecting and measuring coronary disorders. ECG leads for attachment to the patient's body and amplifiers are necessary peripheral equipment for this test. An ECG strip chart recorder is optional for hard copy output.

Once the ECG leads are attached to the patient, the operator calls the ECG program from the decimal keyboard. Messages are displayed on the CRT screen asking for pertinent patient information. When all information is entered, three ECG channels are sampled and an analysis is performed using the orthogonal XYZ Franck lead system.

The three ECG leads are recorded for approximately 20 seconds. Following the 20 seconds recording, a 1 millivolt calibration signal is transmitted on each of the three channels. When all data are received, the analysis is performed. The results are immediately displayed back to the operator. The operator is then able to determine whether the analysis is technically correct. This is based upon two factors. One is the calibration values which are displayed back, and the second is a graph of the wave forms analyzed. Normally, five ECG complexes, shown in Fig. 6.2, are analyzed. The operator can view

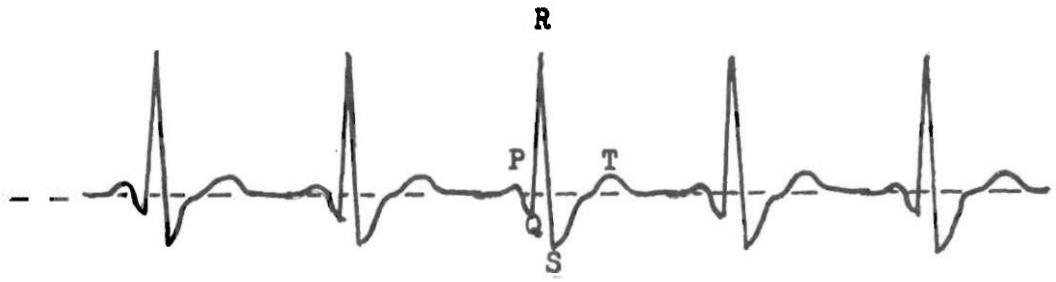


Figure 6.2. Typical ECG Waveform For Healthy Heart
The small, rounded pulse prior to the dip at Q indicates atrial contraction, while the QRS waveform relates to ventricular contraction. The small rise after point S corresponds to the end of the ventricular systole action.

the oscilloscope to determine how many complexes were actually used in the analysis. If less than three complexes are displayed, the operator repeats the test.

Once the operator is satisfied that the results are technically correct, the results (normal, left bundle branch block, etc.) are printed by the teletype. The test may be repeated and results recorded, as desired.

6.4. Classification

The ECG is classified into one of the morphological or arrhythemic classifications shown in Appendix A.

The results of the morphological analysis are presented to the operator on the CRT display. If the result is other than "normal," the analysis is usually repeated for verification, or if there is a question regarding the results, the analysis may be repeated at the discretion of the operator. Following the morphological analysis, an arrhythemic analysis is performed by the computer.

The over-all accuracy of the HTS ECG program exceeds 90 per cent and the accuracy on normal ECGs is over 99 per cent.

6.5 Cardiac Catheterization

The HTS procedure for heart catheterization is similar to the above. Once the program is called, instructions are presented to the operator and the tests are made. The results are immediately available to the operator. Because of the volume of data taken (over about a three hour period), this test requires disk or tape storage. At the option of the operator, a hard copy may be obtained from the teletype.

The following major tests are performed:

Arterial & Venous Pressures

Cardiac Output (Dye Dillution Method)

O_2 Saturation

Gradient Analysis

Use of the computerized HTS is especially significant for this set of tests because of the time savings. The test is performed with

a local anesthetic at the patient's left wrist and left side of the groin, the two places where the catheter (a 1/8" diameter, 6' long tube) is inserted into a vein and fed up into the various heart chambers (24). The consciousness of the patient is vital since some of the tests with the catheter in the heart can cause fibrillation (rapid pulsation) of the heart, and recovery to normal after withdrawal is faster. It is also important for the physician to know the blood pressure (constantly changing) and oxygen saturation in each of the four chambers for both the resting and exercising condition of the patient. Some of the tests are performed while the patient lies on his back and pumps a bicycle wheel similar to that used in an exercise salon. Of course this can only be done if he is conscious.

The patient's comfort is usually the limiting factor in the length of time spent taking test data. The patient must lie flat on his back on un uncushioned table for the duration of the test. His endurance limit is generally three to four hours. Taking data by the old, manual method, using s strip chart recorder requires about four to five hours. Two separate sessions in the operating room are often required. Scheduling sometimes makes these sessions days apart, incurring additional expense while the patient waits in his hospital room.

Since the physician cannot visually interpret whether the live data is "reasonable" or not, he tries to perform each test three times to ensure that at least one test will have good data. For example, to measure the pressure in the left atrium (top left chamber), it is necessary to pass the catheter through both chambers of the right side

of the heart and into the pulmonary artery leading to the lungs. By wedging the catheter into a small arteriole, near the lungs, he can sense the back pressure from the left atrium through the pulmonary vein and the lungs. Until he knows the calculated pressure value at that point, he is uncertain whether or not his catheter made a good "seal" in the arteriole. He can see the approximate location on his x-ray fluoroscope, but the resolution is only as good as that of a fuzzy television picture.

Real time data collection and analysis using the HTS allows the physicain to take only one set of data, reducing the operating room time to as little as two hours. If a doubtful set of readings is taken, the test can be repeated on the spot since the calculated values are displayed immediately on the CRT. Besides adding to the comfort of the patient and increasing the availability of the operating room, the tests no longer use the three days calculation time previously required of a cardiologist to interpret the graphs.

6.6 ICU Monitoring

Patient monitoring in an Intensive Care Unit (ICU) requires polling of many different patients (up to 16) at infrequent intervals (1 second). The procedure is different from the other tests in that measurements are made continuously, but there is no operator intervention unless an exception occurs in the normal ECG pattern of one of the following:

Heart rate	Cardiac output
Stroke volume	Peripheral Vascular Resistance

Systolic Duration	Diastolic Pressure
Systolic Pressure	Mean Venous Pressure

The tests require an executive monitor for the computer and a time sharing system. Once this is developed, the basic ECG and catheterization programs can be adapted as has been done with the MEDLAB system.

6.7 Future Applications

While the Health Testing System is broader in scope and development than the screening application described here, the most economical use of the HTS is in screening applications. The modular nature of the HTS allows new tests to be readily automated and added. Proposed extensions shall provide automation of other desired screening functions such as:

1. Blood Chemistry
2. Urine Analysis
3. Anthropometry
4. Audiometry
5. Vision Acuity and Ocular Tension
6. Blood Pressure
7. Chest X-ray

An attractive feature of the HTS pre-admittance screening system is that it can provide the physicain with immediate information that would otherwise require considerable time to gather. Thus the extremely busy doctor is not so hesitant to take on new patients, since he can easily and rapidly determine their physiological condition once they have been through the screening.

Pre-admittance screening weeds out or calls attention to any

abnormality which would affect treatment. The test results are available by the time the patient reaches a hospital bed.

The system is valuable for use in, or adjacent to, hospitals for admittance of elective and non-emergency cases. It aids in the discovery of secondary diseases which could hinder treatment of the primary disease if not detected. It eliminates "false admittances;" thus saving doctor time and hospital space.

CHAPTER VII

CONCLUSIONS

7.1 HTS in Perspective

This thesis has attempted to incorporate a marriage of the interdisciplinary concepts of systems engineering. Though the primary focus has been on building the hardware and software components into a unified system, consideration of the "broader system" which includes marketing and economics has led to unexpected synergy of the completed Health Testing System. A compact, mobile computing package is available for any number of research and business applications outside the health care field. Whether or not the manufacturer will seek these new markets depends on the wisdom of his marketing strategy, but at least it can be said for the systems approach that the way has been opened by increased awareness of the alternatives.

APPENDIX A

HEALTH TESTING SYSTEM BROCHURE

Bio-Logics

Mobile Patient Screening and Monitoring System

Pulmonary Function · ECG Interpretation · Heart Catheterization · ICU Monitoring

The Bio-Logics Patient Screening and Monitoring System includes a modular computer, sensor interface circuitry, and data display and recording equipment to provide accurate and reliable data for health evaluation, research, and diagnosis.

Operation

Programs are selected and activated by means of a keyboard. Once a program is initiated, the remainder of the test is under program control from the computer. Instructions and options are presented to the operator on the memory oscilloscope. When tests are completed, the results are displayed to the operator and a permanent record is made by a teletype and/or magnetic tape, at the option of the operator.

