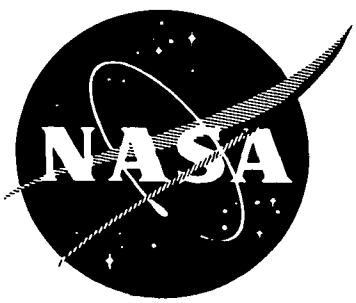
Applications of Aerospace Technology in the Public Sector



APPLICATIONS OF AEROSPACE TECHNOLOGY IN THE PUBLIC SECTOR

A Semi-Annual Review

of the

BIOMEDICAL AND PUBLIC SECTOR TECHNOLOGY APPLICATION TEAM PROGRAM

for

THE TECHNOLOGY UTILIZATION OFFICE
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by the

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THE GEORGE WASHINGTON UNIVERSITY
Medical Center
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INTRODUCTION

The NASA Technology Utilization Program embodies a broad range of activities designed to transfer aerospace technology to nonaerospace sectors. This semi-annual report summarizes current activities of the Program intended to accelerate specific applications of space related technology in major public sector problem areas.

The report focuses on those projects active during the period 1 June 1971 through 30 November 1971. An abbreviated description of the overall Technology Utilization Applications Program is provided as background for the specific applications examples. More detailed descriptions of the Technology Utilization Program are contained in other documents available from:

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TECHNOLOGICAL REQUIREMENTS IN THE PUBLIC SECTOR

Biomedical Sector Needs

The growing population, the rising expectation of the general public for improved health care and a larger elderly population place severe strains on the present health care delivery system. An increasing proportion of high-quality medical care is confined in a few medical centers and emergency medical services have deteriorated severely or are nonexistent in many urban and rural areas. These problems will not be solved merely by supplying more doctors and nurses. There is a need for a comprehensive review of the situation and for the introduction of new skills and new technologies. This would probably bring about a restructuring of the entire system for health care delivery in the United States.

New technology and improved management techniques are needed for expansion of general health care delivery to inner-city and remote rural areas. Cardiovascular disease detection and treatment require inputs of new technology. Cancer treatment can benefit from a wide range of new radiographic and radioisotope techniques. Pulmonary and respiratory disease detection and treatment needs enhanced diagnostic, treatment and monitoring methods and hardware. Surgery, despite many advances, is in constant need of improved techniques to precisely track patient response prior to, during and after operations. Rehabilitation of the handicapped needs a wide array of improved methods to meet requirements ranging from better prosthetics and wheelchairs to the enhanced comfort of long-term bedridden patients.

Finally, the vast amount of data associated with medical histories and hospital clinical and administration record-keeping are highly amenable to computerized streamlining techniques.

The application of new technologies to urgent problems in the biomedical field is often difficult to achieve. Technological innovations must survive a maze of obstacles in the governmental, industrial, academic and medical complex in order to have some impact on the delivery of health care services. This state of affairs is complicated by a general lack of knowledge of the mechanism by which biomedical research moves through development into more effective instrument devices and systems. The task of transfer in such an environment is difficult but the systematic effort to find, evaluate and apply new technology must continue in order to free the doctor for more humanized, effective and less costly care of the patient.

Public Sector Needs

In our growing economy, social and environmental conditions that were adequate in past years no longer meet today's standards or requirments. For example, in 1964 about 15 percent of the population was considered to be living at or below the poverty level. This estimate has risen to well over 20 percent; however, it should be noted that in the intervening years, the standards of measurement have also risen. Standards of housing and the urban services characteristic of former years are no longer considered satisfactory. The populace itself, spurred on by the rising economy and an awareness of advances in science and technology, upgrades the minimum requirements. New unmet human and community needs result both from changing social patterns and rising desires of the population.

The Report of the National Commission on Technology, Automation, and Economic Progress defines these unmet needs in two categories. The first is private, the needs of those living in poverty; the second is the public requirement of the total populace. The public needs are related to the readily acknowledged problems of housing, medical care, air and water pollution, mine safety, crime and transportation, to name some of the most urgent.

Crime, as shown by the public opinion polls and political campaigns, is of great concern to both urban and rural Americans. Law enforcement, criminalistics and the administration of justice can benefit from the increased application of modern technology in such areas as computerized command and control facilities, semi-automatic fingerprint systems, small, inexpensive portable radios for foot patrols and automatic car locator systems. New technology can also enhance heroin detection methods, new methods for coping with

bombs and standards for police equipment. Intensified application of modern technology will be required to increase the efficiency of police effectiveness as well as that of our judicial system and forensic science capabilities.

In the housing construction and rehabilitation fields, there are many barriers hindering wide technological breakthroughs. The housing industry itself is often unwilling to invest capital in innovation that represents a risk. The unions often resist innovations which may lead to loss of jobs. The mortgage bankers are often wary of providing risk capital. Construction industry suppliers, who bear a high amount of risk in developing new products, and the consumer, with generally conservative taste in housing styles, frequently resist innovative construction techniques.

There are a number of technologically related areas in which innovative developments could contribute greatly toward overcoming the obstacles to meeting housing requirements. These include, among many others, better techniques for rehabilitation buildings, improved fire-extinguishing and fire- and smoke-detecting systems, better exterior surface materials, better fireproofing materials, more efficient electrical distributing systems, improved sewage disposal systems, better insulation materials to decrease heating costs and detection of lead in paint.

