

SELECTED CONTRIBUTIONS

Prepared for

**Technology Utilization Office
National Aeronautics and Space Administration
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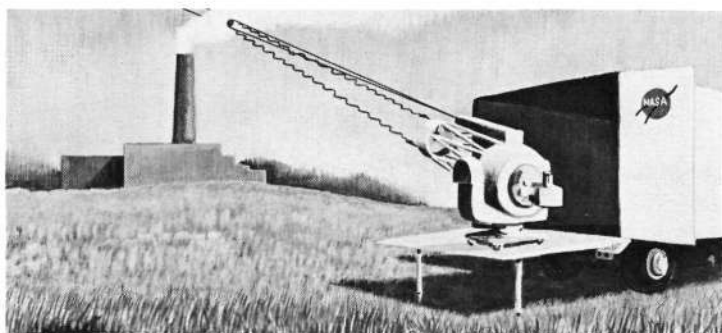
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INTRODUCTION

Over the past several decades, research and development efforts associated with the Nation's aerospace program have exerted a significant influence on health care in a number of ways. Examples of this influence include the use of bioinstrumentation in intensive care units, computer technology for providing more readily accessible medical data, and dynamic (as opposed to static) electrocardiographic procedures. A recent National Academy of Sciences study* outlined three categories of aerospace technology which hold particular promise for the health sciences. These categories included improved experimental techniques, advanced instrumentation, and large-scale system and information-analysis techniques.

Experimental Techniques. A few examples are: (a) the remote sensing and control of physical parameters; (b) telemetry and telestimulation of a living subject at a remote location (when properly designed instruments are attached to or implanted in a subject, such techniques may minimize interference with normal activities, simplify the experiment, and extend the useful period of observations); (c) signal-transmission and noise-reduction techniques.



Remote sensing application.

Instrumentation. Many instruments developed for spaceflight experiments can be modified for health science research applications. These

*Life Sciences In Space, report of the study to review NASA Life Sciences programs conducted by the Space Sciences Board, National Academy of Sciences, National Research Council, 1970.

instruments include: (a) sensors and transducers such as electrodes, pressure detectors, and light detectors; (b) analyzers such as bacteria-counting units, gas chromatography, and mass spectrography equipment; and (c) portable miniature instrument blocks such as amplifiers, modulators, and recorders.



Sleep-cardiovascular analysis.



Video hematology.



Metabolic cost evaluation.

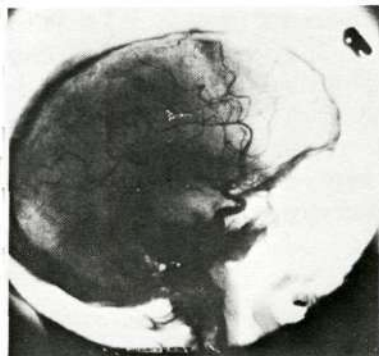
Integrated medical-behavioral laboratory measurement system.

Large-Scale System and Information-Analysis Techniques. The methodology developed by aerospace researchers for complex data transmission, analysis, and extraction of signals from noisy channels is potentially useful for investigators in the health sciences.

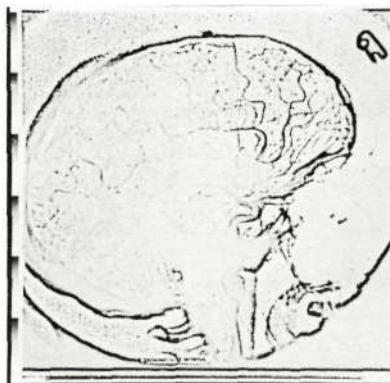
Techniques for the correction of photometric, geometric, and frequency response distortions in television pictures received from spacecraft have now been applied to the study of medical X-rays. The X-ray picture is first converted into digital form by a cathode-ray device that scans the film on a line-by-line basis and converts each point of the picture into a number proportional to the film's optical density. Each sample (typically 500,000 samples for a one-inch-square transparency) is recorded on a magnetic tape which is subsequently fed into a computer.

Further computer enhancement is achieved by a two-dimensional digital filter to modify the frequency spectrum of the picture. Filtering is used to restore high frequency losses of fine detail resulting from the use of fluorescent X-ray intensifying screens.

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X-ray image before enhancement by computer.



X-ray image after enhancement by computer.

Computer-enhanced X-ray image.

From these few examples, it can be seen that the technology which made the Apollo moon landings possible is being examined to an increasing extent by those concerned with the pressing health-related problems facing man on Earth, seeking ways to capitalize upon the remarkable advances being made on the aerospace front.

This document was prepared particularly in response to inquiries from health-science professionals seeking information on how aerospace research and development can help health-care systems here on Earth. It is not exhaustive in its treatment, but, rather, focuses on selected contributions in the areas of physiological measurements and monitoring, medical information management, clean room technology, and reliability and quality assurance. The intent of the document is to make the health professional—whether physician, administrator, or researcher—aware of instances in which aerospace-related technology has been, or could be, applied to meeting important health needs. Hopefully, such exposure will serve as a catalyst, prompting members of the health-care community to identify yet other areas in which aerospace technology might make major contributions in achieving the aim of providing improved health services for all.

CHAPTER I

PHYSIOLOGICAL MEASUREMENTS AND MONITORING: AN OVERVIEW

In common with physicians engaged in the day-to-day practice of medicine, NASA shares in the need for effective techniques to monitor human vital functions.



Monitoring vital functions.

By serving its own unique needs for bioinstrumentation and telemetry, NASA has played a catalytic role in the rapid growth of technology associated with physiological monitoring, particularly with regard to the following parameters:

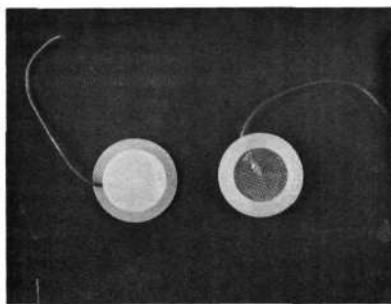
- electrocardiography
- blood pressure
- oxygen saturation
- respiration
- other measurements.

Electrocardiography

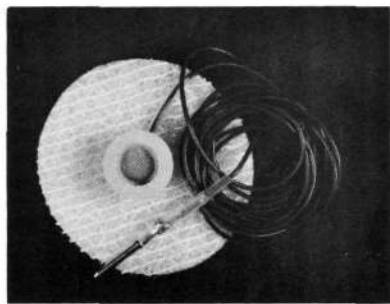
Electrical activity of the heart produces characteristic waveform patterns on electrocardiograph (EKG) tracings. These patterns provide valuable information concerning cardiac function. In the past, however, problems in acquiring, displaying, and interpreting the EKG data have prevented full realization of the method's potential. Examples of how aerospace-related technology has helped solve some of the problems are discussed in the following paragraphs.

Data Acquisition

A major problem encountered in electrocardiography and other bioelectric measurement techniques involves the transducer/tissue interface. The weak electrical biopotential involved in making such measurements requires maximum efficiency in establishing the interface. In electrocardiography, two types of transducers have been used to obtain tracings of the heart's electrical activity: *high-hat* and *adhesively applied* electrodes.



Typical high-hat electrode.



Typical adhesively applied electrode.

Difficulties with the high-hat electrode have centered upon its failure to provide adequate contact and, consequently, to produce adequate signals. The adhesively applied electrode represents an improvement both in terms of tissue contact and resultant signal. However, such electrodes are stable only for about 36 hours. This period of stability is inadequate for monitoring the physiologic function of astronauts during extended space voyages or, for that matter, on earth for monitoring the vital signs of a patient in a hospital's intensive care unit.

NASA Contributions to the Interface Problem

NASA has made the following significant contributions toward solving the interface problem. The advantages of the newly developed technology are listed below each item.

(1) *Development of a new type of electrode*

- Is gelatin-coated
- Is nearly artifact-free
- Allows prolonged measurement.

(2) *Development of an improved electrode paste*

- Minimizes "noise"
- Prolongs bioelectric measurement capabilities.

(3) *Development of a spray-on electrode*

- Applies easily within 20 to 30 seconds
- Provides excellent electrical contact
- Achieves relatively low resistance
- Avoids wearer discomfort
- Resists motion artifacts
- May be applied over chest hair



Spray-on electrodes.

- Retains stability over an extended time period
- Is readily available through commercial sources.

(4) *Development of ultra-flexible electrodes and wires*

- Fabricated from silicone rubber elastomer and impregnated with conductive powder
- Is useful for monitoring active subjects

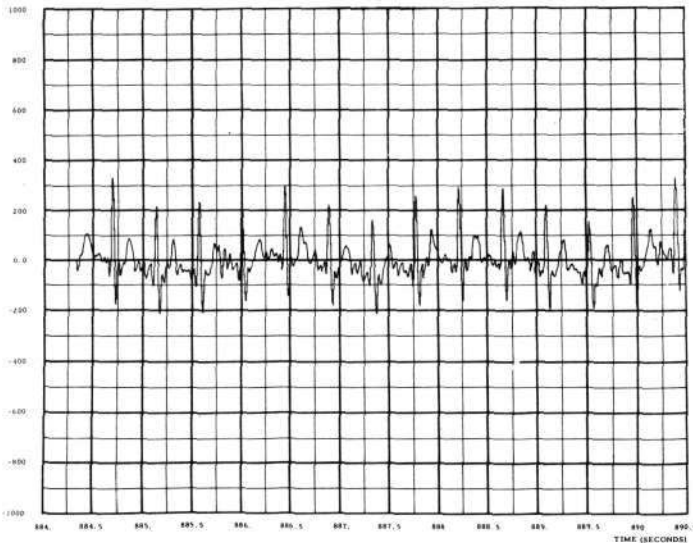


Ultra-flexible electrodes and wires.

- Avoids wires tugging or pulling on electrodes
- Can be shaped to desired form and size
- Retains stability over an extended time period.

(5) *Digital and/or analog filtering techniques*

- Removes motion artifact signals
- Avoids false alarms when monitoring acutely distressed patients
- Can detect immediately an abnormality of heartbeat if needed for single beat(s).



Effect of low-pass (18-Hz) digital filtering on a noisy ECG signal.

(6) *Apex-cardiography*

- Detects effective cardiac activity and effective respiration as subsidiary mechanisms

- Measures local relative motion of the chest wall keyed to movements of the heart



- Suggests possible relationship to acute changes in disease state
- Could possibly sense the "alarm state."

(7) *Phono-cardiography*

- Presents sound vibrations of heart action graphically and objectively
- May compare closely to sounds heard through the stethoscope
- Can be easily programmed for computer analysis and storage
- May be useful in a device to detect and calibrate the intensity of ventricular gallop (third heart sound)

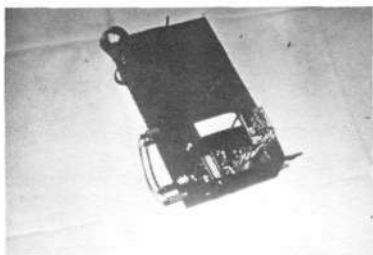


NASA phonocardiograph microphone

- May be combined to measure the degree of early congestive heart failure or to follow myocardial infarction patients on an hour-by-hour basis during acute situations
- May be limited to cases where appropriate chest area is available to attach the probe.

(8) *Economical method to record and play back EKG signals via inexpensive audio tape recorders*

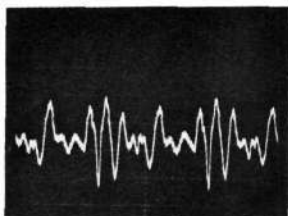
- Features signal conditioner/modulator permitting low cost tape recorders to record and play back EKG signals
- Permits required circuitry to be built into recorder's accessory compartment
- Provides physician with economical method of acquiring EKG data under a variety of conditions.



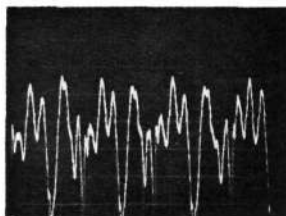
Low cost EKG tape recorder/playback instrument.

(9) *Vibro-cardiography*

- Measures acceleration produced at the chest wall by myocardial pumping action
- Measures accurately the phases of isometric contraction, ejection, systole, and diastole as compared with direct cardiac catheterization
- Incorporates new transducers and instrumentation
- Provides wave recognition for location of significant waves
- Displays time and energy levels between any significant waves.



Relaxed and holding breath.



Post exercise and holding breath.

Vibrophonocardiogram.

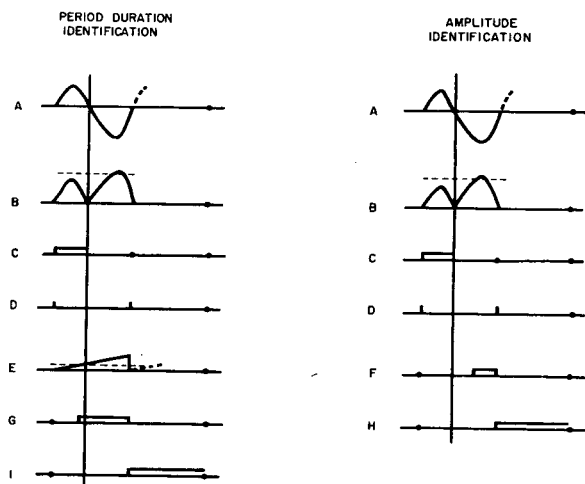
Signal Processing Analysis

Manually processing recorded biopotential measurement data is exceedingly expensive and time consuming. Also, during examination of recorded measurements, such as analyses of EKG tracings to detect significant differences in morphology of the wave form, there is always the possibility of a degree of undesirable subjectivity by the physician.

NASA Contributions to the Problems of EKG Signal Processing and Analysis

The development of electrical spectrum filtering techniques for "yes-no" analysis presents the following advantages:

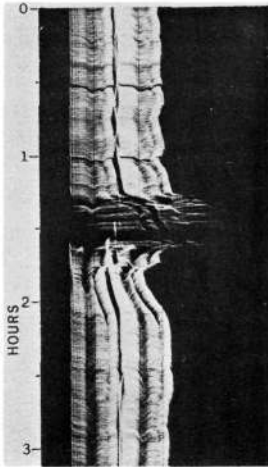
- Defines each QRS complex as an event
- Tabulates rhythm data
- Selects "different" from "normal" data
- Detects events in presence of background noise
- Can be adapted to analyze beat *width*, *height*, or *length* of certain derivatives
- Detects potentially serious arrhythmias.



Signal reduction waveforms resulting from the "Yes/No" analyses technique.

Data Display and Presentation

Clinically important trends in QRS events can be determined from histograms, bigrams, or a series of bigrams of R-R intervals. In such analyses, time and accuracy are important parameters. NASA has made significant contributions in improving the display and presentation of data depicting QRS events.



A contourgram permits observation of the heart's electrical activity in a concise and time-oriented perspective.

- Condenses large quantities of EKG data
- Displays 12 to 24 hours' data accumulation for glance detection of aberrant activity.

Other Contributions to Electrocardiography

When measured by the EKG, the heart rate becomes more difficult to interpret, especially when cardiac activity increases because of physical exertion.

NASA Contributions to the Problem of Interpreting Exertion-induced Changes in Heart Rate

The cardiometer has the following characteristics:

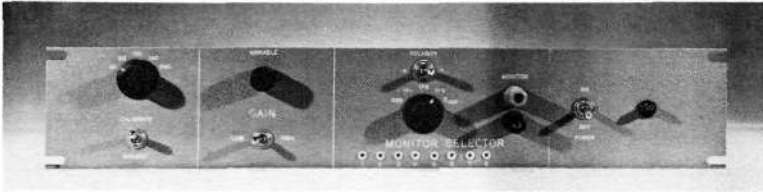
- Responds with linear beat-to-beat frequency

NASA Contributions to Data Display

The NASA-developed contourgraph visual display system provides the following advantages:

- Displays groupings comparatively
- Presents display in real-time contour
- Contours minor cycle-to-cycle variations tri-dimensionally
- Illuminates a major signal change as a pattern change

- Detects and displays heart rate accurately
- Provides early recognition of small changes during rapid adjustments in cardiac activity
- Identifies ventricular extra systoles.



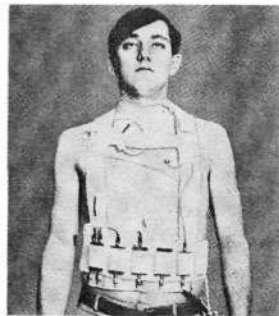
NASA-developed linear, low-frequency response cardiometer.

To a considerable extent, success in heart surgery is dependent upon adequate monitoring of various cardiac parameters before and after surgery. Prognosis is seriously affected if invasive means are used to obtain the required measurements.

NASA Contributions to the Need for Noninvasive Monitoring Techniques

An improved, refined impedance cardiograph provides these advantages:

- Provides information without penetrating the skin
- Performs as simply and easily as the EKG
- Creates minimal hazard or discomfort to a patient
- Is simple, convenient, and inexpensive
- Uses disposable and comfortable electrodes
- Records as long as four days without difficulty
- Monitors heart transplant patients during critical periods



NASA-developed impedance cardiograph used for cardiac output measurement.

- Warns of the onset of edema
- Provides a permanent record
- Functions through a strip chart recorder or visual display
- Aids diagnosis and management.

Blood Pressure

For years, blood pressure has been measured manually by the sphygmomanometer. This technique is both inconvenient and time consuming in many situations. Alternative techniques to measure blood pressure, such as indwelling catheters, involve potential hazards and are used only under the most compelling circumstances.

NASA Contributions to the Need for Improved Blood Pressure Measurement Techniques

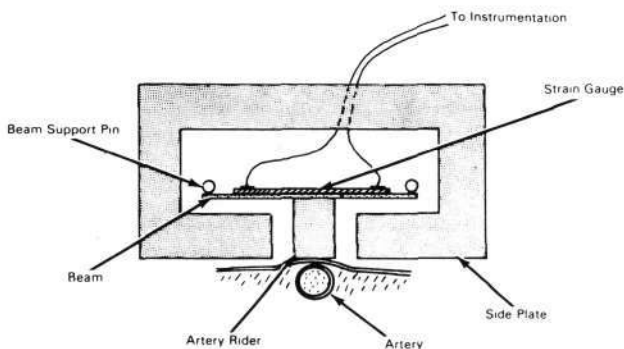
NASA has made the following contributions in providing improved blood pressure measurement techniques. The advantages of each contribution are listed.