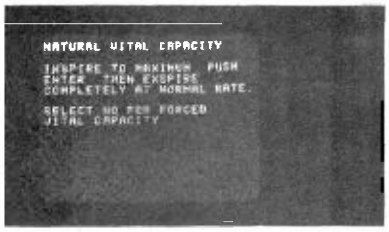
Features

- The system is small, lightweight, and mounted on casters for mobility.
- The system is simple to operate since all operations are controlled by a keyboard and step-by-step instructions are presented visually to the operator.
- Power is supplied by plugging the unit into a standard 115 V AC wall outlet.
- All construction is modular and uses micro-electronic technology with medium scale integration which minimizes the number of components and provides excellent reliability with very little maintenance.
- The system is versatile because modular construction permits the addition of new programs at any time without hardware modification.*

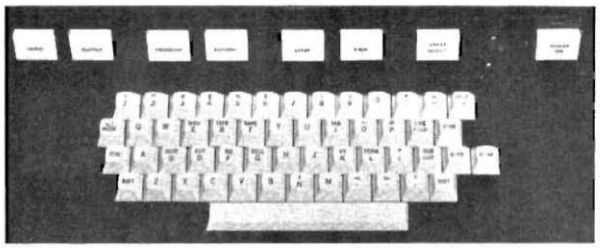
Equipment

Small Digital Computer
Pluggable Memory Modules
Memory Oscilloscope with Graphic and Alpha Numeric Character Generator
Magnetic Tape (Optional)
Teletype (Optional)

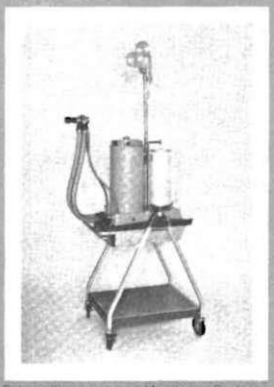
* A Pulmonary Function Program is currently available. ECG, Heart Catheterization, and ICU Monitoring will be available in the near future.



Test-by-step program instructions and resulting diagnostic data are presented visually to the operator.



Patient data and program instructions are entered through this simple keyboard.



Patient screening and Monitoring System interfaces directly with a standard spirometer.

All data can be recorded permanently by a standard teletype.

Standard breathing maneuvers are performed by the patient. The Patient Screening and Monitoring System computes respiratory volume and flow rate data from which the physician derives his diagnosis.

Functions Performed*

Pulmonary Function Tests

Vital Capacity (VC)
Forced Expiratory Vital Capacity (FVC)
One-second Volume ($FEV_{1.0}$)
Maximum Mid-Expiratory Flow ($FEF_{25-75\%}$)
Maximum Expiratory Flow ($FEF_{200-200}$)
Maximum Voluntary Ventilation (MVV)

ECG Interpretation

A. QRS Classifications

Normal
Left Bundle Branch Block
Right Bundle Branch Block
Incomplete RBB
Intraventricular Conduction Defect
Left Ventricular Hypertrophy
Right Ventricular Hypertrophy
Anterior Myocardial Infarction
Inferior Myocardial Infarction
Lateral Wall Myocardial Infarction
Left Axis Deviation
Right Axis Deviation

B. ST and T Classifications

Normal
Injury Pattern
Sub-endocardial Injury Pattern
Ischemia Pattern
Digitalis Effect Pattern

C. P Classifications

First Degree Block
Abnormal Atrial Focus
P Pulmonale
P Mitrale

D. Arrhythmia Analysis

Tachycardia
Bradycardia
Sinus Arrhythmia
Atrial Fibrillation
Ventricular Bigeminy
PVC
Abnormal Rhythm

Cardiac Catheterization

Arterial and Venous Pressures
Cardiac Output (Dye Dilution Method)
O_2 Saturation
Gradient Analysis

ICU Monitoring

Heart Rate
Stroke Volume
Cardiac Output
Peripheral Vascular Resistance
Systolic Duration
Diastolic Pressure
Mean Venous Pressure

* A Pulmonary Function Program is currently available. ECG, Heart Catheterization, and ICU Monitoring will be available in the near future.

Bio-Logics

Mobile Patient Screening and Monitoring System

Pulmonary Function

The Patient Screening and Monitoring System is connected to an electrical-output spirometer for pulmonary function testing. When the pulmonary program is activated, a message on the memory oscilloscope requests the operator to enter patient statistics (name, age, sex, etc.). These data are entered through the keyboard and displayed back for positive identification. After the information is verified, instructions are presented to the operator to proceed with the functional tests. When a patient completes the pulmonary function maneuvers, test results are presented visually for evaluation. If the results appear questionable, the test can be repeated and the results recorded as many times as desired. Forced Vital Capacity, One Second Volume, Maximum Expiratory Flow, and Mid-Expiratory Flow results are computed from the spirogram of the forced VC maneuver and are presented to the operator as well as the predicted percentage of normal, based on the patient's age, height, and sex. As the patient performs Forced Vital Capacity and Maximum Voluntary Ventilation maneuvers, the screening system plots a spirogram on the memory oscilloscope for real-time evaluation. Optionally, Residual Volume and Diffusing Capacity data can be computed with the Pulmonary Function Program. The results may be stored on magnetic tape or printed by a teletype.

ECG Interpretation

The Patient Screening and Monitoring System, connected to a modern ECG machine, provides the physician with a computerized data analysis plus ECG traces from the 12 standard leads and the 3 Franck leads.

The operating procedure is to first connect the leads to the patient, enter patient statistical data via the keyboard, and start the ECG machine. Data from the 12 standard leads and the 3 Franck leads are recorded automatically. The operator then pushes a button and initiates the computer analysis. ECG interpretation (normal, right axis deviation, etc.) plus such measurements as QRS, QT, PR intervals, P, R and T amplitudes and heart rate are displayed for the operator to decide if the conclusion is valid or if the analysis should be recycled. Once the operator is satisfied that the results are technically correct, the print button is pushed and the results are printed by teletype and/or stored on magnetic tape.

Catheterization and Patient Monitoring

The operation for heart catheterization and patient monitoring of vital functions is similar to that used for Pulmonary Function and ECG Interpretation. Programs which will soon be available for heart catheterization include pressure, cardiac output, oxygen saturation, pressure gradient analysis, and data editing. Once the program is called, instructions are presented to the operator and the tests are made. The results are immediately available to the operator. At the option of the operator, and after editing of the data, a permanent record may be made by the teletype and/or magnetic tape.

Bio-Logics, Inc. One Research Road, Salt Lake City, Utah 84112 • (801) 521-6195
Subsidiary of I-T-E Imperial Corp.

APPENDIX B

SYSTEM SUBROUTINES

SPECIAL ASSEMBLER SYMBOLS

```
SLT A,B  ;  SKIP IF A < B
SLE A,B  ;  SKIP IF A<= B
SEQ A,B  ;  SKIP IF A = B
SNE A,B  ;  SKIP IF A ≠ B
SGE A,B  ;  SKIP IF A>= B
SGT A,B  ;  SKIP IF A > B

AC0 = 0 ; Nova accumulators
AC1 = 1
AC2 = 2
AC3 = 3

[illegible]
```

BIOLOGICS I/O DEVICES

```
CRT          = 20  ;  Scope display
KB           = 21  ;  Auxillary keyboard
SW           = 22  ;  PROG SELECT switches
MT           = 23  ;  Magnetic tape
ATD          = 40  ;  A/D Converter + CHØ
CH1          =  1  ;  Multiplex channel #1
CH2 THRU CH15      ;  Multiplex channels
```

PAGE ZERO CONSTANTS

```
BB      =  4ØØ  ;  Buffer Begin (ATD)
BE      =  1377 ;  Buffer End

[illegible] =  177  ;  7 bit octal mask
[illegible] =  377  ;  8 bit octal mask

CR      =  15   ;  Carriage Return
LF      =  12   ;  Line Feed

NO      =  51   ;  Panel switch
YES     =  5Ø   ;  Panel switch
```

MEMORY MAP

```
Page Zero       Adr Ø thru 377 (octal).  Page zero is
                the only memory location which can be
                addressed directly from anywhere in core.

Adr Ø - 1       Program interrupt locations
        2       Start address for EDITOR & ASSEMBLER
        3       Restart EDITOR or ASSEMBLER

              Reserved for Floating Point Interpreter
        4       Start of Interpreter
        5       Start address of FINI
        6       Save when re-enter
        7       Address of write area

10 thru 17      Scratch pad

20 thru 27      Auto incrementing locations
30 thru 37      Auto decrementing locations

4Ø              Contains address of TTY input routine (GETC)
41              Contains address of TTY output routine (PUTC)
42              Interpreter link address
43

44 thru 237     User programs

24Ø thru 376    Variables for [illegible]
         377    Power fail [illegible]
                [illegible]

********  End of Page Zero  ********

4ØØ thru 7777   [illegible]

********  End of block #1  (4Ø96 words)  ********

       1ØØØØ    Bio-Logics System Routines
```

Jan 20, 1970
S. L. S.