Research in coal mine safety is required in numerous areas. Requirements include instantaneous explosion-quenching systems, fire detectors, chemicals to stabilize roofs and walls of passageways, rock stress indicators and detectors and miner's breathing devices.

Water pollution can be reduced by massive capital investment and by introducing innovative technology to solve various problems. Equipment and techniques that could play important roles in providing solutions include sludge dewatering equipment, improved water quality monitoring systems and improved oil dispersion or removal methods.

The hazards associated with air pollution are having an important effect on health. A recent study of several types of cancer shows significant correlation of this disease with chronic exposure to sulfur dioxide and nitrogen dioxide.

Air pollution control and abatement are being advanced through the application of new technology. Problem areas requiring introduction of new technologies include development of new classes of advanced pollutant sensors, aircraft and satellite remote sensory systems and control techniques for various pollutants.

Transportation difficulties illustrate the complexities of applying technology to significant areas of public concern. In transportation, as in other public sector areas, technology is interrelated with political, organizational, economic, social and financial problems. Technological improvements alone cannot solve the major problems in transportation. On the other hand, when roads and parking lots require 40 percent of some cities' total land use and when 64 percent of American commuter or work trips are made in private automobiles, generally at very low speeds, technological improvements are obviously needed.

Some of the many problem areas in transportation that need technological assistance are systems planning of urban transportation needs, improvements in passenger restraint systems and improved pavement striping materials.

Postal Service needs include the development of context analysis software to interpret incomplete address information, development of a standardized system for controlling the conveyerized sorting of nonletter mail, improvement of noise reduction and control methods and improvement of surveillance systems. Because of the size and labor characteristics of the Postal Service, employing hundreds of thousands of people, even small improvements can have tremendous long-term benefits to cost and service efficiency. Last but not least is the need to handle an ever-increasing burden of mail for our expanding population.

AN OVERVIEW OF NASA TECHNOLOGY

Space related research and development has provided many technological advancements which are of potential use in nonaerospace areas. It is this broad base of technology which, along with identified technological requirements in the public sector, forms the basis for the technology applications activities described in this report. The following paragraphs provide a very brief overview to indicate the breadth of space related technology.

Aerospace-developed advances in new materials include "composites" with high-strength-to-weight ratios, plastics with valuable new properties, versatile solid lubricants and fire-retardant materials. Filament composites have been required for the fabrication of missile bodies and rocket engine nozzles. Advances in plastics include improvement in the formulation of high-temperature polymers. Because of the high temperatures in moving parts, commonly used petroleum oils have become inadequate and have had to be replaced by new synthetic materials. Fire retardant materials have been developed for areas of constant exposure to propellant materials as well as for the interior of spacecraft.

In the biomedical field, development of instrumentation required to ensure the well-being of astronauts includes new techniques for electrocardiography, cardiac output monitoring, indirect blood pressure measurement and peripheral, arterial and venous blood flow measurement.

Advances in analytical chemistry technology have come from the need to explore from earth the nature of distant planets. Refinements in ultraviolet spectroscopy sprang from the necessity of detecting ultraviolet radiation in space for a definitive analysis of stellar and planetary atmospheres. Gas chromatography instrumentation applied to space exploration has required modifications to improve the construction and operation of automated models to increase the reliability of electronic circuitry and to provide efficient separation of compounds in complex mixtures.

Also, NASA-developed life-detection systems, such as Gulliver, Marbac, Multivator and Wolf Trap have represented advances in automation and miniaturization. The Gulliver, a successfully automated device, is based on a technique involving the measurement of the radioactive carbon dioxide released by the metabolism of an isotope-labeled nutrient by extraterrestrial microorganisms. The Marbac system is based on measurement of the changes in chemical oxidation-reduction potentials caused by the metablic processes of microbial life. The Multivator is a miniaturized and automated system utilizing spectrophotometric techniques that include nephelometry, fluorometry and calorimetry.

In the environmental-monitoring field numerous techniques have been developed for space-cabin atmosphere analysis. A small mass spectrometer was developed to continually monitor the respiration of a test pilot for correlation of various respiration products with stress conditions being experienced by the pilot. A trace gas analysis procedure has been developed to collect and analyze gases in the Apollo cabin. Other instruments and techniques developed include a hot-wire detector used for cabin contaminant identification and analysis and a microwave spectroscope in which detection of molecules is based on the absorption of various microwave wavelengths by different gases.

NASA has developed a number of remote control machines for performing manipulative tasks in space. This teleoperator technology provides an ability to augment man's hands, arms, and legs with machines.

NASA has been active in the development of microelectronics. This encompasses technologies by which electronic circuit functions are fabricated in small solid structures that are both reliable and inexpensive. Microelectronics has been invaluable in such applications as the IMP I satellite's optical aspect computer, the test apparatus that provides ground support equipment for the Apollo guidance computer and the circuitry of multichannel digital computers. Digital computers have been widely used in the aerospace community to correct various photometric, geometric and frequency response distortions in the images received from the television cameras of Ranger, Mariner and Surveyor spacecraft.

A range of NASA-developed nondestructive testing techniques include laminography and mutual coupling for the inspection of circuit boards, water-coupled impedance, contact impedance and eddy-sonic techniques for the assurance of complete bonding in composite materials. These techniques also include ultrasonic methods for measuring surface stresses in aluminum and for strength evaluation of bonded materials and radiographic examinations of electronic components.