(1) Autosphygmomanometers

- Are indirect, objective, accurate, and easy to read
- Simplify long-term monitoring by automatically reading at preset intervals
- Have limit alarms and redundant safety features
- Distinguish motion artifacts easily
- Conserve time of physicians and nurses.

(2) *Direct Force-Measuring Transducer*

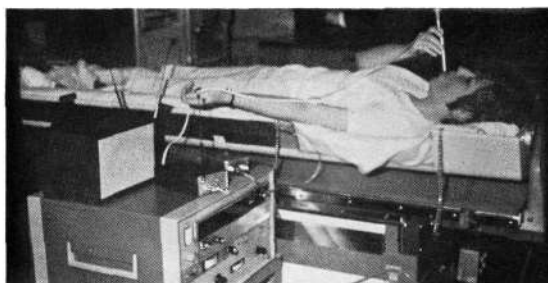
- Is noninvasive
- Acts as an arterial tonometer
- Gives a direct readout to instrumentation
- Is unaffected by ambient noise.



Direct force-measuring transducer.

(3) *Noninvasive Venous Pressure Measuring Device*

- Uses thin, paste-on, transcutaneous, Doppler blood flow sensor to determine venous flow cessation
- Uses an oral, air-pressure sensor to determine the lung pressure at which venous flow ceases
- Permits patient to exhale through a constricted device, causing lung air pressure to rise and periodically exceed venous return pressure
- Is currently being perfected in laboratory trials.



NASA-developed venous pressure measuring device.

(4) *Blood Pressure Measurement*

- Provides an atraumatic means for monitoring blood pressure using the ultrasonic Doppler principle

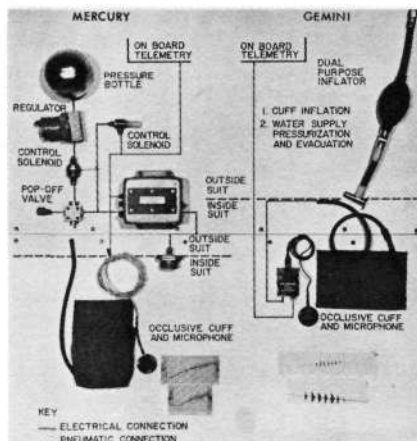


Blood pressure measurement device using the ultrasonic Doppler principle.

- Can be used in high-noise environment
- Minimizes motion artifact.

(5) *Blood Pressure Telemetry*

- Features complete implantable pressure transducing systems
- Uses a diaphragm-type capacitance transducer
- Requires small amount of power
- Transmits low output level of the implanted pressure cell to remote receiver accurately.



Blood pressure measuring system developed for Mercury and Gemini missions.

Oxygen Saturation

Oxygen vapor pressure (PO_2), pH, and carbon dioxide pressure (PCO_2) determinations are used by the physician to assess the metabolic state of acutely ill patients. These blood values are more useful to the physician when they can be obtained quickly and accurately without the time delays associated with conventional laboratory test procedures.

NASA has contributed an improved ear oximeter toward the problem of obtaining rapid and accurate blood gas saturation data. The improved ear oximeter has the following advantages:

- Fits on subject's ear like a frame for glasses
- Determines accurate blood oxygen saturation, blood pressure, heart rate, and pulse waveform
- Solves part of the problem of calculating bicarbonate concentration in the blood rapidly and continuously
- May assist in early determination of shock.

However, the oximeter is limited by:

- The derived nature of the output data
- Distortion of the peripheral pulse waveform
- The requirement to know pH to calculate PO_2 from O_2
- Differentials in the extremely vasoconstricted state between peripheral ear lobe circulation and the central situation.



NASA-developed ear oximeter.

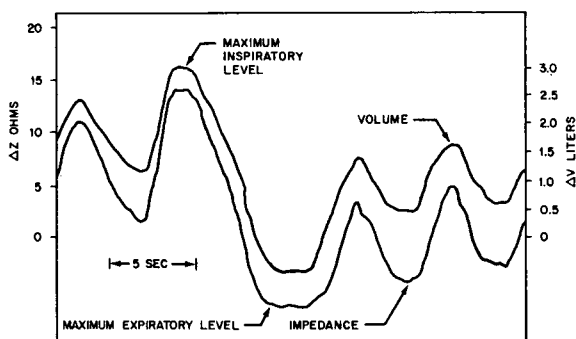
Respiration

Continuous monitoring of respiration—an important indicator of a patient's condition—by spirometers, pneumographs, thermistor sensors, etc., has been unreliable and cumbersome.

NASA has made the following contributions to the problem of accurately monitoring respiration:

(1) *Impedance Pneumograph*

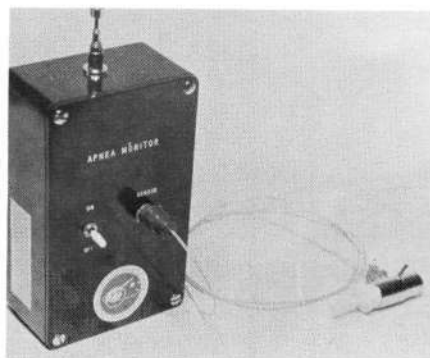
- Measures respiratory volume indirectly by relationship between transthoracic impedance and volume of expired air
- Does not require the patient to wear a facemask
- Does not require a separate air system
- Is insensitive to barometric pressure, temperature, or gravitational forces
- Permits EKG recording from convenient location of electrodes
- Measures respiratory rate and tidal volume noninvasively, conveniently, and reproducibly



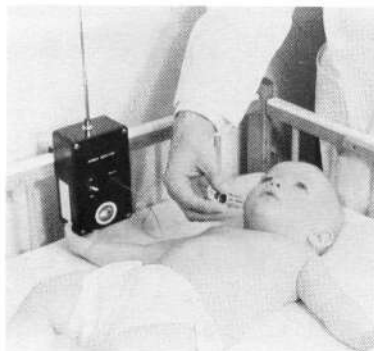
Simultaneous tracings of respiratory volume and transthoracic impedance.

(2) *Thermistor Probe Used as an Apnea Monitor with Wireless Alarm System*

- Senses temperature changes in inspired and expired air
- Converts temperature changes to audible FM frequencies
- Uses wireless telemetry for transmission of breathing information
- Monitors from points distant to nurses' station
- Is compatible to entubation and mechanically assisted ventilation
- Activates alarm ten seconds following respiratory arrest.



Apnea monitor—developed for use with infants.



Size of apnea monitor components in relation to a newborn infant.



Apnea monitor developed at NASA's Ames Research Center.



Sketch showing the Apnea monitor in place.

(3) *Nosepiece Respiration Monitor*

- Involves minimum contact with the body
- Provides fast response
- Avoids encumbering headgear or chestbands
- Is relatively inexpensive.

Other Measurements

NASA has made significant contributions in areas of measurement vital to the



Nosepiece respiration monitor.

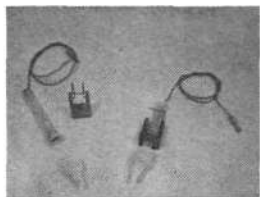
physician. The most important are in the areas of electroencephalography and remote measurements.

Electroencephalography

Two problems frequently encountered in obtaining electroencephalography (EEG) data center upon excessive preparation time and skin irritation associated with use of conductive pastes. To help eliminate these problems, NASA has contributed the following instruments:

(1) Wireless Helmet EEG Telemetry

- Readily adjustable sponge-type electrodes reduce preparation time
- Skin irritation is minimal (no shaving required)
- Built-in battery-powered amplifiers and transmitter provide wireless telemetry of EEG signals
- Subject's activity is unrestricted during monitoring
- System produces high quality EEG signals.



The special EEG electrodes (note the threads which permit precise adjustment when placed in the helmet).



The electrodes in place in the helmet. Audiometric signals are administered via the earphones.



The evoked cortical response (audiometric) helmet in position on the subject. Auditory input is made possible by built-in high-quality earphones.

The evoked cortical potential measurement system developed by SwRI for the National Aeronautics and Space Administration.

(2) Lightweight Soft Cap Incorporating Two EEG Electrodes

- Presently being clinically evaluated for feasibility
- Promises to be more comfortable than the helmet version
- Will feature an 8-channel transmitter with a broadcast radius exceeding 200 feet.



Lightweight soft cap incorporating EEG electrode developed at NASA's Manned Spacecraft Center.

Remote Measurements

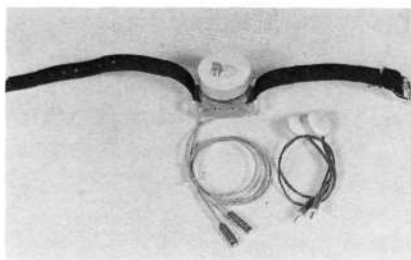
The capability of obtaining physiological data on a remote basis from patients in remote settings (en route to the hospital during emergency situations, during convalescence, or while at home or work undergoing treatment) has considerable potential for improving medical care. In the past, continuous monitoring of patients has not been feasible due to the considerable expense associated with personal observation. NASA's need for techniques to permit continuous monitoring of astronauts on a remote basis has generated remarkable advances in this area of instrumentation research. The NASA contributions to remote measurement technology include the following:

(1) *Miniaturized Wireless Telemetry Techniques and Devices*

- Telemeters information directly from ambulatory or bed-ridden patient



Miniature telemetry system developed for implantation in experimental animals.



A wrist-watch size telemetry system developed to telemeter EKG signals.

- Feeds information into a central monitor for control
- Monitors any measurable data such as EKG, body temperature, respiration, etc.
- Possesses useful battery service life of up to five days.

(2) *Emergency Vehicle EKG Telemetry System*

- Acquires EKG data from patient en route to hospital
- Converts EKG signals to normal audio frequencies
 - Transmits converted data over normal radio-telephone linkups
 - Converts audio frequencies to EKG signals at receiving stations
 - Provides information to a single or multiple receiving station
 - Registers data on a scope or provides a permanent record through linkup to a chart recorder



Phone connection to electrocardiographic machine in hospital.

- Registers data on a scope or provides a permanent record through linkup to a chart recorder
- Permits physician to develop a treatment plan before the patient arrives at the hospital.

(3) *Multiple Complete Radio-Linked Patient Monitor System*

- Collects several channels of physiological data from as many as 64 patients (ambulatory or bedridden)
- Shares a broadcast frequency pair between control station and patient unit
- Electronically signals inactive patient unit to transmit upon interrogation by control station
- Signals data in digital form for processing by computer

- Accepts continuous monitoring from any patient by setting switch to **single patient** mode of operation
- Employs conventional medical sensors for input.

(4) *Patient Vital Signs Monitoring System*

- Uses R-wave component of EEG to monitor respiration
- Signals onset of apnea to nurse's station, permitting institution of resuscitative measures
- Plugs into existing nurse call signal system
- Features special flexible electrodes for long-term application
- Readily moved from one location to another
- Features optical coupler to protect monitored patient from electrical shock.



Radio-linked patient monitor system.



The vital signs monitor plugs into the nurse's call panel at patient's bedside.



Cessation of vital signs is signaled on the central call system console.

The vital signs monitor. Note that the monitor plugs into the existing patient call system.

CHAPTER II

MEDICAL INFORMATION MANAGEMENT APPLICATIONS OF AEROSPACE TECHNOLOGY

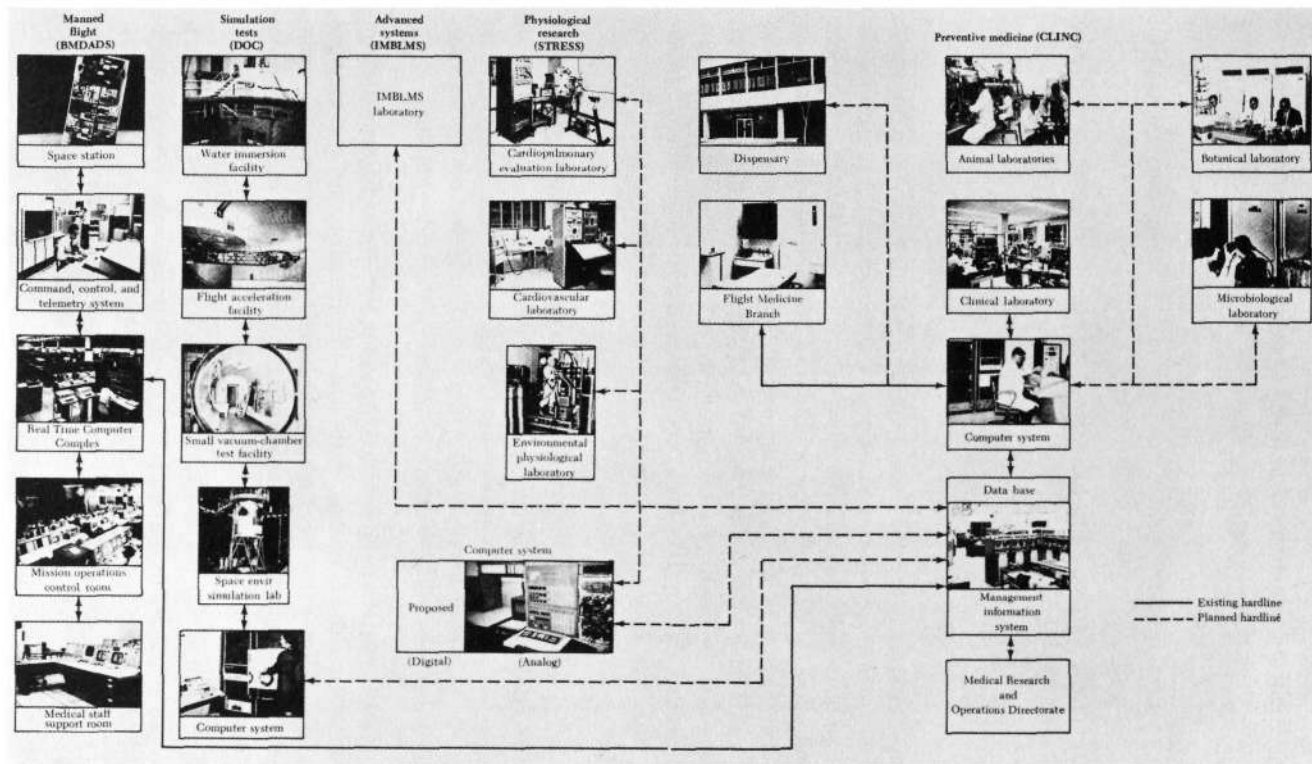
Research into the biomedical variables surrounding safe and efficient manned spaceflight has resulted in the advanced application of computers to help solve the many problems involved. To date, problem areas dealt with include automated medical data storage and retrieval systems and continuous monitoring and interpretation of physiological data. It seems logical to expect that the computer science expertise which has successfully dealt with the variety of complex problems confronting the Nation's space program can materially assist in management of the increasing amounts of medical data which require reduction and interpretation. The pioneering work in biomedical data processing undertaken by NASA during the last decade has, to a considerable extent, helped foster emergence of a new discipline in the health sciences: medical information management. Medical information management can be defined as the supportive activity responsible for providing coordination of informational needs and resources among the various components of the medical environment, including patient-care, teaching, research, and administrative service components. The emergent discipline has three functional components—record keeping, data analysis, and communication—each of which is at least partly amenable to computer support, and for which applicable aerospace-related technology has been developed.

Computerized Information Processing

Medical Information Management System

Anticipating problems in storing, maintaining, manipulating, and analyzing the voluminous medical data base associated with medical aspects of the spaceflight program, NASA initiated a research and development effort to explore automation of the medical records process. This research and development effort followed two parallel paths—a medical information project and an information management project—collectively called the Medical Information Management System (MIMS). The following advantages commend the system for use in the medical environment:

- Provides a well-defined subset of patient data
- Minimizes the number of records to be maintained



The NASA Manned Spacecraft Center's Information Processing System. Many of the information processing computer programs available are of benefit to the biomedical community.

- Is capable of selectively retrieving a large number of variables
- Generates information required to prepare meaningful reports
- Is capable of scheduling surveys, patient follow-up, and hospital utilization
- Accommodates record keeping and management information function into one complementary system
- Is readily adaptable to include additional information that may be desired
- Avoids the need for expert knowledge by permitting straightforward computer interaction.

The MIMS data retrieval approach was designed with the user's needs and level of sophistication in mind. In the system, retrieval is conversational and consists of two phases, interrogation and response. During interrogation, the program poses a series of seven questions to the user, which he answers in turn. In answering these questions, the user automatically defines what files are to be examined, what conditions are to be placed on the data in the files, what action is to be performed, and on what portion of the file the action is to be performed. The system then uses a character search technique, incorporating Boolean logic and ranging, to find the desired structure of characters.

Since file maintenance constitutes an important part of any information system, the MIMS provides a mechanism for updating, allowing the user to add, change, or delete headings and data. Additionally, the system permits data files to be sorted and merged without difficulty by employing user-defined judgments regarding relative importance of the leader headings.

In 1969 the MIMS approach developed for NASA was implemented on a commercial time-share system. Although the file structure was changed slightly and new programs were written to handle data entry and file maintenance, the basic approach remains identical to the system used at NASA's Manned Spacecraft Center.

The time-share version of MIMS has some advantages over the batch system in use at the Manned Spacecraft Center. For example, the user can sit at a terminal and ask certain questions of his data and then, based on the answers he receives, he can alter his questions until he gets exactly the information he is after. This ability to "browse" the file is available only on a time-shared computer.