Bio-Logics, Inc.

PHYSIOLOGICAL MEASUREMENT AND ANALYSIS

JAN. 13, 1970

85

PMA SYSTEM ROUTINES

PULMONARY FUNCTIONS

CALIB	Calibrate
FVC	Forced Vital Capacity
HSTRY	Personal history
MVV	Max Voluntary Ventilation
NVC	Normal Vital Capacity
PLMFN	Pulmonary option select
REPOR	Report
TV	Tidal Volume

INITIALIZATION

CLOCK	Set clock frequency
INTR	Acknowledge interrupt & determine source
OPTN	Select a sub program
PROG	Select a program
PWR	Power fail
REST	Restore system from R.O.M.

INPUT / OUTPUT

ATD1	Convert analog data samples to digital
ERASE	Erase CRT & position X=Ø, Y=15 (Upper left hand corner)
GETC	Read char & echo on TTY
GETT	Read tape character
GRAPH	Plot n data points on CRT
KEY	Read char & echo on CRT
MARK	Mark data graph at sample points
PUTC	Type TTY char from ACØ
PUTT	Write tape character
SCALE	Re-scale graph data for CRT display
SCOPE	Print CRT char from ACØ
TAPE	Block I/O handler

COMMENTS

INSRT	Change a binary number to ASCII decimal and insert into a .TXT message
MES1	Read message from keyboard (Eg. name)
MESS	Send a .TXT message to CRT
MEST	Send a .TXT message to TTY

CONVERSIONS

ATB	Core ASCII decimal to binary core
BTA	Binary to ASCII decimal (core to core)
DTB	Keyboard ASCII decimal to binary core
PRTY	Calculate odd parity in carry bit

MATHEMATICS

DIVU	Unsigned divide
MPYU	Unsigned multiply

EDITOR

COMMAND	FUNCTION
A	Append a source tape to the edit buffer. Add to end of current contents
B	Move CP to beginning of edit buffer, Before first character
C	Change "STRING1" to "STRING2" CSTRING1$STRING2$
nD	Delete n characters, starting at CP
F	Punch a form feed
nF	Punch n inches of leader (N<1ØØ)
I	Insert source statements in front of CP ISTRING$
nJ	Jump n lines from beginning of buffer
nK	Kill (Delete) n lines following the CP
L	Move CP to beginning of current line
nL	Move CP past n carriage returns
nM	Move CP n characters from current CP
N	Search for STRING; if not found, punch, Read and continue search ... NSTRING$
Q	Search without punching ... QSTRING$
P	Punch entire edit buffer & form feed
PW	Punch without form feed
nP	Punch n lines from current CP
nPW	Punch without form feed
R	Perform PY 1 time
nR	Perform PY n times
E	Perform P then YP to end of input tape
S	Search for "STRING", with CP After STRING ... SSTRING$
T	Type entire buffer W/O moving CP
nT	Type n lines from current CP
Y	Yank a page of source tape into edit buffer Delete current contents before reading
Z	Position CP after last character in buffer

SPECIAL COMMANDS

=	Print number of characters in edit buffer
:	Print number of lines in edit buffer
.	Print line number of current CP
RUB OUT	Erase last character typed
↑	Means "CTRL" key plus character
↑C	Cancel command STRING, or halt execution
↑G	Bell
↑I	Tab (N*8+1 = 9,17,25,...)
↑P	Complement tab echo switch
↑T	Reset input buffer & stop input device

DEBUG

COMMAND	FUNCTION
	"Open" means examine the contents of a register or address. "adr" means an octal memory address
A	Examine contents of all accumulators
nA	Open accumulator n
B	Examine all breakpoint locations
adrB	Place a breakpoint at adr
nN	Open count register for breakpoint n
C	Open the carry register
D	Deactivate all breakpoints
nD	Deactivate breakpoint n
nF	Punch n inches of tape leader
I	Open interrupt enable register (Enabled = 1, Disabled = Ø)
L	Specify program starting location
P	Proceed with program execution
nP	Proceed from the breakpoint and break again the nth time it is encountered
n,mP	Punch memory in binary format from adress n to address m inclusive. Punch end block of binary tape ...
E	Halt after loading
adrE	Jump to adr after loading
H	Open punch device register (TTO = Ø, PTP = 1)
R	Run, starting at address in L register
adrR	Begin execution at adr
S	Search, print memory contents from .. Ø thru 77777 inclusive
adrS	Ø thru adr inclusive
n,mS	n thru m inclusive Set bit pattern for search command ...
M	Mask says which bits to look at
W	Word tells value of digits to sense
T	Open teletype DONE flags register (TTO DONE = Bit 11, TTI DONE = Bit 15)

SPECIAL COMMANDS

"CR"	Close current address
"LF"	Close current address & open next one
↑	Close current address & open previous one (↑ means shift + N)
adr/	Examine adr contents
adr!	Open address without printing contents
EXP=	Evaluate EXP (arithmetic expression) and give octal result

```
                    **********************
                    *  HEALTH TESTING    *    STEVE STUMPH
                    *  SYSTEM ROUTINES   *
                    **********************

PAGE                        *** COMMENTS ***
----                          ------------
  5       MESI    INSERT MESSAGE FROM KEYBOARD (EG. NAME)
          MESIW   SAME WITHOUT END OF MESSAGE CHAR (NULL)
          MESS    SEND A .TXT MESSAGE TO THE SCOPE
          MESSW   SAME WITHOUT CR & LF
  6       MEST    SEND A .TXT MESSAGE TO THE TTY
          MESTW   SAME WITHOUT CR & LF
          PACK.   PACK TWO 8-BIT BYTES PER WORD
          PICK.   UNPACK .TXT MESSAGES

                    *** CONVERSIONS ***
                      -------------
  7       ATB     CORE ASCII DECIMAL -TO- CORE BINARY
          BTA     CORE BINARY -TO- CORE ASCII DECIMAL
          BTAL    SAME, LEFT JUSTIFIED
  8       BTD     CORE BINARY -TO- SCOPE ASCII DECIMAL
          BTDU.   CORE BINARY -TO- CORE ASCII DECIMAL (UNPACKED)
          DTB     KEYBOARD ASCII DECIMAL -TO- CORE BINARY

                    *** INITIALIZATION ***
                      ---------------
  9       BFINI   INITIALIZE A BUFFER FROM AC0
          CLOCK   REAL TIME CLOCK
          ERM     NON-ZERO ERROR CODE
          ERR     RECOVERABLE ERROR
 10       INT     INTERRUPT RETURN IF USING CLOCK
          INTR    INTERRUPT RE-ENTRY, POWER FAIL, ETC.
          OPTN    SELECT AN OPTION WITHIN A MAIN PROGRAM
          PROG    SELECT A MAIN APPLICATION PROGRAM
          SAVE    SAVE ACCUMULATORS & CARRY BIT
          RSVEW   RESTORE AC'S & CARRY

                    *** INPUT/OUTPUT ***
                      ------------
 11       ADOUT   OUTPUT "ATDI" DATA FROM CIRCULAR BUFFER
          ATDI    CONVERT DATA SAMPLES FROM ANALOG TO DIGITAL
          ATDS    RE-ENTRY FOR ATDI AFTER INTERRUPT
          ERASE   CLEAR CRT & REPOSITION X=0, Y=14
 12       GETC.   READ A 7 BIT ASCII CHAR FROM TTY
          GETT    READ A TAPE CASSETTE WORD
          GRAPH   PLOT A DOT GRAPH ON THE CRT
          KEY.    READ A 7 BIT ASCII CHAR FROM SCOPE KEYBOARD
 13       MARK    MARK DATA GRAPH AT SAMPLE POINTS
          PUTC.   TYPE AN ASCII CHAR ON THE TTY
          PUTT    WRITE A TAPE CASSETTE WORD
          REPOS   REPOSITION SCOPE (X=0, Y=14) WITHOUT ERASE
 14       READ    FORMATTED INPUT
 15       SCALE   RESCALE GRAPH DATA FOR CRT
          SCOPE   PRINT A 7 BIT ASCII CHAR ON THE SCOPE
          TAPE    BLOCK I/O HANDLER FOR CASSETTE
 16       WRITE   FORMATTED OUTPUT

                    *** MATHEMATICS ***
                      ------------
 17       DIV.    SAME W/O SAVING ACCUMULATORS
          DIVI.   UNSIGNED INTEGER DIVIDE W/O SAVING ACCUMULATORS
          MPY.    SAME W/O SAVING ACCUMULATORS
          MPYU.   UNSIGNED MULTIPLY W/O SAVING ACCUMULATORS
```

GENERAL DESCRIPTION:

EACH OF THE NAMES ON THE PREVIOUS PAGE CALLS A SYSTEM SUBROUTINE. THE NAME IS STORED IN THE "BIO-LOGICS ASSEMBLER" SYMBOL TABLE AND IS CONVERTED WITH A ".DUSR" COMMAND TO A "JSR @XXX". THE "XXX" IS A PAGE ZERO ADDRESS WHICH CONTAINS THE STARTING ADDRESS OF THE SUBROUTINE. THIS PERMITS THE ACTUAL ADDRESS TO VARY WITHOUT AFFECTING APPLICATION PROGRAM ASSEMBLYS. THE ONLY TIME IT IS NECESSARY TO REASSEMBLE AN APPLICATION PROGRAM IS WHEN A MAJOR CHANGE IS MADE TO THE "BIO-LOGICS ASSEMBLER". THIS HAS HAPPENED ONLY ONCE.