The need for adequate water supplies and sanitation facilities in spacecraft has led to research and development concerning water management, waste processing and recycling systems.

Finally, the great complexity of the space program has required the development of planning techniques including careful program management and a range of systems analysis methods. Some of these techniques include operations research, operations analysis, cost-benefit analysis, and engineering-economic analysis.

TECHNOLOGY APPLICATIONS ACTIVITIES

The objective of the Technology Applications activities is to facilitate applications of NASA-related technology to significant public sector problems. To accomplish this the program:

- Identifies problems in conjunction with responsible mission-oriented agencies.
- Systematically seeks relevant NASA technology.
- Assists in effecting application of the technology.

In its efforts to facilitate applications of NASA-related technology to significant public sector problems, the Technology Utilization Office Applications Program had underway, as of November 30, 1971:

- Cooperative efforts with more than 150 public sector agencies, groups and institutions.
- Analyses of more than 300 public sector problems.
- More than 130 specific technology application projects.
- Specific projects at 11 NASA field installations.

NASA is now cooperating with other agencies in the fields of biomedicine, sensory aids for deaf and blind, air and water pollution control, criminalistics, law enforcement, mine safety, postal services, urban construction and transportation.

NASA is presently cooperating with:

- Department of Health, Education and Welfare
  - National Institutes of Health
  - National Center for Health Services R&D
  - Social and Rehabilitation Service
- Department of Housing and Urban Development
- Department of Interior
  - Bureau of Mines
- Department of Justice
  - Law Enforcement Assistance Administration
- Department of Transportation
  - Federal Highway Administration
  - Federal Railroad Administration
  - Office of High Speed Ground Transportation
  - Urban Mass Transit Administration
- Environmental Protection Agency
  - Office of Air Programs
  - Water Quality Office
- National Oceanographic and Atmospheric Administration
- U.S. Postal Service
- Veterans Administration
- Over 77 Medical Schools and Health Care Institutions
- 25 Criminalistics Laboratories
- 6 State Highway Departments

In addition, an *Advisory* function is provided in the biomedical area by an interdisciplinary committee of the National Academy of Engineering. *Applications engineering* support is provided primarily by NASA Field Centers. The NASA Field Centers provide a major thrust to the program, contributing vital engineering support and suggesting potential solutions to problems in response to stated needs. The efforts of the Field Centers have recently been expanded by two "new starts" described in the last section.

The criteria used for applications project selection ensure:

- A focus on significant problems.
- Professional and mission agency support.
- Nonduplicative effort.
- Aerospace related contributions to nonaerospace problems.

Liaison with user groups and agencies and identification of technical requirements is a function performed primarily by interdisciplinary "Application Teams" under contract to the NASA Technology Utilization Office. There are seven NASA funded Application Teams currently in the program. Team locations and the special problem areas in which each team concentrates are shown in Table I.

TABLE I

PROBLEM AREAS STUDIED BY NASA APPLICATION TEAMS

TEAM LOCATION	PROBLEM AREAS
Abt Associates, Inc. Cambridge, Massachusetts	Urban Construction and Planning
IIT Research Institute Chicago, Illinois	Law Enforcement Mine Safety Water Pollution
Research Triangle Institute (2 Teams) Research Triangle Park North Carolina	Air Pollution & Environmental Sciences Biomedicine
Southwest Research Institute San Antonio, Texas	Biomedicine
Stanford University School of Medicine Palo Alto, California	Biomedicine
Stanford Research Institute Menlo Park, California	Criminalistics Transportation Postal Services

SUPPORTING ACTIVITIES

The special studies and projects that support the overall Applications project activities are briefly described here.

National Academy of Engineering (NAE). The NAE's Committee on the Interplay of Engineering with Biology and Medicine (CIEBM) has undertaken a "Study of Aerospace Technology Utilization in the Civilian Biomedical Field". The study is being accomplished through the NAE Subcommittee on Technology and Systems Transfer, chaired by Dr. David Rutstein of the Harvard Medical School. Now in its second year, the NASA-sponsored effort is designed to:

- Identify aerospace engineering technology which appears relevant to specific technological requirements in the biomedical field;
- Relate the biomedical requirements to identified engineering technology in a manner which will facilitate followup activities by NASA at its option;
- Provide expert professional advice concerning initiation of specific projects identified in the preceding activities;
- Identify and recommend to NASA interfaces with the mission–oriented organizations on a continuing basis that will contribute to furthering the goal of transferring engineering technology to biomedicine.

During the past year, the Subcommittee created three ad hoc groups to focus study efforts on the areas of *cardiovascular care, pulmonary care,* and *remote diagnosis and treatment.* Each of these groups prepared initial statements identifying significant medical problems amenable to technological solutions within their specialities. They reviewed and evaluated a variety of current NASA projects and technologies related to biomedical technology. Problem identification and technology review were facilitated by conferences and meetings, and by trips to NASA field centers. Based on their correlations of needs and available technology, the groups submitted a set of recommendations for further concentrated development of NASA biomedical technology of significant potential to the biomedical community. The groups have also suggested means for improving the application process.

The first Subcommittee recommendation being pursued is the further development of mass spectrometers and respiratory flow sensors. The Subcommittee's ad hoc group on pulmonary care recommended that mass spectrometry technology could contribute substantially to clinical care. Instruments that are unstable and unreliable, with short component lifetime, inflexibility, and high costs have handicapped accurate and continuous monitoring and analysis of blood and respiratory gases. Through the efforts of the Subcommittee, HEW's National Heart and Lung Institute (NHLI) and National Center for Health Services Research and Development (NCHSRD) have expressed interest in pursuing a joint program for further development of such instrumentation.