The time-share version of MIMS has been used for several applications, including a study of the geographic incidence of pediatric cancer. Information collected included the diagnosis, date of diagnosis, and previous addresses from conception to date of diagnosis. MIMS was then used to analyze the data, using the zip codes of the patient's addresses. In another study, MIMS analyzed nursing incident reports (reports of accidents that occur in the hospital). These data include the patient's name, his age, sex, room number, his physical and mental status at the time of the accident, and the date, time, kind, and severity of the accident. These data are then examined to determine which patients need to be watched more closely than others and what policy changes can be made to help eliminate occurrence of the accidents.

The advantages inherent in MIMS are its flexibility and ease with which new users can learn the system. The philosophy guiding its development emphasized the ultimate user and MIMS has been successful in this respect.

Limitations of the system mainly center upon cost factors, since a premium in storage expense is extracted for the desire to store both headings and data. Also, since the storage technique used is sequential, retrieval and update costs become fairly significant as the sizes of data files increase.

The present version of MIMS can be recommended for research projects where complicated manipulations of data are anticipated, for teaching and demonstrating the mechanics of computer-stored records, and for other limited data storage and retrieval problems. Commercial time-shared application of MIMS for permanent or semi-permanent large volume medical records is not yet sufficiently cost-effective to warrant routine adoption of a medical environment. However, efforts are underway to modify the system so as to retain the simplicity, flexibility, and general utility of the MIMS concepts while rendering it more cost-effective. A more detailed discussion of the system may be found in Appendix A.

Automated Recovery of Medical Laboratory Data

An integral—and important—part of medical laboratory operations centers upon data analysis, which includes data compilations, arithmetical and statistical computations, graphical presentations, and data tabulations. Consequently, the availability of a computer system capable of efficient storage and uncomplicated retrieval, along with the facility for logical and arithmetical operations, holds considerable potential for introducing greater efficiency and economy into the operation of medical laboratories. Recognizing the value of such a system for handling the vast quantity of laboratory

data associated with the space medicine program, NASA initiated development of an information system designed specifically for use with medical laboratory data. The system was developed to permit rapid handling and analysis of data associated with critical variables monitored before, during, and after spaceflights. This system—termed MEDOL for Medically Oriented Language—has the following advantages:

- Uses a language (source) that can be successfully handled by individuals with little or no training in computer science
- Program layout approximates logical processes normally employed by the scientific investigator
- Operates in two modes—the data-maintenance and the query mode
- Provides for decision-making capability, such as testing the data bank against certain conditions
- Can store and retrieve data in multiple arrays located in a temporary storage area
- Provides a mechanism for “formatting” the data for three output media: punched cards, magnetic tape, or printed reports.

In summary, the basic MEDOL system provides procedures for (1) generating and updating files, and retrieving data from these files; (2) generating libraries and glossaries; (3) performing arithmetical operations on data; (4) extracting information for array grouping; and (5) outputting data. Additional information concerning the system may be found in Appendix B.

1. Keyword requires specific words not results.
 2. For file and postflight results.
 3. For attempt to return data the collection data for these tests for the period for the selection and as already listed.
 4. Action: Manual change for these tests.
 5. For file and postflight results.
 6. Action: Manual change for these tests.

Automatic: Format: R: One
 Period: Pre and postflight

Period	Date	NOCT	NOPE	NOPE	NOPE	NOPE	NOPE
	1967	11	11	11	11	11	11
Postflight	2 Jan	19	8	1967			
Postflight	2 Feb	19	10	11			
Postflight	10 Apr	19	10	11			

44

Automatic: Format: R: One
 Period: Pre and postflight

Test	Postflight Date	NOCT	NOPE	NOPE	NOPE	NOPE	NOPE
	1967	11	11	11	11	11	11
NOCT 1.1	19	21	19				
NOPE 1.1	19	10	11				
NOPE 1.1	19	10	11				
NOPE 1.1	19	10	11				

1 All results are averages of three days

Format of a typical MEDOL query.



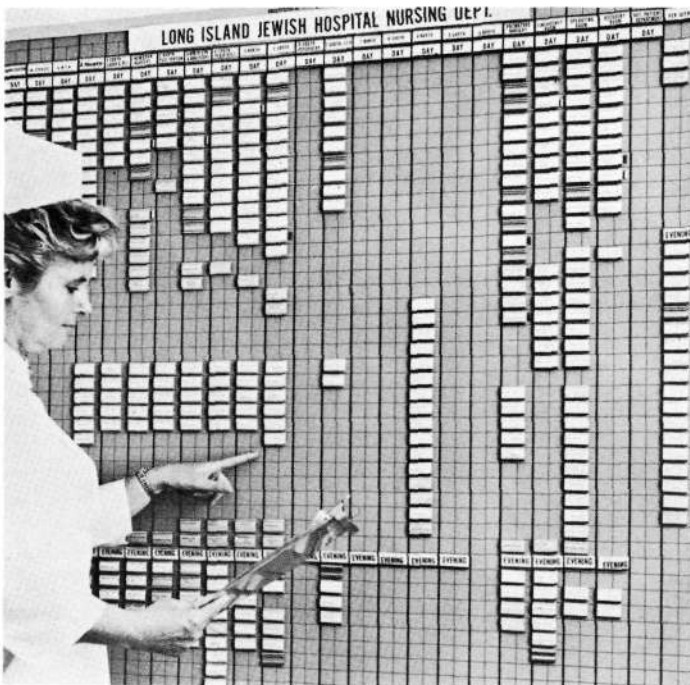
The Manned Spacecraft Center's clinical laboratories.

Planning and Coordination Functions

The steadily increasing complexity of planning in the medical environment—both on an intra-hospital and inter-hospital (regional) basis—has underscored the need to facilitate required coordination. NASA has contributed the following techniques in planning and coordination:

(1) VIS-A-PLAN Management Technique

- Is a magnetic, flow chart visual display system
- Reduces broad scope programs to graphic terms
- Can be assessed with a glance
- Posts and adjusts schedules for staff or facilities
- Maintains bed control

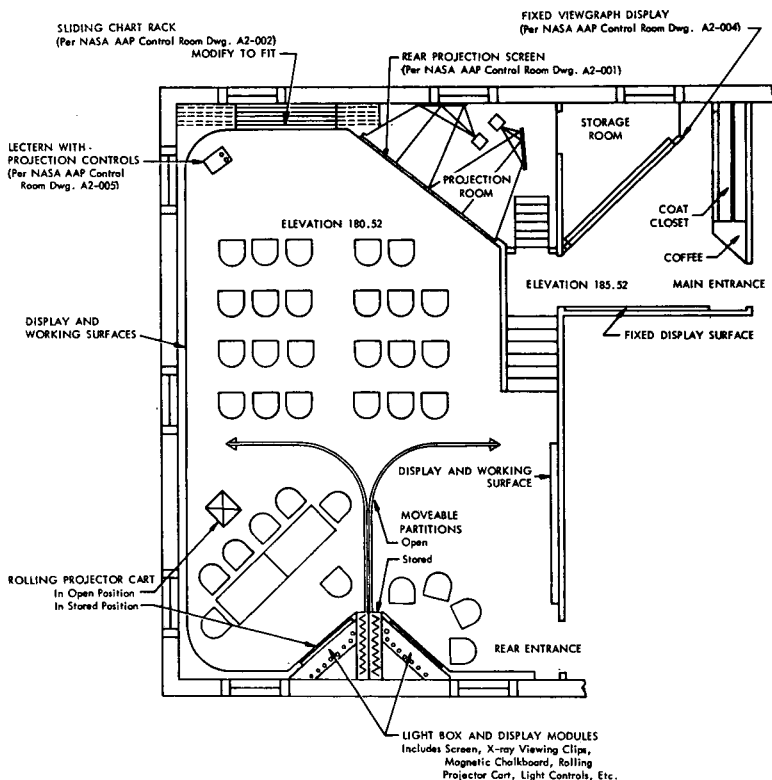


Scheduling using the Vis-A-Plan management technique.

- Improves utilization of staff facilities
- Provides pattern layout for master plans
- Is easily programmed and easily modified.

(2) Hospital Control Room

- Provides an easily accessible source of information to the staff
- Establishes a centralized communications point
- Displays a visual record of hospital projects
- Aids administration in management.



Hospital control room.

(3) *Forecasts and Appraisals from Management Evaluation (FAME) Techniques*

- Reports, analyzes, and forecasts operational data on critical program areas
- Can be adapted to monitor, forecast, and evaluate regional cost control
- Indicates emerging statistical trends automatically
- Can predict shortages and oversupplies of skills for area facilities
- Enables decision-makers to quickly react to conditions
- Can indicate occupancy and utilization rates for facilities.

(4) *Simulation Techniques*

- Establishes intercoordinated layout schemata for ease of viewing interactions
- Assists in planning introduction of new facilities
- Suggests alterations of economical patterns of manpower within a facility
- Schedules facility operations by adjusting services to changes in demand
- Estimates health-care delivery systems costs
- Provides cost-effective comparisons for alternative systems
- Specifies alternative systems demands on scarce resources (nurses, beds, etc.).

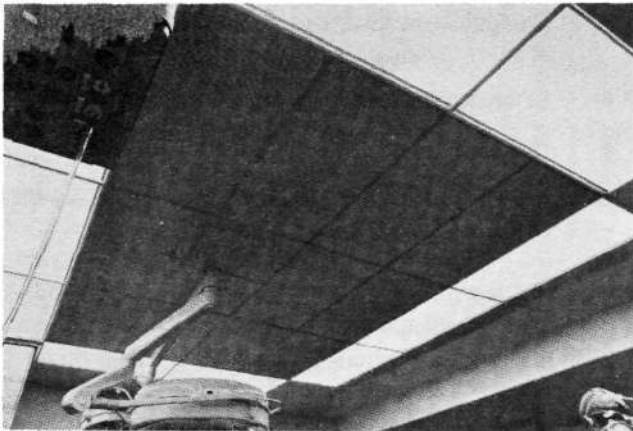
A number of other management techniques have been refined, updated and tested by NASA, including the Program Evaluation and Review Technique (PERT) and the Planning, Programming, and Budgeting (PPB) Technique. Many of these techniques hold considerable potential for application to resolving health-care services management problems.

CHAPTER III

CLEAN ROOM TECHNOLOGY

During the past decade, rapid improvements have been made in the care and survival rates of patients suffering from what were formerly considered to be fatal illnesses. The techniques of open heart surgery, organ transplants, joint replacements, and cancer chemotherapy have saved many lives. Yet they have also produced medical problems which demanded new answers. Foremost among these has been the problem of infection in the highly susceptible patient. Infections initiating in the operating room can occur from a breakdown of sterile technique, seeding from a member of the operating team or the patient, or through airborne bacteria. Careful supervision, vigilance, and precautions could greatly reduce the infection rate from all sources except, until recently, airborne bacteria.

Modern air handling technology jointly developed by the National Aeronautics and Space Administration and the Atomic Energy Commission has now been applied to the medical field in order to lower contamination by airborne bacteria. These agencies needed a near particle-free environment in which to manufacture and assemble precision devices or to operate sophisticated systems. The clean rooms that they developed were found to reduce the

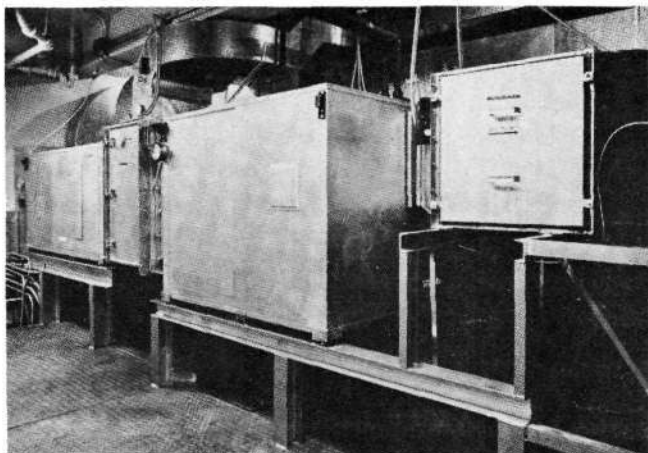


Photograph of renovated surgical suite. Clean air enters the remodeled operating room through perforated epoxy-coated panels with a maximum linear velocity of 1.27 ft/sec. A service column is in the upper left corner.

bacteria concentration from 1000 to 5 micro-organisms per 100 cubic feet of air. This reduction was accomplished by eliminating 99.97 percent of particles larger than 0.3 microns. When incorporated into medical treatment facilities, these installations have been reported to lower infection rates.

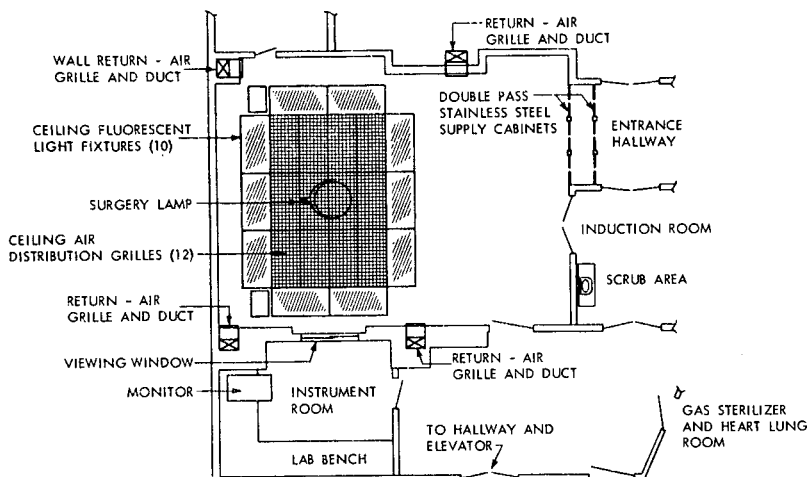
This technology was recently utilized by a midwestern hospital when its 42-year-old operating suite was renovated.

Renovation of the cardiothoracic surgical suite and accompanying installation of a laminar flow ventilation system was prompted by bacterial air sampling which consistently showed the presence of *Staphylococcus albus*. The renovation plans drew heavily from NASA/AEC experience in clean room technology and included consideration of construction materials, traffic flow, and clothing procedures.

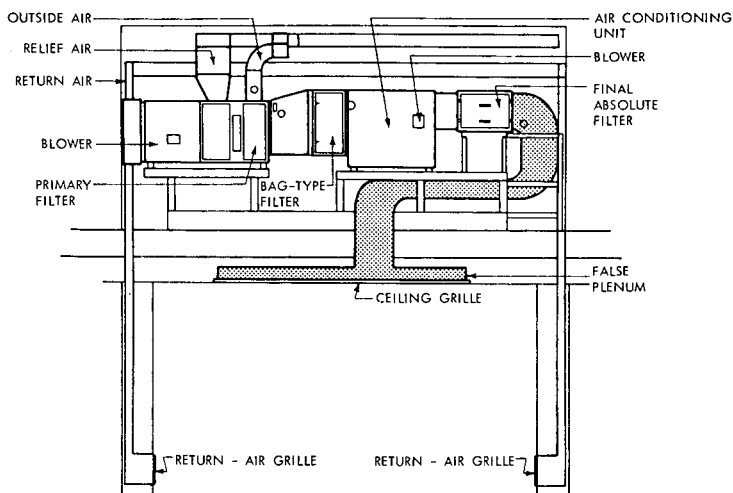


Ventilation system of the clean room. The ventilation system is located in the remodeled facilities' gallery. The 99.97 percent efficient HEPA filter is on the right.

Multiple data sources were utilized to aid in the job description and renovation plans, and specifically for the justification of the expenditure. Data sources specifically used included descriptions of laminar flow systems, room layouts, high-efficiency particulate air (HEPA) filters, ventilation system design, and bacterial monitoring. The renovation, completed in six weeks, provided the hospital with one of the most up-to-date surgical suites in the nation.



Floor plan for the remodeled surgical suite. All rooms peripheral to the operating room have a separate ventilation system.



A schematic side view of ventilation system for the remodeled operating room. Capacity is 100 room changes per hour.

The specifications for the remodeled surgical suite are as follows:

General

- The operating room measures 20 feet X 24 feet.
- The operating area is continuously flushed with clean, bacteria-free air.
- The plaster walls are coated with Teflon-covered vinyl.
- All cabinets and storage shelves are stainless steel.
- Three ancillary rooms, ventilated by a separate system, provide room for the necessary instrumentation, induction of anesthesia, and scrub and preparation area.

Ventilation System

- The operating room ventilation system is entirely separate from all other systems.
- The system maintains a positive pressure differential between the operating room and the hospital and ancillary rooms of 0.25-inch water pressure.
- The blower system is a single 7.5 hp motor and squirrel-cage fan on the air supply and 7.5 hp motor and squirrel-cage fan on the air return.
- Blower capacity is approximately 7,300 cubic feet per minute.
- Blower output is adjustable by changing pulleys to permit a range of 25 to 100 room changes per hour.
- Filtration is accomplished in three stages: 30 percent efficient 5-micron fiberglass element rough filter; bag-type primary filter, 95 percent efficient at 3 microns; HEPA final filter, 99.97 percent efficient at 0.3 microns.
- Heating and cooling coils control air temperature in the mixing chamber.
- A humidifier downstream of the HEPA filter controls the relative humidity.
- The system permits total recirculation of 100 percent outside air, or any ratio thereof. Makeup is provided by outside air.

- A single distribution plenum delivers air to 12 ceiling grilles in the operating room. The 2 feet X 4 feet grilles, comprise a total area of 96 square feet.
- Return air exits the room through four wall grilles and return ducts mounted in the walls near the floor. Each of these grilles measures 2 feet X 2 feet.

Electrical Characteristics

- Vapor-tight service is provided throughout the operating room.
- Conductive tile floor with electrical ground maintains limits on the resistance between electrical ground and any location on the floor within 75,000 to 400,000 ohms per city code. Less than 1 millivolt potential exists between any two points in the wiring ground system.
- Fluorescent light fixtures are mounted flush in the ceiling around the air inlet grille.