THERE ARE TWO TYPES OF SUBROUTINES IN THE SYSTEM:
1) THE SIMPLE TO USE, GENERAL PURPOSE ROUTINES. THESE HAVE A NAME WITH NO "." AT THE END. TO USE THESE, A PROGRAMMER MERELY ENTERS THE NAME IN HIS PROGRAM, WITH SUCCESSIVE LINES CONTAINING THE ARGUMENTS FOR CALLING THAT ROUTINE. EXCEPT FOR AC3 (ACCUMULATOR #3), WHICH IS DESTROYED BY THE "JSR" USED TO CALL THE SUBROUTINE, ALL OTHER ACCUMULATORS & AND THE CARRY BIT ARE UNCHANGED AFTER THE RETURN FROM THE SYSTEM ROUTINE.
2) THE SPECIAL PURPOSE ROUTINES ARE MEANT PRIMARILY FOR USE BY THE BIO-LOGICS PROGRAMMERS. THESE NAMES END WITH A "." AND DO NOT SAVE ANY ACCUMULATORS. IT IS UP TO THE USER TO PREPARE ANY NEEDED ACCUMULATOR VALUES REQUIRED BY THESE ROUTINES. THIS ALTERNATIVE IS AVAILABLE FOR A PROGRAMMER WHO WANTS TO SAVE THE (APPROXIMATELY) 100 MICRO-SECONDS EXTRA OVERHEAD REQUIRED TO SAVE AND RESTORE THE ACCUMULATORS.

WITHIN THE SYSTEM ROUTINES ASSEMBLY LISTING, A GENERAL RULE HAS BEEN TO BEGIN THE NAME OF AN ENTRY POINT LABEL WITH A ".". FOR EXAMPLE, THE ROUTINE CALLED BY THE NAME "KEY.", WOULD ACTUALLY BE NAMED ".KEY". SIMILAR NAMES ARE USED FOR CALLING AND ENTRY WHENEVER POSSIBLE.
ALL NAMES USED FOR CALLING SYSTEM ROUTINES ARE RESERVED WORDS, AND CANNOT BE USED BY AN APPLICATION PROGRAMMER. IN ADDITION, THERE ARE A NUMBER OF COMMONLY USED CONSTANTS WHICH HAVE THEIR NAMES CONTAINED WITHIN THE "BIO-LOGICS ASSEMBLER" AND THEIR VALUES STORED IN PAGE ZERO WHEN THE SYSTEM ROUTINES ARE PRESENT.

```
SPECIAL CONSTANTS CONTAINED IN PAGE ZERO:

        THESE BUFFER VALUES SHOULD BE MODIFIED BY USER
        BB      = 0     BUFFER BEGIN (ATD CONVERTER)
        BE      = 0     BUFFER END
        CLKS    = 0     ADDR OF CLOCK USER PROGRAM
        CR      = 15    CARRIAGE RETURN
        LF      = 12    LINE FEED
        NO      = 51    PANEL SWITCH CODE
        SP      = 40    ASCII BLANK SPACE
        YES     = 50    PANEL SWITCH CODE
        ZERO    = 60    ASCII ZERO

OCTAL CONSTANTS:

        C7      = 7
        C10     = 10
        C12     = 12
        C24     = 24
        C27     = 27    ATD BUFFER POINTER ADDRESS
        C177    = 177   7 BIT MASK
        C377    = 377   8 BIT MASK
        C400    = 400
        C1400   = 1400

DECIMAL CONSTANTS:

        D15     = 17
        D128    = 200
        D200    = 310
        D256    = 400
        D273    = 421
        D300    = 454
        D310    = 466
        D1200   = 1200
        D7000   = 15530

DEFINE BIO-LOGICS I/O DEVICES:

        TTI     = 10    TELETYPE KEYBOARD
        TTO     = 13    TELETYPE PRINTER
        CRT     = 20    SCOPE DISPLAY
        KY      = 21    AUXILLARY KEYBOARD
        SW      = 22    PROGRAM SELECT SWITCHES
        MTA     = 23    MAGNETIC TAPE
        ATD     = 40    ANALOG TO DIGITAL CONVERTER

SPECIAL ASSEMBLER MNEMONICS:

        AC0     = 0
        AC1     = 1
        AC2     = 2
        AC3     = 3
        NOP     = 401   JMP .+1

        SLT #,# = SKIP IF AC# <  AC#
        SLE #,# = SKIP IF AC#<=  AC#
        SEQ #,# = SKIP IF AC# =  AC#
        SNE #,# = SKIP IF AC#<>  AC#
        SGE #,# = SKIP IF AC#>=  AC#
        SGT #,#   SKIP IF AC# >  AC#
```

****** MESSAGE HANDLING ******

ALL MESSAGE HANDLING ROUTINES HAVE CHARACTER ADDRESSING CAPABILITIES. SINCE WE PACK TWO ASCII CHARACTERS PER WORD, A METHOD IS NEEDED TO DESIGNATE THE LEFT OR RIGHT CHARACTER. BY SUPPLYING A MESSAGE ADDRESS MULTIPLIED BY 2, THE RIGHTMOST OR LEAST SIGNIFICANT BIT CAN BE USED AS A FLAG TO INDICATE WHICH HALF OF THE WORD IS BEING ADDRESSED. AN EVEN NUMBER (ZERO) SELECTS THE LEFT CHARACTER AND AN ODD NUMBER (ONE) SELECTS THE RIGHT CHARACTER. THIS TECHNIQUE IS FURTHER EXPLAINED IN "HOW TO USE THE NOVA", UNDER "BYTE MANIPULATION".

```
        ASSEMBLED
ADDRESS INSTRUCTION     MNEMONIC        EXPLANATION
------- -----------     --------        -----------
XXXXX   006XXX          MES1    ; JSR @XXX
XXXXX   002055          M1*2+15 ; MESSAGE ADDRESS * 2 + 15 OCTAL CHARS
                        ....    ; SUBROUTINE WILL "RETURN" TO HERE
                          .
                          .
1020    XXXXXX  M1:     .TXT"PATIENT AGE:    "
```

INSERT A MESSAGE STARTING AT THE 15TH OCTAL (13 DECIMAL) CHARACTER OF A .TXT STATEMENT LABELED "M1". THE FIRST 14 OCTAL CHARACTERS WILL REMAIN UNCHANGED, BUT ALL PREVIOUS CHARACTERS WHICH FOLLOW WILL BE ERADICATED BY THE NEW MESSAGE. A CARRIAGE RETURN ON THE KEYBOARD INDICATES THE END OF THE MESSAGE TO BE INSERTED. THE CARRIAGE RETURN GOES INTO CORE AS A NULL (ALL ZEROS) CHARACTER, WHICH THE MESSAGE OUTPUT ROUTINE RECOGNIZES AS AN END OF MESSAGE.