Another recommendation was to evaluate the applicability to civilian health care of Reliability and Quality Assurance methodologies which were originally codified by NASA. Widespread use of the bioassay device for automated fast urine bacteria detection was recommended by the Subcommittee at large.

The ad hoc committee on cardiovascular care concluded that further research and development are needed in noninvasive cardiovascular measurements before they can be used clinically.

The Remote Diagnosis and Treatment (RDT) ad hoc group was concerned with a new method of health service delivery, as opposed to the other two ad hoc groups that focused on instrumentation problems in current delivery modes. The RDT group uncovered some crucial unanswered questions con-

cerning the physician's need for information–questions that require answers before specifications for communication links can be established. The Subcommittee identified specific NASA facilities and personnel to assist in the research efforts (e.g. evaluation of slow-scan T.V. systems) to provide answers to some of these questions.

All of these activities bear directly on health care delivery. Thus, the conviction of the CIEBM and the Subcommittee is that mission-oriented Federal agencies dealing with health care should join in the technology transfer process. As a result, representatives from the Office of Science and Technology, the Veterans Administration, and several agencies within the Department of Health, Education and Welfare were contacted. Subcommittee findings have been discussed with them, and alternatives for joint participatory programs with these agencies and NASA are being explored. It is hoped that the major suggestions for technology transfer (specific development and evaluation protocols) will be implemented under jointly funded and supported interagency projects.

For the next 12 months, the CIEBM proposes to continue, and to augment its services to NASA. Maintaining the Subcommittee on Systems and Technology Transfer as the basis, the CIEBM proposes two primary efforts:

> First, the Committee will continue followup on the transfer process it has initiated, for the specific devices–mass-spectrometer, flowmeter, and urine bacteria detector. Efforts are actively underway to involve the National Heart and Lung Institute of NIH and/or the Veterans Administration in collaborative projects toward effective civilian applications of these devices. The Committee will act as an overview and liaison body as the development and evaluation of projects (the next phases of the transfer process) are undertaken, and will keep NASA and the mission agencies informed on work progress. Second, the Committee proposes to carry on its initial study of remote diagnosis and treatment more extensively during the next 12 months. The report of the *ad hoc* Group on Remote Diagnosis and Treatment documented the need for a thorough examination of the potential for remote health care, alternative strategies that can be used, and roles that technology (primarily measurement, communication, and transportation) can play in developing such systems for health services delivery. Specifically, the Committee has outlined controlled parametric studies which should be undertaken as a part of an overall assessment of 'telemedicine' (remote diagnosis and treatment). The Committee noted further that within NASA there is the requisite expertise in communication, transportation, system analysis and operations research. These are the necessary tools for the interdisciplinary team which would undertake making the assessment.

"Engineering in Medicine-Biotelemetry" Conference. A conference to explore technical problems and the coordination of biomedical communications within regions was cosponsored by NASA's Technology Utilization Office and the National Academy of Engineering. Arrangements were made by the Engineering Foundation for the August 1971 conference in Henniker, New Hampshire. The Foundation develops research conferences that focus on vital areas in engineering research as they relate to urban problems and the public sector.

The topics discussed by the conference were:

- Biotelemetry from remote emergency vehicles
- Biotelemetry in remote health care
- Biotelemetry in intensive and coronary care units

Personnel from industry, Government, and the biomedical community were brought together at the conference. It was structured to provide background information in various problem areas, and to identify national funding resources to support problem solution. The conference also served as a forum for defining future developmental work.

It became clear that the major problems facing the implementation of improved systems were the economic and institutional coordination aspects. A consensus was reached that the technological problems could be dealt with by a modest research and development effort.

Representatives from the federal health related agencies indicated clearly that funds were in very short supply, if not completely unavailable. They did however indicate a willingness to engage in cooperative ventures that did not require dollar funding. Exhortations to consider the interplay between devices and people were echoed throughout the meetings. Participants were cautioned that in attempting to improve medical telemetry systems they must carefully examine exactly what is their final goal. This is essential to avoiding the situation of having "a gadget looking for a job". In the final analysis, the value of any technology must be determined by its ability to diminish disease, disability, and untimely death.

Technology and the Neurologically Handicapped. Ways in which technology might aid the neurologically handicapped was the subject of a 3-day conference jointly sponsored by NASA and the United Cerebral Palsy Research Foundation. It was held at NASA's Ames Research Center, Moffett Field, California. A presentation was made on the etiology and physiology of neurological handicaps, and techniques for meeting the basic needs of the neurologically handicapped were discussed. The conference focused primarily on current therapeutic techniques, and an adapting technologies already developed for other purposes to the needs of the handicapped. Topics discussed were: long-range prospects for neural control, objective measurement of recovery from neurological disease, exoskeletal technology, artificial sensory systems, models of the sensory system and postural control, manual control theory and applications, neurological applications of man-machine systems analysis and the role of intelligent mechanical aids.

Discussion at the close of the meeting centered on future means of improving communications, and technology transfer from physiology and engineering to neurology and rehabilitation.

Projects have resulted from discussions at this conference. Studies have begun on NASA-developed exoskeletal devices to improve a spastic's control of limb motion and to implement improved methods of measuring limb motion for evaluation of therapeutic effectiveness.