Room Operating Conditions

- Blower output is set for 100 room changes per hour.
- Air velocity is approximately 69 feet per minute or 1.15 feet per second.
- Temperature and relative humidity are 70°F and 55 percent, respectively.
- Air mixture is 80 percent, recirculated, 20 percent outside and makeup air.
- Noise level measured at 100 room changes per hour was 53 dB with the room empty.

CHAPTER IV

GUIDELINES FOR PROCUREMENT OF HOSPITAL EQUIPMENT

In general, each major advance in biomedicine has been accompanied by the need for development of new and expensive instrumentation. Acquisition of this new instrumentation, coupled with installation and maintenance costs, has contributed greatly to today's rising costs. Also, addition of this complex equipment to the hospital's inventory has served to introduce additional reliability and safety problems. Historically, hospitals have not had to overly concern themselves with the reliability and safety of their equipment, since such equipment was relatively simple and generally well understood by personnel responsible for its use. However, due to increased emphasis on providing the best medical care as soon as possible, hospitals have many times purchased new equipment as soon as they appear on the market. As a result, they may not have a thorough understanding of the cost effectiveness, safety, and reliability of the products.

Solutions derived for many of the problems NASA faced with regard to its hardware acquisition program hold considerable potential for use by hospital administrators facing the problems outlined, if certain basic limitations are overcome. Since much of the equipment needed for the Nation's space program was developed under contract, NASA has been in a position to develop complete specification and procurement guidelines. Such guidelines not only assure that specific needs are clearly communicated to the vendor, but also provide a benchmark against which to test and evaluate the final product.

Reliability and Quality Assurance

In the area of reliability and quality assurance, NASA's success has been largely due to its substantial resources—both in terms of funds and personnel. The availability of such resources has permitted dealing with equipment manufacturers from a position of considerable economic strength. However, *individual* hospitals, due to their smaller dollar volume procurements, can expect only limited effectiveness in dealing independently with equipment manufacturers. Quite simply, individual hospitals do not have, on their own, the economic leverage required to influence significant modifications in an equipment manufacturer's product lines. This is partly because such modifications generally involve substantial monetary considerations on the

part of the manufacturer, with it being unlikely that an individual hospital's needs could ever justify, nor could its budget support, procurement of extensively customized equipment. Another limitation in the use by individual hospitals of NASA's reliability and quality assurance approach centers on the fact that NASA's highly flexible systems for specifying and monitoring would place a considerable burden on the individual hospital to (1) develop specific reliability and quality requirements from general guidelines and (2) provide adequate surveillance to ensure that the requirements are met by the manufacturer. Performing these functions requires a well-qualified specialized staff. The cost renders the matter impractical for an individual hospital.

While it may appear impractical for an individual hospital to attempt to duplicate NASA's proven reliability and quality assurance program, the problems previously discussed can be resolved if the hospitals deal with equipment suppliers collectively as members of an association, rather than as individual institutions. Several recommendations concerning the function that such an organization can play in reliability and quality assurance follow:

- The association could evolve within the framework of a representative organization capable of speaking to the medical equipment industry for *all association members*.
- The organization could prescribe performance requirements and other criteria for various classes or types of equipment encountered in the hospital environment.
- The association could develop criteria specifying key parameters and performance characteristics quantitatively with stated tolerances and means of verifying that such parameters have been met.
- The association could advise member hospitals on methods and techniques for ensuring that the developed specifications are met.
- The association could capitalize on the technique of failure mode effect and criticality analysis perfected by NASA by sponsoring such analyses and subsequently recommending the kind of equipment and procedures needed for various patient life-risk failure modes in connection with various types of equipment.
- The association could provide guidance in the area of maintainability engineering for its member hospitals since problems in this area have become both sophisticated and diverse.

The association could sponsor the development of guideline approaches to maintenance-type problems using a criticality basis so that member hospitals could meet such by a planned preventive and corrective maintenance program.

A move in this general direction is evidenced by the Veterans Administration's adoption of standardized requirements for its medical facilities to follow in purchasing medical equipment. Veterans Administration Specification X-1414, dealing with biomedical monitoring equipment, is included as an example of the approach used by the Veterans Administration in its procurement program.

VETERANS ADMINISTRATION
SPECIFICATION X-1414
AMENDMENT NO. 1
September 1, 1970

BIOMEDICAL MONITORING SYSTEMS (Electro-Biometrics for Intensive Care Units)

(See Note on page 9)

3.1.1.1 Cardiovascular. The cardiovascular monitoring and display functions are as follows:

(a) Heart Waveform - Continuous monitoring cathode raytube (CRT) display [or equivalent] at bedside. Selectable or continuous CRT display [or equivalent] selectable direct writing recorder and continuous interval tape recorder [or equivalent] at the remote station.

(b) Heart and/or pulse rate continuous monitoring and [meter or equivalent] display at bedside, and selectable [meter or equivalent] display at the remote station.

(c) Blood Pressure - [Function selectable or continuous monitoring with meter or equivalent display of the systolic, diastolic, mean or venous pressure at bedside. Patient selectable meter or equivalent display at the remote station.]

3.1.1.2 Temperature. The temperature monitoring and display functions include monitoring and [meter or equivalent] display at bedside. Selectable [meter or equivalent] display at the remote station.

3.1.1.3 Respiration Rate. The respiration rate monitoring and display functions include: Continuous monitoring and [meter or equivalent] display at bedside. Selectable [meter or equivalent] displays at the remote station.

3.1.2 Alarm Functions.

3.1.2.1 Bedside. The bedside alarm functions consist of separate alarm lights automatically illuminated for each monitored and [meter or equivalent] displayed parameter which violates preset low or high limits. Alarm lights are manually [or automatic] reset at the patient's bedside when the alarm condition has been corrected.

3.1.2.2 Remote Station. The remote station alarm functions consist of separate alarm lights automatically illuminated for each patient whose monitored and [meter or equivalent] displayed parameter falls above one bedside preset limit or below another bedside preset limit. A single aural alarm sounds whenever any alarm condition occurs. Visual and aural alarms are automatically [or manual] reset when the bedside alarm lights are [automatically or manually] reset.

3.1.2.3 Display Continuity. During an alarm condition all physiological displays will continue to function.

3.1.3 Switching and Control Functions. The following switching and control functions are in addition to the essential switching and control functions for operation, calibration, alarm setting and resetting, etc.:

(a) Manual selection for display at the remote station of all monitored parameters of [a specific] patient.

(b) Automatic initiation of the direct writing ECG recorder and selection for display at the remote station of all monitored parameters of patient in alarm status.

3.1.4.1 Heart Pacing. The heart pacing function consists of the capability to intermittently stimulate the heart at either a preselected [fixed rate or demand mode.]

3.2.1.1 Input. The input to the ECG amplifier shall consist of signals from surface electrodes. The ECG amplifier shall accept differential signal of up to [5] MV peak-to-peak. The differential input impedance shall not be less than $\pm$ [5] megohm from [.05] to 60 Hz.

Sample of Veterans Administration Specification X-1414.

In the specification, each function is quantitatively and unambiguously defined. By reviewing these specifications with qualified electronic equipment experts, the hospital staff can then clearly communicate their requirements to industry. These specifications can, in turn, be incorporated into a request for a proposal from manufacturers who may wish to supply the equipment. This procedure will help assure that the equipment will be offered, and subsequently judged, on an objective, uniform basis. Additions and/or modifications can be referred to a specific section of the specification and clearly understood by both hospital and vendor personnel.

The hospital staff and their technical consultants can then review the vendor's proposals in terms of specific points enumerated in the specification. This review permits conduct of cost-benefit analyses on the alternative systems offered by the bidders, encompassing the entire spectrum of significant variables. These variables include cost, quality, reliability, safety, and other important considerations (e.g., on-going costs of service and maintenance, which often receive little attention during the procurement cycle).

Specifications such as Specification X-1414 constitute an excellent guide for the generation of specifications, and the subsequent evaluation of vendor proposals. However, the availability of such specifications is not a substitute for the expert knowledge of the biomedical engineer. His services will still be needed to evaluate end items submitted as candidates for procurement. The primary value of such specifications is one of communicating to all concerned—the physician, the engineer, the administrator, and the vendor—exactly what is to be procured and precisely what purpose it will serve.

Reliability and Safety

While the safety and reliability of medical equipment have become of increasing concern to hospital personnel and the general public, equipment reliability and safety can only be ensured if a well thought out program is initiated and maintained. NASA, having no margin for error in its space efforts, has pioneered in developing procedures to cope with these important variables. Several approaches useful in terms of medical equipment are outlined below.

- NASA has developed a method for establishing hardware service life margins for equipment susceptible to malfunction due to excessive time or operation cycles, and for identifying limited life

equipment so that monitoring and replacing can be accomplished before hardware failure. All functional dynamic hardware, such as engines, gears, actuators, valves, springs, pumps, switches, and certain electrical components are susceptible to failure due to wear. Depending upon the type of hardware, excessive time or operation cycles will normally result in performance degradation or failure. Good practice generally requires replacing hardware that is suspected of approaching its design service life limit, particularly if its failure could result in personnel hazard, loss of ability to perform a critical function, or excessive cost.

This method of establishing service life is considered applicable to any hardware where a design service life has been established and where a reasonably accurate prediction of expected usage (time or cycles) can be made. The procedures and specifications used in developing the method are available* for use as guidelines in developing requirements for specific equipment.

- NASA has developed control plans, procedures, and complete specifications for the management of age-sensitive hardware. Materials used in gaskets, seals, lubricants, hose assemblies, batteries, adhesives, and fabrics are among those that deteriorate and create safety hazards or cause system failure if not replaced at scheduled intervals. A method of identifying limited life materials and related components, assigning responsibility, and scheduling replacement or service is necessary for establishing spare parts stock levels, maintenance schedules, material storage methods, and product warranty schedules. Methods and specifications available from the Technology Utilization Officer at Marshall Space Flight Center can be used as guidelines in controlling age-sensitive materials by defining the necessary tasks and delegating the responsibility for their accomplishment. The control plan identifies shelf life or age-control requirements for materials considered to be age-sensitive, use-sensitive, or time service or shelf life controlled items. The methods of arriving at the age controls through adherence to detailed specifications are described. The plan presents methods for determining the processes through which the useful life of materials might be extended by constantly reviewing the technical considerations underlying the present age limitations and provides a procedural outline for the timely replacement of over-aged materials.

*Technology Utilization Officer, Marshall Space Flight Center, Huntsville, Alabama 35812.

The NASA reliability publication **Reliability Program Provisions for Aeronautical and Space System Contractors** constitutes an excellent source document for general guidelines in regard to methods for assuring the availability of reliable equipment. The publication pays particular attention to design specifications, reliability prediction and estimation, failure mode, effect, and criticality analyses, and maintainability and elimination of human-induced failure. Adherence to the guidelines will aid in assuring that delivered equipment will be satisfactory in terms of required performance, reliability, and maintainability. One of the most useful techniques employed in the aerospace program to assess the reliability needs and the design criteria of instruments has been the technique of failure mode, effect, and criticality analysis. In this technique, all the different ways a system or instrument could fail, what the consequences would be and what actions would be taken to alleviate the condition are postulated. As a result, many possible failures are avoided by proper design of the instrument or alternative methods can be made available in case of failure. The identification and minimization of the risk of failure of all equipments used in life-critical situations, such as artificial kidney machines, artificial heart machines, etc., by these techniques should be given the highest priority.

The importance of applying criteria such as previously discussed to medical instruments and procedures cannot be overemphasized, particularly since failure of such equipment represents possible hazard to the patient as well as representing the most costly item of service. A recent study reported in the *Journal of the Association for the Advancement of Medical Instrumentation* underscores the importance of failure mode analysis with respect to cardiac and special care systems. The study analyzes two proposed safe patient power systems. Included in the study are comparative reliability figures and the significance of factors such as hospital procedures, practices, and available personnel on system reliability. By identifying, isolating, and predicting these failure effects and determining potential corrective actions, potential malfunctions can be minimized and often remedied before they occur, helping to assure better patient care.

Specifications such as have been developed by the Veterans Administration establish a procedure for the selection of medical equipment, the evaluation of its design, the establishment of a reliability and quality assurance program, an equipment test program, and a maintenance calibration program. These steps, coupled with failure effects analysis, allow the hospital to evaluate the cost-benefits and the degree of risk associated with different reliability levels. There is no "best" solution to any of these problems outlined earlier. In each case, there must be a trade-off between physician,

engineer, and manufacturer, the specifications and guidelines provide a quantitative method of evaluating these trade-offs. In addition, the specifications and guidelines provide the hospital with a technique to apply in other areas of hospital management. For example, most medical institutions have historically modified their requirements to conform to equipment which is commercially available. By undertaking equipment procurements through the generation of specifications, not only can hospitals have the manufacturers modify their products so as to meet the hospitals' precise needs, but they will also have a quantitative method of evaluating their purchases. However, as stated earlier, the effectiveness that an *individual* hospital can have in dealing with equipment manufacturers is limited, since they do not generally deal in large dollar procurement and do not have technical staffs capable of tailoring specifications to particular needs and enforcing those specifications.

Significant advances in the reliability and quality assurance area can be made, however, if active "collective" programs are initiated by professional medical associations (whose primary memberships consist of individual hospitals of various sizes) and by those larger hospital systems (such as the large state, regional, or municipal systems having large dollar volume procurements). Much of the work that NASA has undertaken in conjunction with its space efforts are directly applicable to this important undertaking.

CHAPTER V

POTENTIAL FOR THE FUTURE

The partnership of the physician and the bioengineer, which has produced many of the advances discussed in the preceding chapters, promises to contribute increasingly to advancement of the state-of-the-art in biomedicine, particularly in the realm of acquiring, processing, storing, displaying, and transmitting a range of physiological and behavioral data. Substantial contributions can be expected from ongoing aerospace research and development activities devoted to solving the problems involved in meeting the need for improved instrumentation and techniques in such important areas as the following:

Integrated Medical and Behavioral Laboratory System

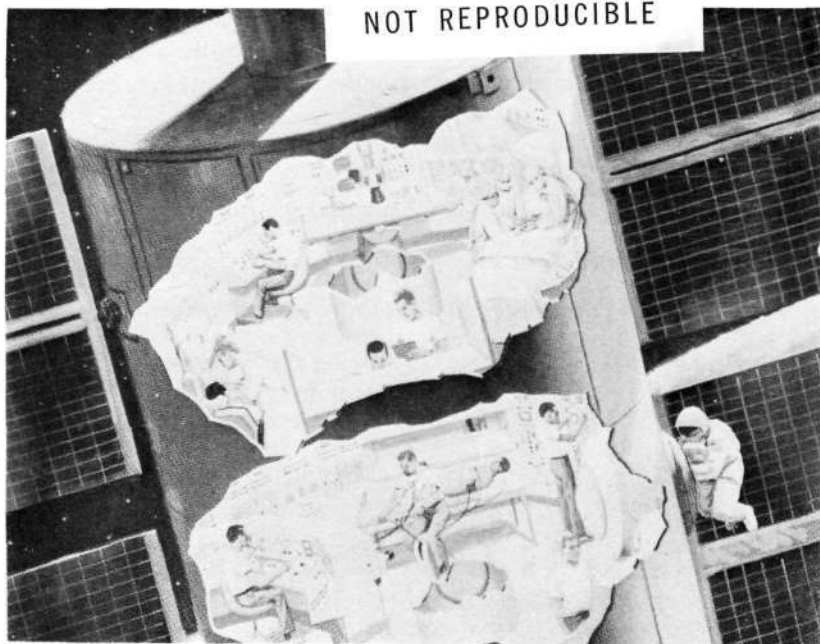
The integrated medical and behavioral laboratory system (IMBLMS) is a highly flexible and sophisticated laboratory system designed to acquire medical and behavioral data associated with NASA's space explorations. The IMBLMS concept presents some unusually challenging aspects. For example, it involves an effort to gain scientific knowledge of human responses to an unknown environment through research in a medium which requires complex engineering and operational interfaces.

Basically, IMBLMS consists of a rack-and-module system which can be assembled into working consoles to suit the particular requirements of the spacecraft and the experiments program of the particular mission. Hardware modules or submodules for any projected specific experiment can be developed for accommodation in the IMBLMS and used as needed.

IMBLMS Five Functional Elements

The modular approach was adopted as a means of (1) reducing lead times, (2) simplifying in-flight maintenance, and (3) providing for the economical updating of equipment. As currently envisioned, IMBLMS incorporates five functional elements: physiological, behavioral, biochemical, microbiological, and data management. Together, these five elements accommodate all the required measurements envisioned in the eight human function areas scheduled for consideration in the medical/behavioral investigation associated with projected space explorations. The IMBLMS will

NOT REPRODUCIBLE



Artist concept of the IMBLMS system.

be composed of two or three consoles with five or six pieces of peripheral equipment. Presently identified peripheral equipment includes a bicycle ergometer, a rotating litter chair, a body-mass measurement system, a lower body negative-pressure device, and a specimen-mass measurement system.

Research and development efforts associated with the IMBLMS can be expected to contribute greatly towards advancement of the state-of-the-art in such areas as behavioral observation, biochemistry, microbiology, energy metabolism, accurate determination of fluid intake and output measurement, venous pressure and cardiac output techniques.

Medical Telecommunications

The principal issues in modern medicine have been identified as cost, quality, and equality of access. Interactive television has been shown to constitute an effective mechanism for helping provide equality of access to medicare by successfully bridging a gulf between a teaching university hospital and a specialist-scarce outlying community hospital. In this

innovative approach, a specialist at one end of the telecommunication link is within sight and sound of the patient on the other end of the link. Advances made by NASA in telecommunications promise to contribute significantly in the following areas:

- Improved image processing techniques
- Advanced transducers and amplifiers
- Reliable telemetering systems
- Improved teleoperator controls for teleoperator systems.