"MESIW" WORKS THE SAME WAY AS "MESI" EXCEPT THAT THE NULL CHARACTER IS NOT ENTERED. THIS ALLOWS INSERTING A MESSAGE INTO THE MIDDLE OF ANOTHER MESSAGE. EXAMPLE:

```
        BEFORE: .TXT"AGE:    YEARS"
        AFTER:  .TXT"AGE: 26 YEARS"
                  .
                  .
1020    XXXXXX  M1:     .TXT"PATIENT AGE:    "

        ********************
        **** CAUTION ****
        ********************
```

WHEN USING ANY OF THE COMMENTS ROUTINES HAVING "W" (WITHOUT CARRIAGE RETURN) IN THEIR NAMES, MAKE SURE THERE IS A NULL CHARACTER AT THE END OF THE INTENDED STRING. THE ABOVE EXAMPLE CAUSES NO PROBLEM. HOWEVER, THE FOLLOWING CASE WILL CAUSE ENDLESS GRIEF IF "MESIW" IS USED:

```
         1:     .TXT"AGE"   HORRORS!!!
        M1:     .TXT"AGE    "   ; THIS IS OK AS LONG AS THE MESSAGE
                                ; ENTERED IS 4 CHARACTERS OR LESS

        MESIW
        M1*2+4  ; INSERT AGE INTO THE MESSAGE
```

```
MESI    INSERT MESSAGE FROM THE KEYBOARD (EG. NAME)
----
CALLING SEQUENCE:
        MESI
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        ....    ; RETURN

ASSUMPTIONS:
        EACH CHAR IS ECHOED ON THE CRT OR TTY AS IT IS ENTERED.  A
        CARRIAGE RETURN OR "ENTER" INDICATES THE END OF MESSAGE.  THE
        CR WILL BE ECHOED, BUT NOT INSERTED INTO THE MESSAGE.  A NULL
        CHAR WILL BE INSERTED IN ITS PLACE.  ALL THE MESSAGE OUTPUT
        ROUTINES RECOGNIZE THE NULL AS AN END OF MESSAGE CHAR AND WILL
        NORMALLY SEND A CR & LF AT THE END.  "MESSW" AND "MESTW" ARE THE
        EXCEPTIONS AND WILL NOT SEND A CR & LF.
        SUFFICIENT STORAGE MUST BE RESERVED TO CONTAIN THE MAXIMUM
        LENGTH MESSAGE TO BE ENTERED.
PROGRAMS CALLED:  GETC., KEY., PACK., PUTC., RENEW, SAVE, SCOPE

        ------------------------

MESIW   SAME WITHOUT END OF MESSAGE CHAR (NULL)
-----
CALLING SEQUENCE:
        MESIW
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        ....    ; RETURN

ASSUMPTIONS:
        SAME AS "MESI" EXCEPT NO CHAR WILL BE INSERTED FOR THE
        CARRIAGE RETURN AT THE END OF THE MESSAGE.
        CAUTION--- MAKE SURE THERE IS AN END OF MESSAGE NULL CHAR
                FOLLOWING "MESIW".
PROGRAMS CALLED:  SAME AS "MESI"

        ------------------------

MESS    SEND A .TXT MESSAGE TO THE SCOPE
----
CALLING SEQUENCE:
        MESS
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        ....    ; RETURN

ASSUMPTIONS:
        NULL OR OCTAL 15 GIVES CR & LF.  THE MESSAGE CONTAINS TWO ASCII
        CHARS PER WORD, AND IS TERMINATED BY A NULL BYTE.
PROGRAMS CALLED:  PICK., PUTC., RENEW, SAVE, SCOPE

        ------------------------

MESSW   SAME WITHOUT CR & LF AT END OF MESSAGE
-----
CALLING SEQUENCE:
        MESSW
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        ....    ; RETURN

ASSUMPTIONS:
        SAME AS "MESS" EXCEPT THE NULL CHAR AT THE END OF MESSAGE
        DOES NOT CAUSE A CR & LF TO BE SENT.
PROGRAMS CALLED:  SAME AS "MESS"
```

```
MEST    SEND A .TXT MESSAGE TO THE TTY
----
CALLING SEQUENCE:
        MEST
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        ....    ; RETURN

ASSUMPTIONS:
        NULL OR OCTAL 15 GIVES CR & LF.  THE MESSAGE CONTAINS TWO
        ASCII CHARS PER WORD, AND IS TERMINATED BY A NULL BYTE.
PROGRAMS CALLED: PICK., PUTC
        ------------------------
MESTW   SAME AS "MEST" WITHOUT CR & LF
-----
CALLING SEQUENCE:
        MESTW
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        ....    ; RETURN

        ------------------------

PACK.   PACK .TXT MESSAGES, 2 CHAR PER WORD
-----
CALLING SEQUENCE:
        PACK.
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS  EVEN=LEFT
        ....    ; RETURN                                  ODD =RIGHT

        ONE CHAR AT A TIME IS PASSED IN AC0 EACH TIME THIS ROUTINE
        IS CALLED.
ASSUMPTIONS:
        AC0 CONTAINS AN 8 BIT BYTE OR CHAR, RIGHT JUSTIFIED.  WILL
        CHANGE ONLY 1 CHARACTER IN THE .TXT MESSAGE.  UNLESS A NULL IS
        PASSED AT THE END OF THE MESSAGE, THERE MUST ALREADY BE A NULL
        (ALL ZEROS) CHARACTER TO INDICATE "END OF MESSAGE".  THE
        "ADDRESS OF MESSAGE" IN THE CALLING ROUTINE IS AUTOMATICALLY
        INCREMENTED BY "PACK".  AN EVEN NUMBERED ADDRESS PACKS THE LEFT
        CHAR OF A WORD.  AN ODD NUMBER PACKS THE RIGHT CHAR OF A WORD.
        DESTROYED:  AC1, AC2, AC3, CARRY
PROGRAMS CALLED: NONE
        ------------------------
PICK.   UNPACK A .TXT MESSAGE
-----
CALLING SEQUENCE:
        PICK.
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS  EVEN=LEFT
        ....    ; RETURN IF CHAR WAS A NULL               ODD =RIGHT
        ....    ; RETURN IF ANY OTHER CHAR

        ONE CHARACTER AT A TIME IS RETRIEVED IN AC0 EACH TIME THIS
        ROUTINE IS CALLED.
ASSUMPTIONS:
        AC0 WILL RECEIVE AN 8 BIT BYTE OR CHAR, RIGHT JUSTIFIED.
        THE TWO RETURNS ALLOW A CALLING PROGRAM TO OUTPUT A STRING
        OF CHARACTERS TO ANY DEVICE, THEN STOP WHEN A NULL CHARACTER
        INDICATES "END OF MESSAGE".  THE "ADDRESS OF MESSAGE" IS
        AUTOMATICALLY INCREMENTED BY "PICK".  AN EVEN  NUMBERED ADDRESS
        PICKS THE LEFT CHAR OF A WORD.  AN ODD NUMBER PICKS THE
        RIGHT CHAR OF A WORD.
        DESTROYED: AC0, AC2, AC3, CARRY
PROGRAMS CALLED: NONE
```