NASA-American College of Radiology Joint Conference on Technology Transfer. NASA and the American College of Radiology (ACR) will hold a joint conference in Albuquerque, New Mexico, February 19-21, 1972. Eighty representatives, half from the NASA family and half from the radiological community, will engage in intensive discussions on ways that NASA-supported research and technology can be applied to problems of the medical specialty of radiology.

Past meetings with this purpose have been too broadly defined to permit direct communication between doctor and scientist, to resolve problems. Radiology is more technologically based than most other medical areas, so that radiologists are inclined to work with other scientists on advanced state-of-the-art technology. Radiology is concerned in the entire province of health care.

Subjects for the conference sessions are: image systems, computers, instrumentation, and cancer therapy. In support of conference planning, members of the Technology Application Group (Biological Sciences Communication Project, The George Washington University) attended national radiology conferences to assess current radiation technology requirements. They have worked on the conference structure, and have recommended qualified NASA representatives as participants. A number of specific development projects are anticipated from the conference for future NASA-ACR cooperation. In support of these projects, resources will be available from NASA and the Federal health related agencies.

The PTI-NASA Technology Applications Program. The International City Management Association (ICMA) and NASA initiated a joint program in the latter part of 1970, for the purpose of applying NASA technology to urban problems. Selected ICMA member cities were invited to participate. Of the 100 cities asked, 79, representing a population of almost 20 million, joined. In the fall of 1971, the program became Public Technology, Incorporated (PTI), under sponsorship of the six major public-interest groups representing local and state governments. These are: the International City Management Association, National League of Cities, U.S. Conference of Mayors, National Association of Counties, National Governor's Conference, and the Council of State Governments.

The cities' problems are complex in nature and have a wide range. Therefore, the long-term goal of this experimental program is to explore and develop effective means of applying new technology to urban problems. The short-range objectives, which are a basis for planning and criteria for future programs, are to:

- Develop an active experimental program to identify and apply aerospace technology relevant to urban problems.
- Improve the policies, strategies, and methodologies for the application of technology in the urban environment.
- Assess program contributions, impact, and effectiveness in helping cities meet their complex and evolving needs for technology.

NASA and PTI held a working conference in October 1970 at the Kennedy Space Center. For two days, representatives from participating cities explored intensively the range of NASA technology and potentials for application to urban problems. City representatives also attended concentrated work sessions in problem definition. The aim was to simplify the assigning of priorities to urban problems that might be solved through new or improved technology. After the conference, when the representatives had returned to their cities, they drew up an initial set of problems which was submitted to PTI for review by a coordinating group of city representatives.

Nearly 500 problem statements, submitted by January 1971, were independently reviewed by NASA and PTI prior to the coordinating group review. The coordinating group compounded this set of problems into 45 generic, high-impact urban technology requirements. Major problem areas included communications, law enforcement, fire safety, transportation system control, public works and utilities, health, sewage disposal, solid waste management, and water pollution control. The problem statements for fifteen top priority problems were rewritten and these were reviewed and modified by three regional groups of city representatives to create regional problem priorities. The coordinating group reconvened in April 1971 to agree on a set of six target problems on which to begin work immediately. The fifteen problems in order of priority are:

1. Firemen's Breathing Apparatus
2. Short-Range Communications Equipment for Firemen and Police
3. Pavement Striping
4. Firemen's Protective Clothing
5. Underground Pipe & Conduit Locator
6. Automatic Fire Hose Flow Regulator
7. Command/Control Systems
8. Protective Body Armor
9. Disposal of Toxic and Flammable Waste
10. Electrical Fault Detection
11. Electronic Traffic Counter
12. New Fire Hose and Hose Couplings
13. Patient Monitoring Equipment, Emergency
14. High Voltage Power Transmission
15. Patient Monitoring Equipment, Non-Emergency

The current status of the top six problems is:

1. *Firemen's Breathing Apparatus.* Specifications for a lightweight compressed air bottle and regulator, harness, and mask have been prepared at the Manned Spacecraft Center. Contracts for the bottle development will be let in early 1972, as will requests for proposals for other parts of the system. A User-Design Committee has reviewed, evaluated, and approved all systems design specifications. Prototypes for demonstration are expected in mid-1973.

2. *Short-Range Communications Equipment for Firemen and Police.* New products under development or commercially available are being evaluated. The experience of cities using the latest equipment is being reviewed. During the first quarter of 1972, it will be decided if available equipment is adequate or whether aerospace technology should be sought and applied.

3. *Pavement Striping Materials and Equipment.* Several new developments, soon to be available commercially, are under consideration. These systems will be evaluated early in 1972 and a decision made whether to pursue further development.

4. *Firemen's Protective Clothing.* Contracts have been let from Manned Spacecraft Center to produce prototype suits, which should be ready for demonstration in March 1972 for testing in 20 cities. The suits will be coordinated with the breathing apparatus and short-range communications problems.

5. *Underground Pipe and Conduit Locator.* A development project is underway at NASA's Marshall Space Flight Center (MSFC). Prototype demonstrations in the cities should begin by the end of 1972.

6. *Automatic Fire Hose Flow Regulator.* Alternative technological approaches have been identified for further evaluation. One alternative, generated by engineers at Lewis Research Center, is being reviewed by the User Design Committee. Other alternative approaches should be available in early 1972.