Other new needs—and the need for refining existing medical techniques associated with the space program—are continually being identified. The results generated are likely to be useful in a much broader context than their



A typical medical telecommunications transaction.

aerospace applications. NASA needs, for example, to continue to perfect noninvasive methods for effectively determining cardiac output, central and peripheral venous pressure, and deep regional blood flow. For purposes of convenient biochemical analysis in the space environment, reagents are needed to improve the accuracy and practicality of its measurement techniques and to compress new technique evaluation and verification time-spans in order to establish accuracy, reliability, repeatability and, in some instances, interpretability.

Progress made in these areas of the Nation's aerospace program can be expected to provide a considerable assist to the health sciences community in its efforts to provide better and more economical health care.

APPENDIX A
MEDICAL INFORMATION
MANAGEMENT SYSTEM (MIMS)

MEDICAL INFORMATION MANAGEMENT SYSTEM (MIMS)

Anticipating problems in storing, maintaining, manipulating, and analyzing the voluminous medical data base associated with medical aspects of the space flight program, NASA early initiated a research and development effort designed to explore automation of the medical records process. This research and development effort followed two parallel paths—a medical information project and an information management project, collectively called the Medical Information Management System (MIMS).

Medical Information. The medical information component of MIMS refers to that body of information or medical data (MEDATA) that is generated during everyday patient-care activities. Its primary purpose is documentation of the factors applied to disposition of patient care. However, in addition, these records are called upon to serve research, educational, and administrative needs. It is important to note that the most compelling reason for development of a structured record system is not simply conversion to automation, but rather the provision of an accurate, detailed, and consistent bank of data.

At least three features are essential for any systematic file structure: (1) provision for unique identification of each individual record in the file, (2) definition of the content of the file, and (3) uniform organization of the component records. A further consideration is that in the medical environment, full exploitation of the computer depends on one vital factor. That is, allowing the user—the physician, research scientist, or administrator—to organize, collect, store, and retrieve all types of medical data without having to resort to mastery of intricacies of formal computer science.

Information Management. Information management, the second path of the NASA research and development effort, refers to the provision of smooth and integrated mechanisms to collect, process, and retrieve records or parts of records. For these purposes, the advantages of the modern digital computer and associated supporting equipment have been amply documented. A later section of this appendix will describe some unique concepts in computer programming and a description of the operational implementation of these concepts for acquiring, processing, retrieving, and maintaining medical information associated with the space program's medical activities.

Though the MIMS approach was developed for use in processing medical data on the astronauts at NASA's Manned Spacecraft Center,

Houston, Texas, the basic techniques involved are equally applicable for use in literature storage and retrieval, administrative records, and many other automated data processing requirements faced by a medical institution, such as storage and retrieval of personnel data for the institutional staff.

System Versatility

As a generalized information storage and retrieval system, MIMS was designed to allow the user to accomplish four vital functions:

- (1) Definition of File Structure
- (2) Data Entry
- (3) Data Retrieval
- (4) File Maintenance

Since each user may have unique problems in establishing a data file which will satisfy his particular needs, MIMS was designed to allow the user to define his own file structure—providing a framework for processing any structure required for the user's purpose.

Also, whereas the MIMS approach was developed using an SDS 930 computer with an IBM 1050 programmed typewriter, the system has been used on a number of other types of computers. The system is both manufacturer and machine independent.

System Features

In developing the MIMS approach, the desire was to design concepts of medical documentation leading toward increased utility of the stored data, and concurrently to provide a computer-supported records-management capability that neither dictates nor restricts the medical information handled by the system.

An effort has been under way since 1965 at NASA's Manned Spacecraft Center to perfect such a system for use with astronauts' medical information. Following is a discussion of these features, as reflected in the MIMS approach.

Record Identification

In general, the orientation of data typically encountered in the medical environment provides a straightforward approach to record identification. That is, medical records are generally accumulated in terms of three parameters: the *who*, the *what*, and the *when*. The *who* may be a patient's name or any of a group of unique numbers (such as hospital number or social security number). The *when* is a date that may or may not be supplemented by time of day. The *what* defines the content in terms of the function and the type or source of the data.

Content

The content of the medical record file constitutes the axis on which the record system revolves. In determining a pattern for medical record file structure, data function has been the paramount consideration. For example, when the content of patient-care information is viewed from the standpoint of functional documentation, three somewhat distinct classes of medical reports are discernible: the survey, the specific problem workup, and the status report. Frequently, the first two classes are intermixed, but can and should be separated for a variety of reasons.

Whether the survey or screening examination is applied to a population or an individual patient, its purpose is the same. That is, it identifies from the whole the parts having a high probability of disease and thereby establishes a set of problems requiring further medical investigation. Equally significant, the survey report also serves to document the parts that are free of recognizable disease. A complete or partial survey may be conducted at any point in the patient-care cycle, either as an independent periodic examination or to complement a workup performed for a specific reason. Generally, the workup is initiated either because the patient seeks help for a problem or because a survey has elicited one or more potential problems. The workup constitutes an attempt to establish a diagnosis and to institute appropriate therapy for each problem encountered. The workup produces two principal functional results: a plan of action that may be either diagnostic or therapeutic and initial implementation of that plan (in terms of a set of orders).

The effectiveness of the plan is evaluated and documented periodically, with the doctor's "progress note" constituting a prime example of such a status report. However, other reports are also included which serve the same basic purpose, such as nurses' notes and reports of procedures. The value of this approach is that it provides a framework for understanding and

categorizing the basic functions of each informational component in the patient-care environment. It can be seen readily that each functional division (survey, workup, status) has a natural group of subdivisions based on the type or source of data. To illustrate, the several types of survey documentation include electrocardiographic, laboratory, X-ray, and review of systems. Data contained in Table A-1 depict the basic pattern of record identification and list the specific types of survey reports currently in use at the Manned Spacecraft Center.

Table A-1. MEDATA Identification Pattern for Survey Records

Category	Heading	Date (examples)
Who	SS No.	
What (A)	Record	Survey
What (B)	Type	Identification Review of systems (ROS) Dental Laboratory X-ray ECG Measurement Vision Summary
When	Date	01 Jun 71

Each type represents a unique step in the survey process and may be generated by a different person at a separate time or in a special location. These same criteria are applied to the designation of types of reports throughout the medical records file system developed for use with the astronauts.

In summary, unique identification is provided by requirement of a standardized set of statements regarding the *who*, *what*, and *when* of each report in the file. In the NASA application, the patient's identity is established by the social security number (SS NO); content is defined by both the function of the RECORD and the TYPE of record, and DATA indicates the time frame.

Organization

NASA's medical data (MEDATA) system divides each medical report into two segments: the *leaders* or identification portion and the *body*. In establishing the body of a particular report, an orderly approach is used to identify informational content.

For example, Standard Report of Medical Examination (Form-88), one of the survey documents in use at NASA's Manned Spacecraft Center, was adopted as the starting point for development of the Medical Records Management System. Once this was done, terms had to be chosen as headings to represent the document's contents, since unidentified data are meaningless. In this connection, although many data when presented in context need no overt headings, the heading concept is nevertheless implied by the context.

In general, most items contained in the data file are accumulated as direct answers to the questions posed by headings. These headings must be organized into an outline so that relations are clear among the various blocks of data. To illustrate, consider items 57 and 58 of Standard Form 88 (Figures A-1 and A-2) which refer to measurements of the cardiovascular system. Now consider the outline arrangement of these basic items shown in Figure A-3. While minor modifications in terminology have been used in Figure A-3, all original content derived from items 57 and 58 remain intact. Also notice the use of standard outline techniques to emphasize the relationships inherent in the outline. All data about pulses are indented under that term, and other degrees of indentation clearly establish the relations among the remaining headings. Such outline or hierarchical techniques provide a pattern by which man (and machine) can recognize the organization of headings and, consequently, the association of data.

The final consideration in establishment of a systematic file structure concerns the policy regarding data "formatting." The format of an item of data refers to the detailed characterization of the way in which that item is to be reported. NASA's system recognizes that three fundamental and distinct kinds of information must be reported in a medical context—quantities, judgments, and facts.

In the present usage, quantities refer to measurements generated in the medical environment directly or indirectly from the patient, such as height, weight, blood pressure, and laboratory values. Quantities are formatted by making the numerical value the first element in the data area or field; this is generally followed by the type of unit in which the value is reported—height, 70 in.; or Hb, 15.4 g.

Judgments are items for which the examiner is expected to evaluate one or more criteria and summarize his opinion. With the NASA system, this expression is formatted by entering the abbreviations POS (positive) or NEG (negative) followed by an explanation or amplification in prose as appropriate. Thus, the entry POS means that, in the opinion of the examiner, the item under consideration is unusual, abnormal, or otherwise noteworthy. NEG indicates normal, within acceptable limits, or not significant. As to be expected, the entry POS is almost always followed by a description of the abnormal finding or some comment to explain why that item is notable. NEG may also be amplified by prose as necessary, as shown in Figure A-4, which depicts a portion of the record of a typical physical examination.

BIOMEDICAL RESEARCH AND COMPUTER APPLICATION

Standard Form 88 (Rev. June 1956) Bureau of the Budget Circular A-32 (Rev.)										REPORT OF MEDICAL EXAMINATION										88-108	
1. LAST NAME—FIRST NAME—MIDDLE NAME										2. GRADE AND COMPONENT OR POSITION										3. IDENTIFICATION NO.	
4. HOME ADDRESS (Number, street or RFD, city or town, zone and State)										5. PURPOSE OF EXAMINATION										6. DATE OF EXAMINATION	
7. SEX		8. RACE		9. TOTAL YEARS GOVERNMENT SERVICE				10. AGENCY				11. ORGANIZATION UNIT									
				MILITARY				CIVILIAN													
12. DATE OF BIRTH				13. PLACE OF BIRTH				14. NAME, RELATIONSHIP, AND ADDRESS OF NEXT OF KIN													
15. EXAMINING FACILITY OR EXAMINER, AND ADDRESS										16. OTHER INFORMATION											
17. RATING OR SPECIALTY										TIME IN THIS CAPACITY (Total)						LAST SIX MONTHS					
CLINICAL EVALUATION (Check each item in appropriate column, enter "N" if not examined.)										NOTES: (Describe every abnormality in detail. Enter pertinent item number before each comment. Continue in item 73 and use additional sheets if necessary.)											
18. HEAD, FACE, NECK AND SCALP 19. NOSE 20. SINUSES 21. MOUTH AND THROAT 22. EARS—GENERAL (For & not, conduct) (Auditory tests under items 70 and 71) 23. DRUMS (Perforation) 24. EYES—GENERAL (Visual acuity and refraction under items 89, 90 and 91) 25. OPHTHALMOSCOPIC 26. PUPILS (Equality and reaction) 27. OCULAR MOTILITY (Associated parallel movements, conjugate) 28. LUNGS AND CHEST (Include breasts) 29. HEART (Throat, size, rhythm, sounds) 30. VASCULAR SYSTEM (Varicose veins, etc.) 31. ABDOMEN AND VISCERA (Include Aorta) 32. ANUS AND RECTUM (Hemorrhoids, fistulas) (Prostate, if indicated) 33. ENDOCRINE SYSTEM 34. G-U SYSTEM 35. UPPER EXTREMITIES (Strength, range of motion) 36. FEET 37. LOWER EXTREMITIES (Range of motion) 38. SPINE, OTHER MUSCULOSKELETAL 39. IDENTIFYING BODY MARKS, SCARS, TATTOOS 40. SKIN, LYMPHATICS 41. NEUROLOGIC (Epileptiform tests under item 72) 42. PSYCHIATRIC (Specimens personality deviation) 43. PELVIC (Females only) (Check box done)										(Continue in item 73)											
64. DENTAL (Place appropriate symbols above or below number of upper and lower teeth, respectively.) O—Restorable teeth X—Missing teeth X X X—Replaced by dentures (8, 9, 10)—Fixed bridge, brackets to include abutments										REMARKS AND ADDITIONAL DENTAL DEFECTS AND DISEASES											
1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32.										L E F T											
LABORATORY FINDINGS																					
45. URINALYSIS: A. SPECIFIC GRAVITY										46. CHEST X-RAY (Place, date, film number and result)											
B. ALBUMIN										D. MICROSCOPIC											
C. SUGAR																					
47. SEROLOGY (Specify test used and result)										48. EKG											
										49. BLOOD TYPE AND RH FACTOR											
										50. OTHER TESTS											

Figure A-1. Front of medical examination report (Standard Form 88).

MEASUREMENTS AND OTHER FINDINGS																					
51. HEIGHT		52. WEIGHT		53. COLOR HAIR		54. COLOR EYES		55. BUILD: (Check one)		SLENDER	MEDIUM	HEAVY	OBESE	56. TEMPERATURE							
57. BLOOD PRESSURE (Arm at heart level)								58. PULSE (Arm at heart level)													
A. SITTING		SYS.		B. RECUMBENT		SYS.		C. STANDING (if applicable)		SYS.		A. SITTING		B. AFTER EXERCISE		C. 2 MIN. AFTER		D. RECUMBENT		E. AFTER STANDING 3 MIN.	
RIGHT 20/		CORR. TO 20/		BY		S.		OX		CORR. TO		BY		CORR. TO		BY		CORR. TO		BY	
LEFT 20/		CORR. TO 20/		BY		S.		OX		CORR. TO		BY		CORR. TO		BY		CORR. TO		BY	
62. HETEROPHORIA (Specify distance)																					
ES°		EX°		R. H.		L. H.		PRISM DIV.		PRISM CONV. CT		PC		PD							
63. ACCOMMODATION				64. COLOR VISION (Test used and result)				65. DEPTH PERCEPTION (Test used and score)				UNCORRECTED									
RIGHT				LEFT								CORRECTED									
66. FIELD OF VISION				67. NIGHT VISION (Test used and score)				68. RED LENS TEST				69. INTRAOCULAR TENSION									
70. HEARING				71. AUDIOMETER								72. PSYCHOLOGICAL AND PSYCHOMOTOR (Tests used and score)									
RIGHT WV		/15 SV		/15		300 850		500 810		1000 1094		2000 2048		3000 3200		4000 4023		5000 5144		6000 6188	
LEFT WV		/15 SV		/15		RIGHT		LEFT													
73. NOTES (Continued) AND SIGNIFICANT OR INTERVAL HISTORY																					
(Use additional sheets if necessary)																					
74. SUMMARY OF DEFECTS AND DIAGNOSES (List diagnoses with item numbers)																					
75. RECOMMENDATIONS—FURTHER SPECIALIST EXAMINATIONS INDICATED (Specify)														76. A. PHYSICAL PROFILE							
														P U L H E S							
77. EXAMINEE (Check)														B. PHYSICAL CATEGORY							
A. ☐ IS QUALIFIED FOR																					
B. ☐ IS NOT QUALIFIED FOR																					
78. IF NOT QUALIFIED, LIST DISQUALIFYING DEFECTS BY ITEM NUMBER														A B C E							
79. TYPED OR PRINTED NAME OF PHYSICIAN										SIGNATURE											
80. TYPED OR PRINTED NAME OF PHYSICIAN										SIGNATURE											
81. TYPED OR PRINTED NAME OF DENTIST OR PHYSICIAN (Indicate which)										SIGNATURE											
82. TYPED OR PRINTED NAME OF REVIEWING OFFICER OR APPROVING AUTHORITY										SIGNATURE											
										NUMBER OF ATTACHED SHEETS											

Figure A-2. Back of medical examination report (Standard Form 88).

CARDIOVASCULAR
BP
SITTING
SYS:
DIAS:
RECUMBENT
SYS:
DIAS:
STANDING
SYS:
DIAS:
PULSE
SITTING:
RECUMBENT:
STANDING:
EXERCISE
IMMED AFTER:
2 MIN AFTER:

Figure A-3. Outline derived from the cardiovascular-measurement section of Standard Form 88.

Item	Judgment	Explanation
Abdomen	NEG	Scaphoid; good tone
Anus and rectum	POS	Asymptomatic large hemorrhoids
GU	NEG	

Figure A-4. A portion of the record of a physical examination showing additional explanation.

This policy permits the rapid scanning of reports for information judged to be medically significant by the examiner. Also, the judgment format may be combined with quantitative reporting. For example, the judgment (POS or NEG), plus commentary, can be entered after the quantity and its type of unit—weight, 185 lb; POS (30 lb overweight for height).

The third kind of data considered—facts—is not subject to quantitation or judgment in the usual sense, since they constitute items of information, such as name, address, history of measles, etc. They are simply placed in the report as communicated from the patient or other informant. While a judgment may be made as to the reliability of the informant, the items themselves are not subject to medical evaluation or quantitation. Obviously, while the formatting of facts is not restrictive, it must nevertheless be uniform, item by item. For example, the question regarding name should always be answered in the same pattern—last name, first name, middle initial.

The Primary/Peripheral Programming Concept

The primary/peripheral concept, incorporated into the NASA medical records system, represents a significant departure from classical programming approaches. For example, the concept offers great flexibility in file structure, which is of immense help to those who are not familiar with computers. Concurrently, it provides a core for smooth integration within the acquisition, processing, and retrieval components of the overall information management system.

As routinely used, the term *computer program* can be defined as a discrete set of instructions which, when applied to the computer, controls the manipulations performed by the computer system on a specified file of data. Usually, the computer program functions at two levels. The primary level refers to the logical task for which the program was initially intended, e.g., to retrieve an existing item from the file or to compute standard deviations. The secondary programming level refers to instructions to the computer which are required to relate (1) data files to primary program steps, and (2) the results of primary programs to man.

Operationally, the difference between primary and secondary programming levels becomes clear when one considers that primary programming deals with concepts (standard deviation, sort, retrieve, etc.) or generalized operations performed on many different data files. In contrast, secondary programming is concerned with the intimate details of a specific file, e.g., for example, the location and arrangement of the numbers from which a standard deviation is to be calculated, or the particular items of data to be sorted or retrieved.

Secondary programming recognizes the formatting and the sequential relations of a specific data file. That is, it defines content and organization. Since, as discussed earlier, these definitions are already contained within the basic structure of each typical medical-information document, their preservation during the acquisition of records in a machine-readable form provides an automatic peripheral mechanism for accomplishing most of the functions of secondary programming.