*** CONVERSIONS ***

```
ATB     CORE ASCII DECIMAL(PACKED) -TO- CORE BINARY
---     (SIMILAR TO DTB)

CALLING SEQUENCE:
        ATB
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        B1      ; ADDRESS OF BINARY NUMBER
        ....    ; RETURN

        CONVERT UP TO 5 ASCII NUMBERS TO A SIGNED 16 BIT
        BINARY NUMBER.
ASSUMPTIONS:
        THE FIRST CHARACTER CAN BE EITHER A SIGN (+ OR -), OR AN
        ASCII DIGIT. THERE CAN BE BETWEEN ONE AND FIVE DIGITS, BUT
        NO COUNT OF DIGITS IS MADE.  MORE THAN 5 DIGITS WILL
        GIVE THE SAME RESULT AS IF ENTERED FROM THE KEYBOARD.
        CONVERSION WILL CONTINUE UNTIL A NULL (ALL ZEROS) BYTE
        IS REACHED OR UNTIL A NON NUMERIC CHARACTER IS REACHED.
PROGRAMS CALLED: NONE

        ------------------------

BTA     CORE BINARY -TO- CORE ASCII DECIMAL (PACKED)
---     SAME AS BTD EXCEPT ADDRESS*2, AND CHARACTERS ARE PACKED

CALLING SEQUENCE:
        BTA
        B1      ; ADDRESS OF BINARY NUMBER (+ OR - IS VALID)
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS (LEFTMOST CHAR)
        ....    ; RETURN

        CONVERT A 16 BIT BINARY NUMBER TO A SIGN AND 5 ASCII NUMBERS,
        TO BE STORED IN 6 HALF-WORDS STARTING AT ADDRESS OF MESSAGE
        + NUMBER OF CHARACTERS. THE DIGITS WILL BE RIGHT JUSTIFIED
        WITH LEADING ZEROS REPLACED BY BLANK SPACES.
ASSUMPTIONS:
        THE PROGRAMMER WILL ENSURE THAT A NULL (ALL ZEROS) CHARACTER
        WILL FOLLOW AT SOME POINT AFTER THE INSERTION TO INDICATE
        "END OF MESSAGE". THE INSERTION MAY START ON A FULL WORD OR
        HALF WORD BOUNDARY, WITH THE OTHER HALF-WORD BEING UNALTERED.
PROGRAMS CALLED: BTDU

        ------------------------

BTAL    SAME AS BTA EXCEPT LEFT JUSTIFIED
----
CALLING SEQUENCE:
        BTAL
        B1      ; ADDRESS OF BINARY NUMBER
        M1*2    ; ADDRESS OF MESSAGE*2 + NUMBER OF CHARS
        ....    ; RETURN
```

```
BTD     CORE BINARY -TO- TTY ASCII DECIMAL
---
CALLING SEQUENCE:
        BTD
        B1      ; ADDRESS OF BINARY NUMBER
        ....    ; RETURN

ASSUMPTIONS:
        LEADING ZEROS WILL BE DELETED AND THE DECIMAL STRING WILL
        BE LEFT JUSTIFIED. THE BINARY NUMBER IS A SINGLE PRECISION,
        SIGNED NUMBER.

        ------------------------

BTDU.   CORE BINARY -TO- CORE ASCII DECIMAL (UNPACKED)
-----
CALLING SEQUENCE:
        BTDU.
        PUTC.   ; ADDRESS OF CHAR OUTPUT ROUTINE ("PUTC." OR OTHER)
        ....    ; RETURN

        CONVERT A 16 BIT BINARY NUMBER IN AC1 TO A SIGN AND 5 ASCII
        NUMBERS PASSED TO "PUTC." THRU AC0.
ASSUMPTIONS:
        A "+" SIGN BECOMES A " " AND THE "-" SIGN IS RIGHT JUSTIFIED.
        THE 7 BIT ASCII VALUES WILL BE UNPACKED WITH ONE CHAR PER
        WORD. LEADING ZEROS WILL BE REPLACED BY " " CHARACTERS.
        THERE ARE EXACTLY 6 CHARS, AND NO NULL AT THE END.
        DESTROYED:  AC0, AC1, CARRY

        ------------------------

DTB     TTY ASCII DECIMAL -TO- CORE BINARY
---
CALLING SEQUENCE:
        DTB
        B1      ; ADDRESS OF BINARY NUMBER
        ....    ; RETURN

        READ A STRING OF UP TO 5 DECIMAL NUMBERS FROM THE KEYBOARD
        AND CONVERT TO A 16 BIT BINARY NUMBER.
INPUT:  CALLS "KEY". ONE ASCII CHAR AT A TIME IN AC0.
ASSUMPTIONS:
        OUTPUT IS A BINARY INTEGER IN ADDRESS SPECIFIED.
        EACH DECIMAL CHARACTER ENTERED WILL BE ECHOED
        ON THE CRT DISPLAY WITHOUT REPOSITIONING THE CURSER.
        EITHER A CR OR "ENTER" WILL TERMINATE THE STRING
        AND A CR WILL BE ECHOED ON THE CRT.
PROGRAMS CALLED: KEY., SCOPE, ATB
```

**** INITIALIZATION ****

BFINI INITIALIZE A BUFFER FROM AC0

CALLING SEQUENCE:
```
        BFINI
        BEGIN   ; FIRST STORAGE ADDRESS
        END     ; LAST STORAGE ADDRESS
        ....    ; RETURN
```
ASSUMPTIONS:
        AC0 CONTAINS THE VALUE TO BE STORED IN LOCATIONS 'BEGIN'
        THRU 'END' INCLUSIVE.
PROGRAMS CALLED: NONE

CLOCK REAL TIME CLOCK

CALLING SEQUENCE:
```
        CLOCK
        FREQ    ; FREQUENCY = 2**N, WHERE N IS 5 THRU 12
                ; EG. 32, 64, 128, 256, .... 4096
        ADR     ; INTERRUPT ADDRESS
        ....    ; RETURN
```
ASSUMPTIONS:
        TO STOP THE CLOCK, CALL THIS ROUTINE USING A '0' FREQUENCY.
PROGRAMS CALLED: NONE

ERN NON-RECOVERABLE ERROR

CALLING SEQUENCE:
```
        ERN
        ....    ; NO RETURN. WILL HALT.
```
ASSUMPTIONS:
        THIS ROUTINE IS ENTERED VIA A 'JSR' INSTRUCTION WHICH RETAINS
        THE CALLING ADDRESS+1 IN AC3. THE ERROR ADDRESS IS PRINTED
        OUT ON THE TELETYPE WITH THE MESSAGE "ERROR AT XXXXX". ALL
        INTERRUPTS ARE CLEARED. AC0 THRU AC2 AND CARRY BIT ARE
        NOT DISTURBED.
PROGRAMS CALLED: NONE

ERR RECOVERABLE ERROR

CALLING SEQUENCE:
```
        ERR
        ....    ; RETURN
```
ASSUMPTIONS:
        SAME AS "ERN" EXCEPT THIS ROUTINE DOES NOT HALT AND THE
        INTERRUPTS ARE NOT CLEARED. AC0 THRU AC2 AND THE CARRY BIT
        ARE NOT DISTURBED.
PROGRAMS CALLED: NONE

INT INTERRUPT RETURN IF USING CLOCK

CALLING SEQUENCE:
```
        INT
        ....    ; RETURN
```
ASSUMPTIONS:

PROGRAMS CALLED: NONE

INTR INTERRUPT RE-ENTRY, POWER FAIL, ETC.

CALLING SEQUENCE:
```
        JSR @0
        JMP @1  ; RETURN
```
ASSUMPTIONS:

PROGRAMS CALLED: @CLKS, ERN, ERR, INKBD, OUTSC, OUTTY, PROG, PWR

OPTN SELECT AN OPTION WITHIN A MAIN PROGRAM

CALLING SEQUENCE:
```
        PRESS "OPTNS" BUTTON
        ....    ; NO RETURN
```
ASSUMPTIONS:

PROGRAMS CALLED: PROG

PROG SELECT A MAIN APPLICATION PROGRAM

CALLING SEQUENCE:
```
        PRESS "PROGM" BUTTON
        ....    ; NO RETURN
```
ASSUMPTIONS:

PROGRAMS CALLED: BLOOD GAS, ECG, EEG, ICU, OPTN, ERASE, MESS, PLMFN

SAVE SAVE ACCUMULATORS & CARRY BIT

CALLING SEQUENCE:
```
        SAVE
        ....    ; RETURN
```
ASSUMPTIONS:
        AC0 THRU AC3 AND CARRY ARE SAVED IN A PUSH DOWN STACK LOCATED
        AT LOC 446. NONE ARE DESTROYED.