User Design Committees, consisting of both technical and administrative personnel from the cities, have been established for several problems. Their meetings with NASA provide an opportunity for the municipal representatives and NASA technical personnel to develop a better understanding of problems, performance needs of end products, and to evaluate proposed solutions. This close coupling between the user and the design team represents an important link in the technology application process. It is a necessary step in developing specifications that will meet the needs of the municipalities and, hopefully, to aggregate municipal markets for new products.

The coordinated NASA/PTI effort is experimental and is directed toward problem solving rather than research. Activities are focused on solutions for discrete, well-defined technical problems.

Personnel from PTI, NASA, Abt Associates, and The George Washington University Technology Application Group are working on final problem definition and analysis of technology requirements, specifications, and search procedures for a wide variety of problems. Positive steps have been taken to maintain current awareness of activities of other Federal agencies that sponsor research and development related to the PTI, to avoid duplication of effort and to foster possible cooperative efforts. The program makes full use of NASA's problem-solving methodology to search for relevant aerospace technologies from NASA's data base and from field center scientists, engineers, and contractors.

Minority Enterprise Program. The NASA Technology Utilization Office initiated a contract in February 1971, with the National Progress Association for Economic Development (NPAED), which was formed by the Reverend Leon Sullivan to aid minority groups in business ownership and management. After a review of the application effort NPAED selected 24 NASA technologies which they believe have potential for either creating a new enterprise or for strengthening an existing one. A report which outlines the marketability, development costs, and a proposed business plan for each technology will be widely distributed to encourage other minority groups to consider these technologies.

Also, the Office is cooperating with a minority business firm in a pilot project to make commercially available a NASA developed behavioral/motor skills testing device with broad potential application in medicine, law enforcement, transportation and other fields. A field tested product should be widely available by the latter part of 1972.

The George Washington University. The Technology Application Group (TAG) of the Biological Sciences Communication Project (The George Washington University Medical Center), under contract with NASA's Technology Utilization Office since 1965, provides technical and analytical assistance to the Application Team Program. The TAG provides NASA with continuing support in analysis of the Application Teams'

work. It supplies detailed monthly reviews of various aspects of the technology transfer process, and helps to improve transfer systems. The TAG determines significant problem areas for the entire Application Team Program, and calls them to the attention of NASA.

Reports on the technological state-of-the-art in the public sector were submitted to NASA in the past year. The TAG works with agencies or organizations to identify new problems, or to further the NASA technology transfer, as required. It coordinated the American College of Radiology Conference, to be held in February of 1972. The TAG has worked closely during the past year with the National Academy of Engineering Committee on the Interplay of Engineering with Biology and Medicine Project. It evaluated the activities of Public Technology Incorporated/NASA Technology Applications Project and lent assistance to the effort with the National Progress Association for Economic Development.

Efforts to Commercialize Biomedical Technology. In early 1970, an Aerospace Subcommittee was established (under the Association for the Advancement of Medical Instrumentation (AAMI) Standards Committee), to find means of stimulating the interest of the biomedical industry in NASA biomedical technology. The Subcommittee was formed through cooperation of AAMI, NASA's Technology Utilization Office, and the RTI Biomedical Application Team. It is composed of representatives from NASA bioinstrumentation groups, physicians, and the biomedical instrumentation industry. At the Subcommittee's first meeting, during the Annual AAMI Meeting in March 1971, a detailed briefing on the NASA Application Team Program was presented. At a later conference (Fall 1971), the Subcommittee received extensive material on NASA biomedical technology.

The subcommittee's concern and discussions center on ways to inform industry that fully developed NASA devices are available, and to encourage their manufacture and marketing. The recently revised NASA patent licensing regulations enable NASA to grant exclusive licenses at an earlier date than was previously possible. It is anticipated that this will accelerate the commercial use of space-related patented inventions or technology. Specifically, rather than wait until two years after a patent has been issued, as previously required, NASA could grant exclusive licenses in appropriate cases as soon as nine months after the invention had been announced as available for licensing. The prime consideration is granting an exclusive license will be whether such a license is necessary to bring an invention to practical application.

The annual AAMI conference in the spring of 1972 will include a special session on NASA developments in biomedical instrumentation.

Goddard Space Flight Center's Third Annual Summer Institute for Biomedical Research. The Summer Institute for Biomedical Research in Technology Utilization is a unique program to further accelerate the flow of NASA aerospace technology toward application to problems in biomedicine. It was undertaken this summer for the third successive year.

The Institute was a joint project of The George Washington University and NASA's Goddard Space Flight Center. It was undertaken to enable ten senior undergraduate students selected from a number of colleges and universities throughout the eastern United States to spend ten weeks in an active technology application program. The students were able to apply their background and aerospace technology toward the solution of defined biomedical problems under the direction of University faculty and Goddard scientists and engineers.

During the first half of the ten-week period, the students spent two mornings each week in a classroom lecture series designed to provide them with a broad, comprehensive view of the biomedical engineering profession and, in particular, the system engineering approach to health care. The lectures, seminars, and demonstrations were conducted by The George Washington University Department of Clinical Engineering in Washington, D.C.