To summarize, primary programming involves the concept of limiting the responsibility of a set of computer programs to performance of basic conceptual tasks. Peripheral programming refers to the inclusion within the body of each computer-stored record of the necessary secondary-level definitions of content and organization in context with the specific data. Appropriate use of peripheral programming precludes the need for special secondary-level program segments attached to each primary program. Instead, only a standard interface segment need be included in the primary program which can interpret the peripherally programmed definitions contained in any given record. The operational details of this concept are referred to as facsimile storage (FACS).

Facsimile Storage

Facsimile storage is the descriptive label applied to construction of the computer record. It is based on preparation (by a standard typewriter keyboard) of a document that is at once not only human-readable but also in

machine-readable format. Facsimile storage preserves the complete content of each individual record in the computer, including not only prosaic (English) headings and associated text of data, but also reorganizational relations. In

the NASA system, the computer handles facsimile storage in a simple manner, which requires only three position codes for each heading/data pair. The first, or hierarchical code set, performs two functions: (1) it identifies the beginning of a heading/data pair, and (2) it specifies the hierarchical relation between its own heading and the preceding and following headings. The hierarchical code set can be any series of typewriter symbols. For purpose of illustration, the present discussion employs zero through 9 (0, 1, . . . , 9). Each digit indicates progressively the degree of indentation from the left margin in the defined outline organization of headings: zero means no indentation, 1 is the first level, 2 is the second level, and so on. Figure A-5 shows application of the hierarchical code to the outline of headings given in Figure A-3.

Code number	Application to heading
0	CARDIOVASCULAR
1	BP
2	SITTING
3	SYS:
3	DIAS:
2	RECUMBENT
3	SYS:
3	DIAS:
2	STANDING
3	SYS:
3	DIAS:
1	PULSE
2	SITTING:
2	RECUMBENT:
2	STANDING:
3	EXERCISE
4	IMMED AFTER:
4	2 MIN AFTER:

Figure A-5. Application of the Hierachial Code set to some headings of Standard Form 88.

The second code functions to separate the variable-length heading field from the variable-length data field of the heading/data pair. The typed colon (:) used for this purpose serves the dual function of being understood by both man and machine. The third code terminates each heading/data pair and can be any unique character code. A special unprintable character automatically generated by the system during data acquisition is used as the terminating code.

In addition to the heading/data codes just discussed, editorial codes are generated at the time of document preparation and stored in the record. These codes control layout involving carriage return, tabulation, line feed, etc. By using a simple program these codes can be translated into functional equivalents in the computer. For example, "carriage return" equals "new print line," and "tabulate" equals "begin print in (specified) space." Thus, it can be seen that the term facsimile storage means just that—a facsimile of the original document resides in the computer.

Systematized Terminal-Acquisition Technique

Peripheral programming is implemented during data acquisition via the systematized terminal-acquisition technique. There is a one-step user-oriented procedure for transcribing information into machine-readable language. It is accomplished by the user in his own environment and under his complete control and replaces the classical key-punch approach to data transcription. Employing a simple typing operation, the method takes advantage of the user's familiarity with specific medical phraseology, spelling, and abbreviations.

At present, the systematized terminal acquisition technique functions through a commercially available terminal (IBM-1050 Tele-Communications System) equipped with a standard keyboard/printer (Selectric typewriter) as well as components that punch and read paper tape and cards. This terminal possesses four characteristics which makes it particularly suitable for use in the medical information management system:

- (1) Operation of the terminal is simple, with clerical and secretarial personnel who have no background in computer sciences being able to perform all required manipulations with only a few hours training.
- (2) The terminal can be programmed. That is, routine instructions such as carriage return, tabulate, tape punch "on" or "off," reader stop, etc., can be punched and stored on paper tape in context with the alphabetic and numeric characters used in the system. Later, as the tape is read through the terminal, each instruction is performed, providing a degree of format control that is limited only by the sequential nature of paper tape. Under the system's program control, data can be accepted from any input device (keyboard, paper-tape reader, or card reader) and subsequently transferred to any or all output devices (printer, paper-tape punch, card punch, etc.).
- (3) With the terminal, human-readable and machine-readable documents can be produced automatically and simultaneously, ensuring that data are available for immediate use, even though the system's computer support may be delayed or periodic.
- (4) The terminal can function on one or both of two channels. The home channel synchronizes the various components attached to a specific terminal, with the line channel adding a telephone line to

the circuit, over which data may be sent to, or received from, another compatible terminal or computer. Consequently, documents can be drafted with the machine on the home channel, with additions, corrections, or deletions being manually entered from the keyboard after editing. The edited document, which is stored on paper tape, can then be transmitted over the line channel to another receiving terminal or computer. Importantly, the direct transcription of material information into computer-readable form (peripheral programming) can be readily accomplished by medical secretaries using the terminal features described above.

Operation of the Systematized Terminal-Acquisition Technique

In the systematized terminal acquisition technique, summarized in Figure A-6, the typist, sitting at the terminal keyboard, places a master tape in the paper-tape reader. This tape functions to control the sequential typing of an organized set of headings (a format), to which the typist adds data from a collection form. Two documents result from this process—the typed page and a paper tape called the data tape. Each document contains pre-defined headings derived from the master tape and data from the collection form.

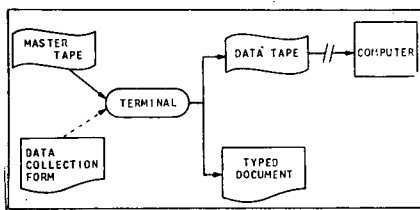


Figure A-6. Acquisition mechanics under the systematized terminal acquisition technique.

Preparation of Master Tapes

Each heading outline (described earlier under the Medical Information Section) is programmed as a master tape. As indicated earlier, facsimile-storage technique involved in peripheral programming requires the use of typewriter symbols to represent indentation of the headings in the outline to assure retention of desired relationships during computer storage. In this application, zero equals no space to the left of the heading, 1 equals one space, and so on through 10 levels. The outline is typed with the appropriate symbol inserted before each heading, with editing codes, such as carriage return or tabulate, inserted if desired to provide a more organized appearance of the document. A typed colon (:) is used to separate the heading field from the data field. Should it be desired to enter manual data during operation of the master tape, a reader-stop code is punched. A special code is used to

indicate the end of each data field. While the finished master tape requires careful preparation, it provides rapid and accurate reproduction of the original outline, to which a typist can add additional data at great speed.

Total operational efficiency of the systematized terminal acquisition technique can be greatly enhanced by using the punch-card capability of the terminal system. By prepunching cards containing the necessary instructions, the time required for preparation of a master tape can be reduced from several hours to 15 or 20 minutes. Under this procedure, a card is prepared for each of the sequential levels of a hierarchical outline (currently consisting of 10 levels). These 10 cards then contain all the instructions required by the master tape, except the specific words of the headings. The systematized terminal acquisition system employs the simple method of marking each card with a number corresponding to the sequential degree of indentation for its heading. Then, the original outline can be coded by assessing the degree of indentation and placement of that number in the margin of the outline. A series of heading cards is ordered sequentially according to the numbers of the outline format. When read through the machine, this deck of cards stops in turn at the correct indentation for the manual entry of each heading. The paper tape which results constitutes a master tape of the outline.

The Data-Collection Form

Design of the data-collection form must adhere to one general rule. That is, it must have the same headings as the corresponding master tape, or their equivalents, displaying similar sequential organization. In the system being described, data collection can be accomplished by dictation, either directly or through a recording device, as easily as by use of a written collection form. However, adherence to the appropriate heading sequence is important in assuring efficient transcription. A portion of Standard Form-88, used as a manual collection document and prepared for transcription, is shown in Figure A-7.

64. DENTAL (Place appropriate symbols above or below number of upper and lower teeth, respectively.)																		REMARKS AND ADDITIONAL DENTAL DEFECTS AND DISEASES	
O—Restorable teeth X—Missing teeth (6 X 6)—Fixed bridge, brackets to include abutments I—Nonrestorable teeth XXX—Replaced by dentures																			
R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	L	good dental function class II type 3	
I	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	E		
N	X																F		
T																		T	

Figure A-7. Portion of Standard Form 88 used as collection form and ready for transcription.

The Results

Typed results obtained by use of the systematized terminal acquisition system is shown in Figure A-8. Corrections may be made by the medical

secretary (1) when errors occur, or (2) during a tape-to-tape duplication of the original data tape. Editing is accomplished simply by proofing the typed document since it—and the data tape—have precisely the same content. After proofing, information from the data tape is then fed into the computer by (1) reading of the data tape by a paper-tape reader attached directly to the computer, or (2) by transmission of the data over a telephone line from the terminal's paper-tape reader.

MEDATA FILE	
RECORD:	SURVEY
TYPE:	DENTAL
SS NO:	[REDACTED]
DATE:	20Jan68
NAME:	Adams, John
STATUS: X=MISSING 0=RESTORABLE /=NONRESTORABLE _=PROTHESIS (7 x 9)=FIXED BRIDGE (BRACKETS INCLUDE ABUTMENTS) (CODED BELOW NO)	
RIGHT:	01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 LEFT
UPPER:	X (X X) X
RIGHT:	32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 LEFT
LOWER:	X 0 X
COMMENTS:	Good dental function
DENTAL CLASS:	2 Type 3
EXAMINER:	J B Moraton, Capt, USAF DC
TYPED:	jlb/01Feb68

Figure A-8. Appearance of final typed document. A facsimile is submitted to the computer as the data tape.

The Information-Management Package

The computer manipulations necessary to service the system's record files (termed MEDATA) are provided in a collection of computer programs called the information-management package and designed and developed on a medium-size, second generation computer (an SDS-930 with 16-K core, three tape drives, a line printer, and a console typewriter). All programming is written in a subset of FORTRAN common to most compilers. The information-management package is ultimately intended for a time-shared, multi-terminal environment, but is equally suitable for less sophisticated operational uses.

The key concept in the information-management package is that of modularity. As shown in Figure A-9, the package is organized into two types of computer-program components: a basic control routine (monitor), and clusters of subroutines.

The monitor computer-program component has three segments: executive segment, update segment, and retrieve segment. The executive segment

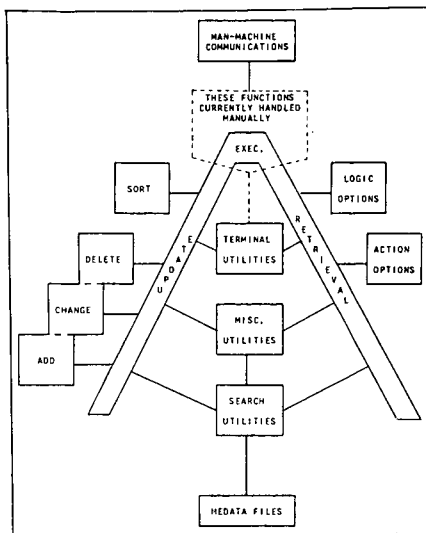


Figure A-9. Organization of the information-management package.

the system. The advantage of this approach is that it permits the alteration, exchange, or addition of subroutines with little, if any, change required in the basic monitor program.

To assure efficiency, the system's subroutines are organized into two classes: general and specific. General subroutines (called utilities) perform functions that may serve any segment of the basic control routine. Three clusters of general subroutines are shown in Figure A-9: terminal "general" subroutines, miscellaneous "general" subroutines, and search "general" subroutines. Terminal "general" utility subroutines provide for such things as translations between computer-code structure and terminal-code structure during transmissions and establish communications-control sequences for polling and addressing. The search "general" utility subroutine cluster includes all the subroutines that search the files for specific records or parts of records, which is necessary in order to retrieve, as well as update, data contained in the file. The third cluster in the "general" subroutine class is a miscellaneous group that performs a variety of useful data manipulation functions.

Each of the "general" subroutines is tied to only one segment of the monitor. The purpose of the sort, add, change, and delete subroutines and the logic and action options shown in Figure A-9 as

clusters are best understood as a function of the data-retrieval and update techniques described in the following paragraphs.

The Data-Retrieval Technique

The system's data-retrieval technique constitutes an organized man-machine communication sequence (or language) by which the user defines the specific information he desires and indicates what is to be done with those data. The necessary communicative interaction may be conducted as an on-line "conversation," employing a terminal device connected to the computer, or as an indirect "batch" operation, using punched cards or other prepared media.

The basic mechanism of the system's data retrieval technique is a question-answer technique similar to that used in the systematized terminal acquisition system. In use, the computer, acting through the programmed management system, poses questions to the user. Answers entered by the user in response to these questions provide the definitions and the action commands which control the programmed manipulation of the filed records.

In the data retrieval process, two sets of responses are provided by the user: (1) a definition of the data of interest, and (2) an instruction indicating the desired action to be performed on the defined data.

The user defines the data of interest by using the same set of questions employed to define each report in the file: SS NO. (social security number), RECORD, TYPE, and DATE. For example, in answer to the question SS NO., the user may enter a particular social security number. RECORD is answered by the name of the record of interest, such as SURVEY. The response to TYPE is the name of one of the sub-divisions of the survey system shown in Table A-1, with DATE being answered by entry of a specific day, month, and year. Additionally, the user may enter the word ALL to indicate that a definition category is to be searched completely.

Table A-1. METADATA Identification Pattern for Survey Records

Category	Heading	Date (examples)
Who	SS No.	
What (A)	Record	Survey
What (B)	Type	Identification Review of systems (ROS) Dental Laboratory X-ray ECG Measurement Vision Summary
When	Date	01 Jun 71

The retrieval of a complete VISION SURVEY is shown in Figure A-10. In the illustration, underlining is employed to indicate information which was entered by the user. Under the system's data retrieval technique, each response from the computer is initiated by a line of printing that restates the definition data for the report that is being retrieved.

SS NO	[REDACTED]			
RECORD	<u>SURVEY</u>			
TYPE	<u>VISION</u>			
DATE	<u>ALL</u>			
ACTION	<u>LIST</u>			
[REDACTED] SURVEY VISION 01 JAN 68				
VISUAL ACUTY				
DISTANT				
UNCORRECTED				
OD	20/15			
OS	20/15			
NEAR				
UNCORRECTED				
OD	20/15			
OS	20/17			
ACCOMMODATION				
OD	7.2			
OS	7.3			
INTRAOCULAR TENSION	15.3 MM HG	O	U	
VISUAL FIELDS				
CONFRONTATION	NEG			
DEPTH PERCEPTION				
TEST USED	VTA-ND			
UNCORRECTED	PASSES			
HETEROPHORIA	DISTANCE	ES	EX	RH LH
1	20"	0	0	0 0
2	13"	0	0	0 0
NPC				
PD				
PRISM DIV				
PRISM CONV				
COVER TEST	ORTHO			
RED LENS TEST				
NIGHT VISION	NIBH			
COLOR VISION	ON RECORD AS PASSES			
DIAGNOSES				
COMMENTS				
EXAMINER	GEORGE L DAILY, MD			
TYPED	MM/01FEB68			

Figure A-10. Complete vision survey under the system's data retrieval technique.

In some cases, the user may not want to retrieve a complete report, but only a portion or even a single item. Under these conditions, in order to limit the amount of data retrieved, the user may specify a portion or a single item of a report by adding the desired heading terms after the TYPE definition. To illustrate, in answer to the question TYPE, the user may enter not only the name of a report (e.g., XRAY) but also an item heading (e.g., DIAGNOSIS):

TYPE XRAY-DIAGNOSIS

In this case, the search program will look within the body of the report and retrieve only the specified heading DIAGNOSIS and any associated data. Also, the user may further define the retrieval criteria by limiting the data of interest, as shown here:

TYPE XRAY-DIAGNOSIS:NEG

Here, retrieval occurs only if the report searched has the term NEG or NEGATIVE stored in the data field associated with the heading DIAGNOSIS.

This capability is referred to as “strong search” logic, because it allows the user to specify any series of alphabetic or numeric characters to be used as a model to guide the computer in searching the stored files. In employing this approach, the user indicates whether a specific series constitutes a heading or data by utilizing the colon (:) just as it is used in the basic file structure. A series preceded by a colon is then understood to involve data, with the absence of a preceding colon indicating a heading.

Another dimension to the search definition offering AND/OR/NOT control is provided by use of Boolean logic. This permits several sets of series or headings—with or without data—to be linked by these terms into complex retrieval parameters. As an illustration of the use of Boolean logic in the system being discussed, assume that the files contain information on only two patients whose height is exactly 72 inches each. One of these, and a third patient, each weigh exactly 165 pounds. Therefore, only one of these three men is both 72 inches and 165 pounds in height and weight. Figure A-11 illustrates application of the AND/OR/NOT logic to the file.

Ranging, another logic option, provides a limited degree of arithmetic latitude, in that a range of values may be specified. In the system, a particular item satisfies the retrieval parameters if its numeric data value falls within the stated range. For example, Figure A-12 shows a simple request for a search of all individual LABORATORY SURVEY reports from any specified date to find those having white blood counts (WBC) between 4500 and 4700 mm. In this example, only one case is retrieved. Also, series, Boolean, and ranging logic may be mixed in a single definition set, as shown in Figure A-13.

Returning now to the general discussion of the system's data retrieval technique, after the user has defined the specific information of interest to him, he next indicates what the computer is to do with it. The ACTION commands available to the user begin with LIST. Figures A-10 to A-13 show the results gained by use of this command. As can be seen, LIST simply directs the computer system to produce the defined data in a standardized format. Also, the system's data-retrieval technique takes maximum advantage of the facsimile storage of information. Here, the basic format in which data are returned to the requestor is identical with the input format, with output being essentially a “dump” of the stored material as shown in Figure A-10. Whenever a definition specifies less than a complete report, the system employs a format modification called diagonal-retrieval formatting. This

SS NO	<u>ALL.</u>
RECORD	<u>SURVEY.</u>
TYPE	<u>MEASUREMENT-HEIGHT: 72 IN AND WEIGHT: 165 LB.</u>
DATE	<u>ALL.</u>
ACTION	<u>LIST.</u>

GENERAL	SURVEY	MEASUREMENT	01 JAN 68
HEIGHT		72 IN	
WEIGHT		165 LB	

—Example of *AND* logic.