RENEW RESTORE AC'S & CARRY BIT

CALLING SEQUENCE:
```
        RENEW
        ....    ; RETURN
```
ASSUMPTIONS:
        RESTORE AC0 THRU AC3 FROM PUSH DOWN STACK.

```
                *** INPUT/OUTPUT ***

ADOUT   OUTPUT "ATDI" DATA FROM CIRCULAR BUFFER
------
CALLING SEQUENCE:
        ADOUT
        BI      ; BINARY DATA WORD (AFTER RETURN)
        ....    ; RETURN

ASSUMPTIONS:
        A STORAGE LOCATION AFTER "ADOUT" MUST BE RESERVED FOR
        "BINARY DATA WORD".

        ------------------------

ATDI    SET UP CLOCK FREQUENCY & AUTOMATICALLY
----    CONVERT DATA SAMPLES FROM ANALOG TO DIGITAL
CALLING SEQUENCE:
        ATDI
        RATE    ; SAMPLE RATE = 2**N, WHERE 'N' IS AN INTEGER(5 THRU 12)
                ; EG. 32, 64, 128, 256, .... 4096
        CHN*400+N1      ; FIRST CHANNEL + NUMBER OF CHANNELS
        ....    ; RETURN

ASSUMPTIONS:
        BITS 0 THRU 8 INDICATE THE FIRST CHANNEL NUMBER. CHAN# * 400
        (OCTAL) SHIFTS THE VALUE 8 BITS TO THE LEFT.  BITS 7 THRU 15
        INDICATE THE NUMBER OF CHANNELS.
        TO STOP SAMPLING, CALL THIS ROUTINE USING A '0' SAMPLE RATE.
        THE SAMPLING MUST BE STOPPED BEFORE A NEW CHANNEL CAN BE
        SPECIFIED.

        ------------------------

ATDS    RE-ENTRY FOR ATDI AFTER INTERRUPT
----    (CAN ONLY BE ENTERED FROM THE INTERRUPT PROGRAM)
CALLING SEQUENCE:
        ATDI
        N1      ; SAMPLES/SECOND
        CHN*400+N1
        ....    ; RETURN

        ------------------------

ERASE   CLEAR CRT & REPOSITION X=0, Y=14
------
CALLING SEQUENCE:
        ERASE
        ....    ; RETURN

ASSUMPTIONS:
        THE NEXT CHAR POSITION WILL BE IN THE UPPER LEFT HAND CORNER
        AS SEEN BY THE OPERATOR.  A "STATION ACTIVE" COMMAND IS SENT,
        FOLLOWED BY AN "ERASE" COMMAND AND A LONG SOFTWARE DELAY
        (269 MILLISECONDS) FOR THE SCOPE HARDWARE.  THE DOT COUNTER
        USED IN "MAPK" IS RESET TO ZERO AND THE X POSITION, Y POSITION,
        & X INCREMENT COMMANDS ARE SENT TO THE SCOPE.

PROGRAMS CALLED: PUTD (INTERNAL)

GETC.   READ A 7 BIT ASCII CHAR FROM THE TTY
----
CALLING SEQUENCE:
        GETC.
        ....    ; RETURN

OUTPUT: AC0 = 7 BIT ASCII CHAR, RIGHT JUSTIFIED
ASSUMPTIONS:
        EACH CHAR IS ECHOED ON THE TTY. AN 8 BIT CHAR IS READ
        AND THE PARITY BIT DELETED, LEAVING A 7 BIT CHARACTER.
        DESTROYED:  AC0, AC3, CARRY
PROGRAMS CALLED: PUTC.

        ------------------------

GETT    READ A TAPE CASSETTE WORD
----

        ------------------------

GRAPH   PLOT A DOT GRAPH ON THE CRT
-----
CALLING SEQUENCE:
        GRAPH
        ....    ; RETURN

INPUT: AC0 = BINARY WORD FOR "Y" VALUE
ASSUMPTIONS:
        X=0 IS ALREADY SET BY "ERASE" BEFORE FIRST POINT IS SENT. THE
        "X" POSITION IS AUTOMATICALLY INCREMENTED. A FULL SCALE GRAPH
        IS 512 X 512. DATA HAS BEEN "MARKED" AND SCALED IF REQUIRED.
PROGRAMS CALLED: XYOUT (INTERNAL)

        ------------------------

KEY.    READ A 7 BIT ASCII CHAR FROM SCOPE KEYBOARD
----
CALLING SEQUENCE:
        KEY.
        ....    ; RETURN

OUTPUT: AC0 = ASCII CHAR, RIGHT JUSTIFIED
ASSUMPTIONS:
        EACH CHAR IS ECHOED ON THE CRT WITHOUT REPOSITIONING THE
        CURSOR.  THE PROGRAM TESTS SWITCH BIT 0.  0=CRT, 1=TTY
        THE ROUTINE CAN HANDLE ALL ALPHA CHARS & 0 THRU 9. THE 8 BIT
        CHAR IS READ AND THE PARITY BIT IS DELETED, LEAVING A
        7 BIT CHARACTER. THE FOLLOWING SPECIAL CHARS ARE PERMITTED:
           ENTER = 215 (SAME AS CR)
               .  = 056 (PERIOD)
             YES  = 072 (ARBITRARY VALUE)
              NO  = 173 (ARBITRARY VALUE)
        DESTROYED:  AC0, AC3, CARRY
PROGRAMS CALLED: SCOPE
```

```
MARK    MARK DATA GRAPH AT SAMPLE POINTS
----
CALLING SEQUENCE:
        MARK
        BI      ; ADDRESS OF DATA POINT
        ....    ; RETURN

        THE NEXT THREE DATA POINTS AFTER THE ADDRESS GIVEN WILL
        BE REDUCED IN VALUE BY 8, 16, & 32, TO CREATE AN ALMOST VERTICAL
        MARK ON THE GRAPH.
ASSUMPTIONS:
        A VALID DATA SAMPLE HAS BEEN TAKEN, SCALED, AND THE POINT
        TO BE MARKED HAS BEEN DETERMINED.
PROGRAMS CALLED: XYOUT (INTERNAL)

        ------------------------

PUTC.   TYPE AN ASCII CHAR ON THE TTY
-----
CALLING SEQUENCE:
        PUTC.
        ....    ; RETURN

INPUT:  AC0 = ASCII CHAR , RIGHT JUSTIFIED.
ASSUMPTIONS:  EITHER A 7 BIT OR 8 BIT CHARACTER IS VALID.  THE
        CHARACTER IN AC0 REMAINS UNCHANGED.  NULL OR OCTAL 15
        GIVES CR & LF.
        DESTROYED:  AC3, CARRY
PROGRAMS CALLED:  TYPE (INTERNAL)

        ------------------------

PUTT    WRITE A TAPE CASSETTE WORD
----
CALLING SEQUENCE:
        PUTT
        ....    ; RETURN

ASSUMPTIONS:


        ------------------------

REPOS   REPOSITION SCOPE (X=0, Y=14) WITHOUT ERASE
-----
CALLING SEQUENCE:
        REPOS
        ....    ; RETURN

ASSUMPTIONS:
        EXACTLY THE SAME AS "ERASE" WITHOUT THE STATION ACTIVE
        AND ERASE COMMANDS.
PROGRAMS CALLED:  PUTD (INTERNAL)
```

```
READ    FORMATTED INPUT
----
CALLING SEQUENCE:
        READ
        KY      ;DEVICE CODE
        F101    ;FORMAT STATEMENT ADDRESS
        ALPHA   ;ALPHA VARIABLE NAME
        FLOAT   ;FLOATING POINT VARIABLE
        INT     ;INTEGER VARIABLE
        ....    ;RETURN

CPUIN:  READ
        CPU     ;SPECIAL CASE REQUIRING DOUBLE ARGUMENTS
        F101    ;FORMAT STATEMENT ADDRESS
        ALPHA   ;ALPHA VARIABLE NAME
        ASCI1*2 ;CHAR ADDRESS OF ASCII INPUT FROM CORE
        FLOAT   ;FLOATING POINT VARIABLE
        ASCI2*2 ;CHAR ADDRESS OF ASCII INPUT FROM CORE
        INT     ;INTEGER VARIABLE
        ASCI3*2 ;CHAR ADDRESS OF ASCII INPUT FROM CORE
        ....    ;RETURN
        ....
        ....
        JMP XXX

ALPHA:  .BLK 19 ; -OCTAL- CAN BE LONGER THAN ACTUAL INPUT
FLOAT:  0       ;MUST BE 2 WORDS
        0
INT:    0       ;SINGLE WORD

F101:   .TXT(A19,F10.2,I7(    ; -DECIMAL-

ASCI1:  .TXT"STEVE'S FOLLY "
ASCI2:  .TXT"123.45"
ASCI3:  .TXT"6789"


ASSUMPTIONS:
        'A' FORMAT SPECIFIES AN EXACT INPUT LENGTH.  EXTRA CHARACTERS
        ARE TRUNCATED; FEWER CHARACTERS ARE PADDED WITH BLANK SPACES.
        A CARRIAGE RETURN MUST FOLLOW EACH ENTRY.  A NULL CHAR WILL
        REPLACE THE CR IN CORE.

        'F' FORMAT IS FREE FORMAT INPUT WITH UP TO 7 DIGITS FOLLOWED
        BY A CR.  FEWER DIGITS CAUSE NO PROBLEMS, BUT MORE DIGITS WILL
        RESULT IN AN ERRONEOUS CONVERSION.

        'I' FORMAT IS FREE FORMAT INPUT WITH UP TO 5 DIGITS FOLLOWED
        BY A CR.  FEWER DIGITS CAUSE NO PROBLEMS, BUT MORE DIGITS WILL
        RESULT IN AN ERRONEOUS CONVERSION.

        'X' FORMAT AND LITERALS ARE ILLEGAL INPUTS.
```

```
WRITE   FORMATTED OUTPUT
-----
CALLING SEQUENCE:
        WRITE
        CRT     ;DEVICE CODE
        F102    ;FORMAT STATEMENT ADDRESS
        ALPHA   ;ALPHA VARIABLE NAME
        FLOAT   ;FLOATING POINT VARIABLE
        INT     ;INTEGER VARIABLE
        ....    ;RETURN

CPUOT:  WRITE
        CPU     ;SPECIAL CASE REQUIRING DOUBLE ARGUMENTS
        F103    ;'X', '/' AND LITERALS ARE ILLEGAL
        ALPHA   ;ALPHA VARIABLE NAME
        ASCII*2 ;CHAR ADDRESS OF ASCII OUTPUT TO CORE
        FLOAT   ;FLOATING POINT VARIABLE
        DIGIT*2 ;CHAR ADDRESS OF ASCII OUTPUT TO CORE
        INT     ;INTEGER VARIABLE
        DIGIT*2+4+12    ;CHAR ADDRESS OF ASCII OUTPUT TO CORE
        ....    ;RETURN
        ....
        ....
        JMP XXX

ALPHA:  .TXT"STEVES FOLLY NO."
FLOAT:  123456
        876543
INT:    3662

F102:   .TXT(A16,4X,F10.2,/,10X,'TODAY IS AUG. 26',I4(
F103:   .TXT(A16,F10.2,I9(

                ; -DECIMAL- FORMAT SIZES
ASCII:  .BLK 20 ; -OCTAL- BLOCK SIZE
ASCI2:  .BLK 20
ASCI3:  .BLK 20

ASSUMPTIONS:
        'A' FORMAT SPECIFIES AN EXACT OUTPUT LENGTH.  EXTRA CHARACTERS
        ARE TRUNCATED; FEWER CHARACTERS ARE PADDED WITH BLANK SPACES.
        SHORT MESSAGES MUST HAVE A NULL AT THE END.

        'F' FORMAT IS FIXED FORMAT OUTPUT WITH ANY LENGTH SPECIFIED.
        FEWER DIGITS WILL BE PADDED TO THE LEFT WITH BLANK SPACES AND
        TO THE RIGHT WITH ZEROS.  MORE DIGITS WILL BE TRUNCATED TO THE
        LEFT OR RIGHT, DEPENDING ON THE POSITION OF THE DECIMAL POINT.


        'I' FORMAT IS FIXED FORMAT OUTPUT WITH ANY LENGTH SPECIFIED.
        THE NUMBER WILL ALWAYS BE RIGHT JUSTIFIED, WITH FEWER DIGITS
        BEING PADDED TO THE LEFT WITH BLANK SPACES, AND MORE DIGITS
        BEING TRUNCATED TO THE LEFT (SIGN FIRST).

        'X' FORMAT, '/' AND LITERALS CAN BE INSERTED ANYPLACE WITHIN
        A FORMAT STATEMENT AS LONG AS THE DEVICE CODE IS NOT 'CPU'.
```

```
                **** MATHEMATICS ****
                ---------------

DIV.    SINGLE PRECISION SIGNED DIVIDE (W/O SAVING ACCUMULATORS)
----
CALLING SEQUENCE:
        DIV.
        ....    ; RETURN

ASSUMPTIONS:
        AC1 = (AC0 *AC1) / AC2          AC0 = REMAINDER

        DESTROYED: AC0, AC1, AC3, CARRY
PROGRAMS CALLED:  .DIVU

        ------------------------

DIVI.   UNSIGNED INTEGER DIVIDE (W/O SAVING ACCUMULATORS)
-----
CALLING SEQUENCE:
        DIVI.
        ....    ; RETURN

ASSUMPTIONS:
        AC1 = INT((AC0 + AC1) / AC2)    AC0 = REMAINDER

        DESTROYED: AC1, AC3, CARRY
PROGRAMS CALLED:  NONE

        ------------------------

MPY.    SINGLE PRECISION SIGNED MULTIPLY (W/O SAVING ACCUMULATORS)
----
CALLING SEQUENCE:
        MPY.
        ....    ; RETURN

ASSUMPTIONS:
        (AC0 + AC1) = AC1 * AC2

        DESTROYED:  AC0, AC1, AC3, CARRY
PROGRAMS CALLED:  MPYU.

        ------------------------

MPYU.   UNSIGNED MULTIPLY (W/O SAVING ACCUMULATORS)
-----
CALLING SEQUENCE:
        MPYU.
        ....    ; RETURN

ASSUMPTIONS:
        (AC0 + AC1) = AC1 * AC2

        DESTROYED: AC0, AC1, AC3, CARRY
PROGRAMS CALLED:  NONE
```