Five well-defined research projects were developed by the Department of Clinical Engineering. These projects were focused on ideas, concepts, or existing instrumentation which needed further design and engineering improvement, so that significant progress in terms of working prototypes could be accomplished by the students during the ten-week program. These projects were:

1. *Rapid Detection of Bacterial Presence in Biological Fluids.* A novel and reliable technique for rapid detection of bacterial infection was developed and successfully tested. The technique measures changes in the redox potential of the growth medium. The change in redox potential appears to be dependent on changes in bacterial oxygen consumption. The text produces a positive indication within 5 to 10 minutes and requires neither a costly growth medium nor incubation chambers. Its detection capability has been successfully demonstrated in blood, urine, and cerebrospinal fluid. A rapid test such as this could be valuable for testing a bacteria's response to a particular antibiotic, increasing the physician's ability to prescribe a suitable antibiotic. Also of interest is its ability to determine the viability of sperm. A follow-on project has been funded in cooperation with the Veterans Administration where parallel tests will be run between this technique and more orthodox methods.

2. *External Recording of Arterial Pulse Waves.* A pressure measuring system capable of accurately measuring carotid artery pressure transients without penetrating the skin was built and tested. A major improvement over the earlier technique was achieved by replacing the pneumatic pressure indicating system with a pressure sensitive semiconductor (PITRAN). The new unit is now being used by the Veterans Administration in their Hypertension Study program.

3. *Myoelectric Control of Paralyzed Muscle.* A system for stimulating and controlling a paralyzed muscle group was designed and tested. The system amplifies the electrical potential generated by a normal muscle group and uses that signal to control the production of a series of electrical pulses which then activate the previously paralyzed muscle. This work was performed with the cooperation of the Veterans Administration and was favorably evaluated by the patients who tested it.

4. *Thermal Dilution for the Measurement of Blood Flow.* An instrument was designed and tested to calibrate available thermodilution techniques for the measurement of blood flow to body organs. An improved technique for making in vivo thermal dilution measurements was also designed and built. This system consisted of a heat source and a heat detector mounted at the tip of a 2.0 mm catheter. Continuous accurate measurement of blood volume flow was achieved.

5. *Systems Analysis of an Intensive Care Unit.* The operation of an intensive care unit was studied and recommendations were made so as to improve the integration of various existing instruments and manual procedures.

More detailed information concerning the 1971 Summer Institute is included in a report issued by the Technology Utilization Office of the Goddard Space Flight Center (GSFC).

CURRENT TECHNOLOGY APPLICATIONS EXAMPLES

INTRODUCTION

This section describes specific applications activities active during the period covered by this report.

CANCER: DETECTION, TREATMENT & RESEARCH

Detection of Eye Tumors Using Radiation Probes. A valuable technique for the detection of eye tumors is based on the detection of beta-radiation emitted by a radioisotope. The isotope, which is selectively absorbed by tumor cells, is administered intravenously to the patient. It is then necessary to differentiate between different levels of radiated energy to detect tumors which are hidden from direct observations, or are in such an early stage of development that they cannot be detected by any other means. A measuring technique currently being used requires insertion of a dime-sized Geiger counter probe between the eyeball and the eye socket. The Geiger probe is both excessively large and insufficiently directional to provide adequate readings. The large size and lack of directionality make it difficult to determine if the detected increased level of radiation is indeed a tumor within the eyeball, or merely an area of increased blood flow, which could take place in one of the eye muscles. Thus, readings from the probe might be falsely interpreted to indicate the presence of an eye tumor, when in fact, there is none. Thus a more precise probe might reduce the number of eyes for which surgical removal is considered necessary.

A semiconductor radiation detector was developed by NASA. It is sufficiently small to put in a 1 mm diameter probe; mounted at the tip of a catheter, it can be inserted easily into the area behind the eye with minimum trauma. The probe, incorporating a thick film preamplifier adjacent to the detector, has a signal-to-noise ratio that is amenable to recording equipment. It is highly sensitive, and provides a realistic measurement of the spatial and energy distributions of beta-radiation. From data gathered from several locations, differences in isotope concentration can then be used to precisely identify and outline the area of increased isotope uptake by suspected tumor cells, if they are present.