SS NO	<u>ALL.</u>
RECORD	<u>SURVEY.</u>
TYPE	<u>MEASUREMENT-HEIGHT: 72 IN OR WEIGHT: 165 LB.</u>
DATE	<u>ALL.</u>
ACTION	<u>LIST.</u>

GENERAL	SURVEY	MEASUREMENT	01 JAN 68
HEIGHT		72 IN	
WEIGHT		165 LB	

GENERAL	SURVEY	MEASUREMENT	16 NOV 67
HEIGHT		72 IN	

GENERAL	SURVEY	MEASUREMENT	06 JAN 68
WEIGHT		165 LB	

—Example of *OR* logic.

SS NO	<u>ALL.</u>
RECORD	<u>SURVEY.</u>
TYPE	<u>MEASUREMENT-HEIGHT: 72 IN AND WEIGHT: NOT 165 LB.</u>
DATE	<u>ALL.</u>
ACTION	<u>LIST.</u>

GENERAL	SURVEY	MEASUREMENT	16 NOV 67
HEIGHT		72 IN	

—Example of *NOT* logic.

Figure A-11. Application of AND/OR/NOT control to the search function.

SS NO	<u>ALL.</u>
RECORD	<u>SURVEY.</u>
TYPE	<u>LABORATORY-WBC: 4500 TO 4700.</u>
DATE	<u>ALL.</u>
ACTION	<u>LIST.</u>

HEMATOLOGY	SURVEY	LABORATORY	01 JAN 68
CBC			
WBC		4600	
DIFF			
NEUT		56	
EO		01	
BASO		00	
LYMPH		43	
MONO		00	

Figure A-12. Example of ranging logic.

SS NO	ALL		
RECORD	SURVEY		
TYPE	LABORATORY-VDRL:NEG AND (HB: 15 TO 16 OR HCT: NOT 0 TO 45),		
DATE	ALL		
ACTION	LIST		
IMMUNOLOGY	SURVEY	LABORATORY	01 JAN 68
VDRL		NEG	
HEMATOLOGY			
CBC			
HB		15 GM	
IMMUNOLOGY	SURVEY	LABORATORY	16 NOV 67
VDRL		NEG	
HEMATOLOGY			
CBC			
HB		16 GM	
HCT		47%	
IMMUNOLOGY	SURVEY	LABORATORY	06 JAN 68
VDRL		NEG	
HEMATOLOGY			
CBC			
HCT		49%	

Figure A-13. Example of combination of string-search, Boolean, and ranging logic.

refers to recovery of all superior and all inferior headings which are related to each defined heading. Figures A-11 to A-13 demonstrate that this formatting technique essentially constitutes facsimile retrieval with all extraneous information removed. The diagonal formatting technique is used as a means of preserving the most complete meaning possible of retrieved information. Experience with the system has shown sometimes unrequested supplementary data which the diagonal-retrieval formatting feature returns may prove useful. An example of such "extra" retrieval is the differential count data printed with the WBC as shown in Figure A-12. This "extra" information resulted because the original organization of headings for the laboratory-survey form placed the differential count one hierarchical level under the white blood count.

In addition to the LIST command discussed above, other action options are being added to the system such as COUNT, which totals the number of valid records matching the retrieval parameters; SPECIAL PRINT FORMATS, which are a group of output programs providing for special-purpose formatting of the output of a retrieval request; and several miscellaneous options to perform other special tasks. Yet another kind of action command is employed in the system to indicate the particular output instrument to be used such as terminal, line printer, magnetic tape, paper tape, punched cards, or console typewriter.

Update Technique

The information system features three levels of update capability, with the system's basic update feature providing for deletion of complete reports. If desired, a new report may be added to the established file by placing an "A" in a specific location in the leader portion of a data tape prepared via the systematized terminal-acquisition technique discussed earlier. Since definition of the report is already present in the data tape, recognition of the "A" allows the program to sort and file the particular report being dealt with in the appropriate location. Deletion of a complete report uses a similar approach, with "D" being positioned in the leader of a data tape which incorporates complete definition of the specific report in question.

The second level of capability used to modify information already stored in the file involves the peripheral update technique. Examples of this technique include correction of errors or addition of new data. This level is designed primarily for use by those who originally prepare data tapes for computer input and for users of the data-retrieval technique. The technique allows modifications *only* in the data fields of the file. Such a restriction is necessary because the format and organization of all reports in a file must remain consistent. Otherwise, if relationships of the standard headings were changed, valuable information could be "lost."

Operationally, the peripheral update technique essentially parallels the data-retrieval technique discussed earlier, the only major difference being in the use of action-command options. In the peripheral update technique, the update-action commands are: ADD, followed by the new information to be added; CHANGE, followed by new information which is to replace the current contents of the defined data field; and DELETE, which needs no following character series, and functions to automatically erase the present contents of the specified data field.

A central or third-level update technique is presently under development. Its function will be severalfold: (1) accommodating generalized changes in file structure so as to allow for uniform reorganization of a report format within a given file; (2) performing a universal alteration on one or more headings throughout the file; and (3) permitting any other necessary modification of the file that is not provided for by the basic and peripheral techniques. Due to its broad power, it is recommended that, when development has been completed, the central update capability be controlled by those responsible for the filing system, and not be available directly to the general user.

Summary

The information management system described in this appendix constitutes an efficient, operational, computerized, medical-record system. Additional development envisioned will provide general and specific programs suitable for data analysis in a variety of settings. With the system, programming for terminal communications depends upon the availability of computer equipment capable of multi-terminal time-sharing. The most significant future contribution envisioned for the system concerns provision of efficient support for continuing improvement of basic medical documentation.

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APPENDIX B
AN INFORMATION SYSTEM FOR AUTOMATED
RECOVERY OF LABORATORY DATA (MEDOL)

INFORMATION SYSTEM FOR AUTOMATED RECOVERY OF LABORATORY DATA(MEDOL)

An integral—and important—part of laboratory operation centers upon the analysis of data, including data compilations, arithmetic and statistical computations, graphical presentations, and data tabulations. Obviously, a computer system capable of efficient storage and uncomplicated recovery, which possessed the facility for logical and arithmetic manipulations, would be of great benefit to the laboratory. This is particularly important in a space-medicine program, where the laboratory data to be analyzed consist of such a large number of critical variables that handling and analysis of data become a formidable task.

To meet the above challenge, NASA developed an information system assigned the acronym MEDOL (Medically Oriented Language) based on laboratory data derived from Project Mercury. The resulting system features such innovations as flexibility for addition of new classes of data and provides for storage and retrieval of data without requiring the user to be familiar with sophisticated computer languages. All critical parameters required for evaluation of quality control and to describe essential detail of each laboratory procedure are described within the MEDOL file structure.

The MEDOL system employs a higher level interpretive source language and, consequently, only requires the use of a few English language-oriented statements for file design, entry, and retrieval of data. A synonym capability is available with MEDOL through a system glossary, and a dimensional library provides for interconversion of units for user convenience.

The MEDOL system features two operational modes: file-generation, and additions and deletions of data. Format changes are handled under the Maintenance Mode, with the Query Mode providing for retrieval, utilizing arithmetic and logical operations, and the generation of reports in tabular or free-form output. The system also provides for the protection of proprietary data by incorporation of techniques which prevents inadvertent data release by unauthorized users.

Technically, MEDOL is a third-generation information-processing system, with origins in System Information Storage Retrieval and Analysis (SISTRAN). This latter system, which was specifically designed as a library system for storing, retrieving, and analyzing aerospace documents, provides the basic system programs for MEDOL. Enhancements have been provided to accommodate the specific requirements for processing of biomedical data.

Primarily, the MEDOL system is written in FORTRAN IV, with a few macroassembly program (MAP) subroutines. It operates on a 7094 tape system or a 7094/7040 direct-couple system under IBSYS; a 16-tape drive system is recommended for maximum efficiency. MEDOL was designed to be independent of secondary storage. Additionally, the system is completely modular and open-ended so as to facilitate conversion to other computer configurations, including on-line computer systems. The MEDOL system was implemented in an English-like syntactical and semantic source language to allow maximum ease in communicating with the system. The basic MEDOL system provides functions or procedures for (1) generating files, updating files, and retrieving data from these files; (2) generating libraries and glossaries; (3) performing elementary arithmetic operations on data; (4) extracting information for array grouping; and (5) output of data.

Source Language

To be maximally effective, any information-processing system must be accessible to many users, each having different requirements. This requires that the system concerned embrace a language (source) that can be successfully handled by the inexperienced as well as the experienced user. The advantage of employing an English-like source language is that the tasks to be performed by the computer can be delineated by individuals who are closest to the data, even though their experience with computers may be somewhat limited. The MEDOL source language was designed with this factor in mind. The language is similar in some respects to FORTRAN, but is easier to learn and use. Basically, the MEDOL language consists of key words and symbols combined into statements that describe the system's procedures. The key words and statements employed are readily comprehended by the user, since they are terms in common usage, such as ERASE, ADD, DELETE, PRINT, and END OF DATA. The statements describing system procedures are combined to form the source-language program which is the mechanism by which the user indicates to the computer what jobs are to be performed. The system's program layout is intended to approximate the logical thought processes which are normally employed by the scientific investigator during his research endeavors.

Data entry to the MEDOL system is accomplished via the source-language program, being entered as a continuous string. The items of data are separated by delimiters and arranged according to the file's tree structure, with absent data being indicated by embedded commas.

Preprocessor and Processor

A significant feature of the MEDOL system relates to its modularity. This feature is most apparent in the operation of the system's preprocessor and processor. Once the source program is read into the computer, the preprocessor analyzes the statements, breaks them into components, and finally codes them in the internal language as procedural directives. This operation is accomplished before (and separately from) execution of the program. Should an error be detected in a statement, an appropriate error message will accompany the source-language listing, preventing a procedural directive from being generated.

In the MEDOL system, procedural directives supply the processor with information regarding which programs to call. As part of the program-execution process, the processor must relate operations, locations, and references from one part of the program to those in another. This activity is in contrast with the work on incremental compilers used for multi-processing and on-line systems, where a statement is compiled and machine-language instructions are generated independently of the next statement.

Two aspects are involved in generation of procedural directives—format design and data input. The file is based on a tree-structure form, with the user defining all his variables and assigning appropriate hierarchical relations between them for creation of the data file tree. The tree can contain up to 15 levels, each with a variable number of attributes, with the data-bearing elements being at the lowest level of each branch.

By use of the system's "update" function, files, data in files, and formats of files can be altered, with format being modifiable to correspond with a change in the data status. Also, attribute names can be added as new data are available and may be deleted when such names are no longer needed. The system also readily accommodates data rearrangements within data strings.

Operational Modes

As suggested earlier, the MEDOL system operates in two modes: the data-maintenance mode and the query mode; however, only one mode can be processed at any one time. Some of the procedures employed are unique to each mode, while others may be used in common. The maintenance mode provides an input function for entry of source-language information and data by which files are set up and updated. Dictionaries, glossaries, and libraries are also provided in the data bank.

In contrast, the query mode is used to obtain information from the data bank for the purpose of computation or output of data as a printed report, punched cards, or magnetic tape with retrieval being by item, group, or file. Retrieval is initiated by referencing of data name(s) to the levels of structure desired. Three basic types of queries are used: Nonarithmetic, arithmetic, and logical. The nonarithmetic operation functions for retrieval of data from either the temporary or permanent files. The arithmetic query performs computations by use of the five basic arithmetic operators: exponentiation, multiplication, division, addition, and subtraction. Also, FORTRAN IV functions can be utilized to augment the arithmetic capability. Special subroutines are used for statistical analysis. The logic query provides for decision-making capability such as testing of the data bank against certain conditions. These expressions can be nested up to 15 levels to provide complex conditional expressions. Additionally, arithmetic and nonarithmetic statements can be used within conditional expressions.

Multiple Files

The MEDOL system is capable of dynamic array. That is, data can be stored and retrieved in multidimensional arrays located in a temporary storage area. Single elements, rows, or entire arrays can be retrieved with one reference. The system's indexing scheme used to identify individual elements and rows is simple, with index arithmetic being available. Also, arithmetic and logical computations can be performed on the data in the "hold" queue as well as in the permanent files. The hold queue is capable of unlimited storage since, when the core area is exhausted, data can be transferred to scratch tape.

Reports

The MEDOL system can be delivered on punched cards, magnetic tape, or printed reports, with the system providing a mechanism for "formatting" of the data for the three output media. Printed reports can be generated in free or formatted form (tabular form).

The system's file format was designed to accommodate aerospace laboratory and other biomedical data, with its file data being based, as mentioned earlier, on the Mercury Program data. However, the system is so flexible that subsequent data from other space programs can be easily added.

The file structure is primarily geared toward the processing of laboratory data, although the system can handle vital signs, fluid-input, and

food-input data. In designing the file, factors common to the processing of routine laboratory data had to be considered as well as those unique to aerospace-data processing. Apart from the ordinary case, information concerning collection, storage, and transportation of specimens, including distribution to two or more laboratories, had to be included in MEDOL. Also, each specimen had to be linked by data to the aerospace activities or experiments under way when the specimen was obtained.

The present MEDOL system contains three files: the Astronaut History File, the Flight Data File, and the Test Description File. These files are described in the attachment to this section. The History File lists the flight(s) in which the astronaut participated, his birth date, comments, and can be expanded to include additional items of pertinence.

The Flight Data File, which contains the bulk of the biomedical data, includes such data as vital-signs, fluid-input, food-input, laboratory, and collection and storage data. Reference data fill a significant position in this file. The reference data cover the significant aerospace experiments associated with each flight and include a detailed chronological history of the flight. The data are divided into four basic periods: base-line, preflight, flight, and post-flight. Within each period, specific reference events are recorded that can be related to the laboratory specimens or other data. Access to the data may be either via the basic periods or through specific events.

The Test Description File, which was assembled to provide the parameters that would be required in evaluation of the data collected, provides a sufficiently comprehensive description of the entire laboratory procedure that comparisons between laboratories can be made, as well as determinations of whether observed responses were significant. To permit this capability, it was necessary to describe each type of sample, the analytical technique, the laboratory, the method, and collection and storage of the sample, and to identify performing personnel. Also included for method-description are the literature reference, the precision to be expected of the method, and a "normal" range with a gate to identify unusual results immediately. With the various tests then assembled by groups of associated analyses, the file allows the user ready access, permitting him to recover desired information. Also, the system's subroutine of table of synonyms provides access without the user having to know the precise description of the test within the file.

During the data-retrieval process, the user merely describes the desired data, using instructions for computer operations which follow the logical

sequence of the input of data into the program. Table B-1 shows the format of a representative query.

Table B-1. Format of a Representative Query†

1. Extract enzyme (specify tests) test results a. For pre- and postflight periods. b. For astronaut X (ensure that the collection dates for these tests for this period for the astronaut are in absolute form). 2. Extract normal range for these tests. 3. Test for out-of-range values. 4. Print out all extracted results in the following format:					
Astronaut: James E. Doe Period: Pre- and postflight					
Period	Date, 1962	Test			
		SGOT, I.U.	SGPT, I.U.	LDH, I.U.	ALK P., B.U.
Preflight	2 Jan	19	6	190	
Preflight	8 Feb	27	10	125	
Postflight	20 Apr	*68	*50	*560	11
or					
Astronaut: James E. Doe Period: Pre- and postflight					
Test	Preflight dates, 1962		Postflight, 20 Apr 1962		
	2 Jan	8 Feb			
SGOT, I.U.	19	27		*68	
SGPT, I.U.	6	10		*50	
LDH, I.U.	190	125		*560	
ALK P., B.U.					11
†All numbers are integers without signs.					

While the present MEDOL system will not satisfy all future requirements within the prevailing time and cost constraints, it does, nevertheless, constitute a basic operations system. The next step in its evolution will be provision of greater repeat-generating capability through plot subroutines and flexible data association in tabular form, so that users can scan the printout (i.e., graphic plots and columnar listing of associative attributes) and quickly reach an appropriate conclusion.