APPENDIX C

PULMONARY FUNCTION CALCULATIONS

APPENDIX C

PULMONARY FUNCTION CALCULATIONS

Computation

The calibration section calculates two conversion factors--one which converts the analog to digital converter (A/D)output to meaningful volume, and one which converts the input volume at room temperature to the volume relative to body temperature.

The A/D output conversion factor is simply a linear fit of the A/D output at two known volumes, which means the program assumes the output of the potentiometer on the spirometer through the A/D is linear. Tests have shown this to be linear to within the resolution of the A/D output.

The pressure-temperature conversion factor converts: Ambient Temperature and Pressure, Vapor Saturated to Body Temperature and Pressure, Vapor Saturated, (ATPS to BTPS). The temperature of the air in the spirometer is usually different from that in a patient's lungs, and this affects the pressure, hence affects the volume according to Charles Boyle's Law.

$$V1 = \frac{T1 * P}{T * p1} * V$$

Where V = Volume of Spirometer

T = Temperature in Spirometer

P = Atmospheric pressure (assumed vapor saturated) minus the vapor pressure as a function of T

V1 = Volume in lugs

T1 = Body temperature

p1 = Atmospheric pressure (assumed vapor saturated) minus the vapor pressure as function of T1

This gives the dry air volume within the lungs at body temperature. The conversion factor,

$$K1 = \frac{T1 * P}{T * P1}$$

is calculated from body temperature, spirometer temperature, pressure adjusted for body temperature vapor saturation, and pressure adjusted for spirometer temperature vapor saturation. In each case, the last non-zero pressure input through the keyboard is used, and adjusted by the last non-zero spirometer temperature input through the keyboard. A body temperature of 47°C (98.6F) is assumed if none is entered. The spirometer temperature range which the program con accurately handle is 15 to 38 degrees Centigrade (59° to 102° F.).

Mathematically speaking, the tidal volume (TV) and maximal voluntary ventilation (MVV) analyses are congruent, as are the vital capacity and forced vital capacity. Thus, whatever relates to TV also relates respectively to MVV.

The TV routine detects maximums and minimums in the data pattern and stores them with their associated times for post-sampling data reduction. The maximums are summed and the minimums subtracted

to calculate the total volume breathed. This value is then divided by the number of minimums and maximums to calculate the tidal volume, or average volume per breath (in milliters). The time for the first minimum, (or maximum) is subtracted from the time for the last minimum (or maximum) and this is divided into the number of breaths. This figure is then used to calculate the respiratory rate in breaths per minute. The total volume is multiplied by four (assuming a 15 sec. test) to obtain minute volume, or estimated volume breathed per minute. Finally, the first maximum and minimum are averaged, then the last maximum and last minimum are averaged. When the former is subtracted from the later, the result gives the base line shift in milliliters.

The base line shift means the following: total air inhaled equals total air exhaled only under ideal conditions. A positive base line shift means more air was inhaled than exhaled, i.e., air was trapped in the lungs. A negative base line shift means more air was exhaled than inhaled. Significant drift in either direction is a probable indication of pulmonary disease.

This program will attempt to interpret the data it accumulated, regardless of the patient's breathing limits. It is the operator's or doctor's decision to accept or reject 4 breaths in 11 seconds (as an example) sampled during the 15 second test periods, as long as there are at least two complete breaths.

The vital capacity routine samples until it detects the maximum volume prior to exhalation. It stores the maximum and its associated time and begins search for the volume 200 ml below the maximum. On finding this volume, it stores the time for determining the one

second volume and 200-1200 ml flow rate. The routine searches for the time of 1 second and a volume of 1 liter after the (maximum-200 ml) volume and stores the associated times and volumes. It should be noted that the 1 second volume is, as far as the routine is concerned, an "N" second volume, where "N" may be changed to suit the presiding authority. Several of these volumes could be detected.

When the above information has been found and stored, the routine searches until the minimum volume has been detected. It continues searching for 1 second to verify it was the minimum. The routine then subtracts the minimum volume from the maximum to determine the vital capacity, or total volume exhaled.

Twenty-five per cent of the volume is determined for finding the times associated with the (Max - 25%) to (Max - 75%) volumes by researching the data buffer. The mid expiratory flow rate is determined by dividing the differences in volume by the differences in time. The one second volume is converted to milliliters. The time for exhalation is determined by subtracting the time at maximum volume from the time of minimum volume. Finally, the 200-1200 ml flow rate is determined by dividing 1 liter by the time from (Max-200 ml) to (Max-1200 ml).

Potential Problem Areas

If the Vc maneuvers lasted less than 1 second or were less than 1 liter, the 1 second volume (or 200-1200 ml flow rate) should not be considered accurate. If the vital capacity lasted longer than 15 seconds, the mid expiratory flow rate (25% - 75% of volume) should not be considered accurate. The routine will attempt to

calculate these values anyway.

The program is completely modular and any one or more of the maneuvers may be eliminated to free computer core for other purposes. The patient information section can be isolated and used by other programs, and has been expanded to receive more information than it requires for the pulmonary function program.

Certain areas of the program can easily be altered or expanded, i.e., the vital capacity routine could calculate a half, two or three second volume. The 25% - 75% mid-flow rate could handle any percentages of volume. The time limits can be changed within broad restrictions (about 15 seconds for vital capacity; any time for tidal volume). The expiratory vital capacity can be changed to inspiratory vital capacity, or both can be measured without calculating the 25% -75% flow rate.

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