NASA'S LABORATORY-DATA SYSTEM'S TREE STRUCTURE

I. Astronaut's History File:

- a) Name
- b) Serial number
- c) Flight number *implicit repeat
- d) Birth date
- e) Comment *implicit repeat

II. Flight-Data File:

- a) Flight number
- b) Astronaut
 - 1. Astronaut name
 - 2. Serial number
- c) Reference data
 - 1. Base-line period (from first data point, or end of last postflight period, to beginning of next preflight period)
 - a. Date/time
 - 1. Begin
 - 2. End
 - b. Lovelace Clinic
 - 1. Date/time
 - a. Begin
 - b. End
 - 2. Comment
 - c. Simulations *implicit repeat
 - 1. Date/time
 - a. Begin
 - b. End
 - 2. Presimulation period
 - a. Begin
 - b. End
 - 3. Simulation period
 - a. Begin
 - b. End
 - 4. Postsimulation period
 - a. Begin
 - b. End
 - 5. Name
 - 6. Comment
 - d. Diurnal studies
 - 1. Date/time

- a. Begin
- b. End
- 2. Comment
- 2. Preflight period (from -30 days to launch)
 - a. Date/time
 - 1. Begin
 - 2. End
 - b. Simulations *implicit repeat
 - 1. Date/time
 - a. Begin
 - b. End
 - 2. Name
 - 3. Comment
 - c. Preflight physical exam (not to include the exam during countdown) *implicit repeat
 - 1. Date/time
 - 2. Comment
 - d. Countdown, abort *implicit repeat
 - 1. Date/time
 - a. Begin
 - b. End
 - 2. Awaken
 - a. Date/time
 - b. Comment
 - 3. Prelaunch breakfast
 - a. Date/time
 - b. Comment
 - 4. Don pressure suit
 - a. Date/time
 - b. Comment
 - 5. Insertion into spacecraft
 - a. Date/time
 - b. Comment
 - 6. Flight cancelled
 - a. Date/time
 - b. Comment
 - e. Countdown, flight (from awaken to launch)

1. Date/time
 - a. Begin
 - b. End
 2. Awaken
 - a. Date/time
 - b. Comment
 3. Prelaunch breakfast
 - a. Date/time
 - b. Comment
 4. Don pressure suit
 - a. Date/time
 - b. Comment
 5. Insertion into spacecraft
 - a. Date/time
 - b. Comment
 3. Flight period (from launch to splashdown)
 - a. Date/time
 1. Begin
 2. End
 - b. Lift-off (from ignition to insertion into orbit)
 1. Date/time
 - a. Begin
 - b. End
 2. Comment
 - c. In-flight (from insertion to firing of retro-rockets)
 1. Date/time
 - a. Begin
 - b. End
 2. Comment
 - d. Reentry (from retro-rockets to splashdown)
 1. Date/time
 - a. Begin
 - b. End
 2. Comment
 4. Postflight period (from splashdown to +30 days)
 - a. Date/time
 1. Begin
 2. End
 - b. Recovery (from splashdown to debriefing site)
 1. Date/time
 - a. Begin
 - b. End
 2. Recovery site (Atlantic or Pacific Ocean)
 3. Comment *implicit repeat
 - c. Debriefing (from arrival to release)
 1. Date/time
 - a. Begin
 - b. End
 2. Period *implicit repeat
 - a. Date/time
 1. Begin
 2. End
 - b. Place (USA, aircraft carrier, Grand Turk Island, or Grand Bahama Island)
 - c. Comment
 - d. Additional activities *implicit repeat
 1. Date/time
 - a. Begin
 - b. End
 2. Name
 3. Comment
- (Under Base-line, Preflight, Flight, and Postflight periods are listed some of the reference points for the Mercury program. The list is by no means complete and will continue to be enlarged for the Gemini and Apollo programs.)
- d) Vital signs
 1. Temperature *implicit repeat
 - a. Date/time
 - b. Value (°F)
 - c. Anatomic site (oral, rectal, or axillary)
 - d. Comment
 2. Blood pressure *implicit repeat
 - a. Date/time
 - b. B.P. data *implicit repeat
 1. Value (mm-Hg)
 2. Arm (right or left)
 3. Position (supine, standing, sitting)
 4. Comment
 3. Weight *implicit repeat
 - a. Date/time
 - b. Value (lb)
 - c. Status (after voiding and/or nude) *implicit repeat
 - d. Comment
 4. Pulse *implicit repeat
 - a. Date/time

LABORATORY DATA TREE STRUCTURE

- b. Pulse data *implicit repeat
 - 1. Position (supine, standing, sitting)
 - 2. Value (beats per minute)
 - 3. Exercise status (before or after exercise)
 - 4. Comment
 - 5. Respiration *implicit repeat
 - a. Date/time
 - b. Value (breaths per minute)
 - c. Comment
 - 6. Extremity measurement *implicit repeat
 - a. Date/time
 - b. Extremity data *implicit repeat
 - 1. Value (in.)
 - 2. Extremity site (wrist, forearm, thigh, calf, and ankle)
 - 3. Side (left or right)
 - 4. Comment
 - 7. Vital capacity *implicit repeat
 - a. Date/time
 - b. Value (liters)
 - c. Comment
 - 8. General comments *implicit repeat
 - a. Date/time
 - b. Comment
 - e) Fluid input
 - 1. Fluid data *implicit repeat
 - a. Date/time
 - 1. Begin
 - 2. End
 - b. Volume (ml)
 - c. Type (water, tea, suspended food, soup, coffee, juice, other, or combinations) *implicit repeat
 - d. Comment
 - f) Food input
 - 1. Food data *implicit repeat
 - a. Date/time
 - 1. Begin
 - 2. End
 - b. Type (e.g., apples, potatoes) *implicit repeat
 - c. Elemental ingredients (e.g., vitamins, calcium) *implicit repeat
 - d. Meal
 - e. Comment
- (Food data for Mercury program should be entered under "Meal" and "Type"; "Elemental ingredients" will be used in Gemini and Apollo programs, but not for Mercury.)
- g) Specimen collection and storage *implicit repeat
 - 1. Specimen (e.g., blood)
 - 2. CS data *implicit repeat
 - a. Collection interval
 - 1. Begin
 - 2. End
 - b. Collection (refers to the entire sample) *implicit repeat
 - 1. Sample collection date/time (end time for urine)
 - 2. Centrifugation date/time (for blood specimens)
 - 3. Volume (for urine specimens)
 - 4. Personnel
 - 5. Comment
 - c. Distribution (a description of division of the samples and distribution to their performing laboratories) *implicit repeat
 - 1. Sample [the types of blood samples that were sent to the lab. (2, below) from this collection; serum, plasma, or whole blood] *implicit repeat
 - 2. Laboratory (performing)
 - 3. Storage *implicit repeat
 - a. Phase (initial and final, or blank)
 - b. Storage method (deep freeze -10° F, deep freeze -40° F, dry ice, or liquid N₂)
 - c. Date/time
 - 1. Begin
 - 2. End
 - d. Comment (e.g., sample thawed or lost)
 - 4. Transport (includes transportation of the sample from the collection-storage area to the distribution point, and from the latter to the performing laboratory; or from the collection-storage area directly to the performing laboratory) *implicit repeat

BIOMEDICAL RESEARCH AND COMPUTER APPLICATION

- a. Phase (initial, final, or direct)
 - b. Storage method
 - c. Date/time
 - 1. Begin
 - 2. End
 - d. Distribution point (applies only to initial phase; WRAIR in this case)
 - e. Comment
 - h) Laboratory Test Performance
 - 1. Blood
 - a. Chemistry
 - 1. Electrolytes
 - a. Sodium *implicit repeat
 - 1. Collection date
 - 2. Result
 - 3. Comment
 - 4. Laboratory (leave empty for Mercury program)
 - 5. Performance date
 - b. Potassium *implicit repeat
 - 2. Enzymes
 - 3. Catecholamines
 - 4. Minerals
 - a. Cations
 - b. Anions
5. Proteins
 - a. Total protein *implicit repeat
 - b. Electrophoresis *implicit repeat
 - 1. Collection date
 - 2. Fractions
 - a. Albumin
 - b. Alpha-1 globulin
 - c. Alpha-2 globulin
 - d. Beta-1 globulin
 - e. Beta-2 globulin
 - f. Gamma
 - 3. Comment
 - 4. Laboratory
 - 5. Performance date
6. Steroids
7. Blood gases
8. Miscellaneous
- b. Hematology
 - 1. Routine *implicit repeat
 - a. Collection date
 - b. Tests
 - 1. Hemoglobin
 - a. Result
 - b. Comment
 - 2. Hematocrit
 - a. Result
 - b. Comment
 - 3. WBC

LABORATORY DATA TREE STRUCTURE

- a. Result
- b. Comment
- 4. RBC
 - a. Result
 - b. Comment
- 5. WBC differential
 - a. Lymphocytes
 - b. Neutrophils
 - c. Stabs
 - d. Monocytes
 - e. Eosinophils
 - f. Basophils
 - g. Comment
- 6. RBC morphology (descriptive)
- 7. Platelets
 - a. Result
 - b. Comment
- c. Laboratory
 - d. Performance date
- 2. Miscellaneous
 - a. ESR *implicit repeat
 - .
 - .
 - .
 - .
- c. Serology
 - 1. VDRL *implicit repeat
 - .
 - .
 - .

[All blood tests not described with a special format are to be treated with the standard format (see Sodium, above).]

2. Urine

- a. Urinalysis *implicit repeat
 - 1. Collection date
 - a. Begin
 - b. End
 - 2. Tests
 - a. Volume
 - b. Specific gravity
 - c. pH
 - d. Albumin
 - e. Glucose
 - f. Ketones
 - g. Occult blood
 - h. Bile
 - i. Microscopic

- 3. Comment
- 4. Laboratory
- 5. Performance date
- b. Electrolytes
 - 1. Sodium *implicit repeat
 - a. Collection date
 - 1. Begin
 - 2. End
 - b. Result
 - c. Comment
 - d. Laboratory
 - e. Performance date
 - .
 - .
 - .
- c. Catecholamines
 - .
 - .
 - .
 - .
- d. Minerals
 - 1. Cations
 - .
 - .
 - .
 - .
 - 2. Anions
 - .
 - .
 - .
 - .
- c. Steroids
 - .
 - .
 - .
 - .
- f. Diurnal studies *implicit repeat
 - 1. Collection date
 - a. Begin
 - b. End
 - 2. Sample *implicit repeat
 - a. Collection period
 - 1. Begin
 - 2. End
 - b. Catecholamines
 - 1. Test *implicit repeat
 - a. Name
 - b. Result

- c. Comment
- d. Performance date
- c. Steroids
 - 1. Test *implicit repeat
 - a. Name
 - b. Result
 - c. Comment
 - d. Performance date
- g. Miscellaneous
 - 1. Albumin *implicit repeat
 - .
 - .
 - .
 - 2. Xylose absorption test *implicit repeat
 - a. Collection date
 - b. Condition (a, b, or c)
 - c. Result
 - 1. H 1
 - 2. H 2
 - 3. H 3
 - 4. H 4
 - 5. H 5
 - d. Comment
 - e. Laboratory
 - f. Performance date

[All urine tests not described with a special format are to be treated with the standard format (see Sodium, above). The following tests have special formats:]

- 3. Bone marrow *implicit repeat
 - a. Collection date
 - b. Result
 - 1. Metamyelocyte
 - 2. Myelocyte-C
 - 3. Myelocyte-B
 - 4. Myelocyte-A
 - 5. Myeloblast
 - 6. Late erythroblast
 - 7. Normoblast
 - 8. Eosinophilic myelocyte
 - 9. Plasma cells
 - 10. Megakaryocytes
 - c. Comment
 - d. Laboratory
 - e. Performance date

- 4. Gastric analysis *implicit repeat
 - a. Collection date
 - b. Test meal
 - c. After ingestion (minutes)
 - d. Tests
 - 1. Volume
 - 2. Total acid
 - 3. Free acid
 - 4. Appearance (text)
 - e. Comment
 - f. Laboratory
 - g. Performance date
- 5. Stool *implicit repeat
 - a. Collection date
 - b. Results
 - 1. Character
 - 2. Direct
 - 3. Concentrated
 - a. Faust
 - b. De Rivas
 - c. Comment
 - d. Laboratory
 - e. Performance date
- 6. Semen *implicit repeat
 - a. Collection date
 - b. Results
 - 1. Volume
 - 2. Sperm count
 - 3. Motility
 - a. Motile
 - b. Moribund
 - c. Inert
 - 4. Morphology
 - a. Abnormal
 - b. Normal
 - 5. WBC
 - c. Comment
 - d. Laboratory
 - e. Performance date

III. Test Description File

- 1) Blood
 - a) Chemistry
 - 1. Electrolytes
 - a. Sodium
 - 1. Laboratory *implicit repeat
 - a. Name
 - b. Period
 - 1. Begin
 - 2. End

LABORATORY DATA TREE STRUCTURE

- c. Method
 - 1. Name
 - 2. Reference
 - 3. Precision
 - (S.D. or %)
 - 4. Normal range
 - a. High
 - b. Low
 - 5. Sample
 - a. Type
 - (serum, etc.)
 - b. Anticoagulant
 - 6. Preservative
 - 7. Comment
 - d. Personnel *implicit repeat
- b. Potassium
 - .
 - .
 - .
 - .
- 2. Enzymes
 - .
 - .
 - .
 - .
- 3. Catecholamines
 - .
 - .
 - .
 - .
- 4. Minerals
 - a. Cations
 - .
 - .
 - .
 - .
 - b. Anions
 - .
 - .
 - .
 - .
- 5. Proteins
 - a. Total protein
 - .
 - .
 - .
 - .
- b. Electrophoresis
 - 1. Laboratory *implicit repeat
 - a. Name
 - b. Period
 - 1. Begin
 - 2. End
 - c. Method
 - 1. Name
 - 2. Reference
 - 3. Precision
 - 4. Normal range
 - a. Albumin
 - 1. High
 - 2. Low
 - b. Alpha-1
 - 1. High
 - 2. Low
 - c. Alpha-2
 - 1. High
 - 2. Low
 - d. Beta-1
 - 1. High
 - 2. Low
 - e. Beta-2
 - 1. High
 - 2. Low
 - f. Gamma
 - 1. High
 - 2. Low
 - 5. Sample
 - a. Type
 - b. Anticoagulant
 - 6. Preservative
 - 7. Comment
 - d. Personnel *implicit repeat
- 6. Steroids
 - .
 - .
 - .
- 7. Blood gases
 - .
 - .
 - .
- 8. Miscellaneous

(RBC morphology not included)

8. Platelets

b) Hematology

1. Routine

a. Laboratory *implicit repeat

1. Name

2. Period

a. Begin

b. End

3. Hemoglobin

a. Method

1. Name

2. Reference

3. Precision

4. Normal range

a. High

b. Low

5. Comment

4. Hematocrit

5. WBC

6. RBC

7. WBC differential

a. Method

1. Name

2. Reference

3. Normal range

a. Lymphocytes

1. High

2. Low

b. Neutrophils

1. High

2. Low

c. Stabs

1. High

2. Low

d. Monocytes

1. High

2. Low

e. Eosinophils

1. High

2. Low

f. Basophils

1. High

2. Low

4. Comment

9. Sample

a. Type

b. Anticoagulant

10. Preservative

11. Personnel *implicit repeat

(For HCT, WBC, RBC, and platelets, use the format under Hemoglobin.)

2. Miscellaneous

a. ESR

c) Serology

1. VDRL

[All blood tests that do not have a special format are to be treated with the standard format (see Sodium, above).]

2) Urine

a) Urinalysis

1. Laboratory *implicit repeat

a. Name

b. Period

1. Begin

2. End

c. Specific gravity

1. Method

a. Name

b. Reference

c. Precision

d. Comment

d. pH

e. Microscopic

f. Preservative

LABORATORY DATA TREE STRUCTURE

- g. Personnel *implicit repeat
 - b) Electrolytes
 - 1. Sodium
 - a. Laboratory *implicit repeat
 - 1. Name
 - 2. Period
 - a. Begin
 - b. End
 - 3. Method
 - a. Name
 - b. Reference
 - c. Precision
 - d. Normal range
 - 1. High
 - 2. Low
 - e. Preservative
 - f. Comment
 - 4. Personnel *implicit repeat
 - 2. Potassium
 - .
 - .
 - .
- c) Catecholamines
 - .
 - .
 - .
 - .
- d) Minerals
 - .
 - .
 - .
- e) Steroids
 - .
 - .
 - .
- f) Miscellaneous (volume transferred to collection group)
 - 1. Albumin
 - .
 - .
 - .
 - 2. Xylose absorption test
 - a. Laboratory *implicit repeat
 - 1. Name
 - 2. Period
 - a. Begin
- b. End
3. Method
 - a. Name
 - b. Reference
 - c. Precision
 - d. Preservative
 - e. Comment
4. Test condition *implicit repeat
 - a. Name (plus text)
 - b. Control data *implicit repeat
 - 1. Control individual
 - 2. H 1
 - 3. H 2
 - 4. H 3
 - 5. H 4
 - 6. H 5
5. Personnel *implicit repeat
- 3) Bone marrow
 - a) Laboratory *implicit repeat
 - 1. Name
 - 2. Period
 - a. Begin
 - b. End
 - 3. Method
 - a. Name
 - b. Reference
 - c. Normal range
 - 1. Metamyelocyte
 - a. High
 - b. Low
 - 2. Myelocyte-C
 - a. High
 - b. Low
 - 3. Myelocyte-B
 - a. High
 - b. Low
 - 4. Myelocyte-A
 - a. High
 - b. Low
 - 5. Myeloblast
 - a. High
 - b. Low
 - 6. Late erythroblast
 - a. High

- b. Low
 7. Normoblast
 - a. High
 - b. Low
 8. Eosinophilic myelocyte
 - a. High
 - b. Low
 9. Plasma cell
 - a. High
 - b. Low
 10. Megakaryocyte
 - a. High
 - b. Low
 - d. Comment
4. Personal *implicit repeat
- 4) Gastric analysis
 - a) Laboratory *implicit repeat
 1. Name
 2. Period
 - a. Begin
 - b. End
 3. Test meal
 4. After ingestion
 5. Total acidity
 - a. Method
 1. Name
 2. Reference
 3. Precision
 4. Normal range
 - a. High
 - b. Low
 5. Comment
 6. Free acidity
 - a. Method
 1. Name
 2. Reference
 3. Precision
 4. Normal range
 - a. High
 - b. Low
 5. Comment
 7. Personnel *implicit repeat
- 5) Stool
 - a) Laboratory *implicit repeat
 1. Name
 2. Period
 - a. Begin
 - b. End
 3. Direct
- a. Method
 1. Name
 2. Reference
 3. Comment
4. Concentrated Faust
 - a. Method
 1. Name
 2. Reference
 3. Comment
5. Concentrated De Rivas
 - a. Method
 1. Name
 2. Reference
 3. Comment
6. Personnel *implicit repeat
- 6) Semen
 - a) Laboratory *implicit repeat
 1. Name
 2. Period
 - a. Begin
 - b. End
 3. Method
 - a. Name
 - b. Reference
 - c. Normal range
 1. Sperm count
 - a. High
 - b. Low
 2. Motility
 - a. Motile
 1. High
 2. Low
 - b. Moribund
 1. High
 2. Low
 - c. Inert
 1. High
 2. Low
 3. Morphology
 - a. Abnormal forms
 1. High
 2. Low
 - b. Normal forms
 1. High
 2. Low
 4. WBC (occasional or absent)
 - d. Comment
 4. Personnel *implicit repeat

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