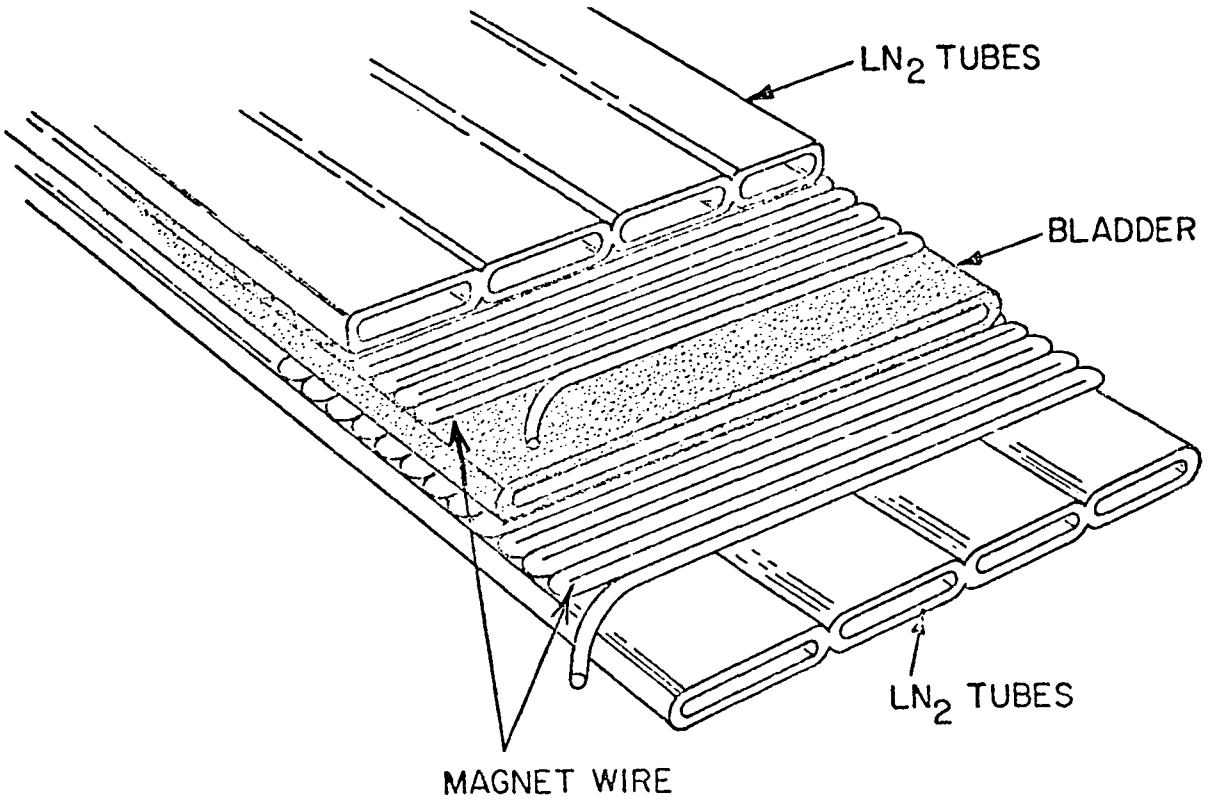
This information will be vital to diagnosis and therapy of the eye. The clinician can determine more accurately the distribution of the isotope, making his diagnosis more specific. This will reduce the present high percentage of false-positive tumor diagnoses, which results in unnecessary removal of the eye. Solid State Radiation Inc. originally developed the semiconductor radiation probes under NASA contract. The firm is planning to market a probe for diagnostic use in the near future.

Method of Controlling Rate of Freezing of White Cells for Leukemia Research. A "cold sandwich," designed by NASA engineers at the Jet Propulsion Laboratory, may prove useful in freezing white blood cells in blood banks to be used for leukemia patients.

Leukemia is a form of cancer characterized by proliferation of white blood cells which are formed in bone marrow. It is treated by killing the cancerous white blood cells in the blood and bone marrow with the use of drugs or radiation. This process can cause loss of all bone marrow, inhibiting or eliminating the production of normal white cells, so that a fresh supply of white cells is required for the patient. It would be desirable to have a white cell "bank" or frozen storage facility to provide ample white cells for leukemia patients. Currently, this is almost impossible, due to destruction of white cells by existing freezing and thawing procedures, where the rate of temperature change is not constant. A method of freezing that provides for a constant rate of temperature change should solve the white cell destruction problem.

In response to this problem, posed by the National Cancer Institute (NCI), NASA's Jet Propulsion Laboratory proposed a design of a heating and cooling "sandwich" which provides for controlled cooling (Figure 1).

The controlled freezing unit would consist of a Teflon bladder containing the white blood cells, surrounded by heater grids which are in turn surrounded by a cold tank through which liquid nitrogen flows. A temperature sensor in the bladder would continuously monitor temperature of the bladder contents and transmit this information to a modified Wheatstone bridge circuit. This, in turn, would control the heater



White blood cells, unlike red blood cells, are destroyed by present freezing and thawing methods. Experiments indicate that the maintenance of a constant rate of cooling is essential to cell survival. By detecting the onset of freezing and then increasing the heat transfer rate during the release of latent heat at the freezing point, a nearly constant rate of cooling can be maintained. Cooling is supplied by the liquid nitrogen tubes and is controlled by heating the magnet wire. When the freezing point is reached, heating is discontinued so that a sharp increase in thermal flow occurs.

Figure 1. Controlled Freezing Unit

grids to provide a constant rate of cooling by the liquid nitrogen. If this design proves successful, it will remove a major obstacle to the availability of white cell blood banks, and lead to improved care and treatment of leukemia patients. The device will be fabricated and tested in a joint program sponsored by the National Cancer Institute (NCI) and NASA's Goddard Space Flight Center (GSFC). A working prototype of the freezing unit will be fabricated by GSFC and delivered to NCI before June 1972.

Scanning Tumors in Small Animals with Gallium-67. Gallium-67, a radioactive isotope, possesses the special property of concentrating in various types of tumors when administered to a patient orally or intravenously. The mechanism of gallium uptake is not well understood; it is not known whether there is a direct binding of gallium in the tumor tissue, or binding to some other agent which in turn is concentrated by the tumor. Whichever the case, gallium-67 appears mainly in viable rather than non-viable tumors. Studies also indicate that gallium-67 is superior to other commonly employed tumor scanning agents, in absolute tumor concentration, and in ratio of tumor to normal-tissue concentration. These observations are among the most significant recent developments in nuclear medicine.

By administering gallium-67 to a patient and scanning the body with an instrument which can detect the presence of radioactive substances, the location as well as the size of a tumor can be determined. Radiologists currently employ a variety of camera and scanning systems which are useful in locating tumors in humans, but are relatively ineffective in studying the response of the tumor to therapy. In order to follow tumor growth on a day-to-day basis, a high-resolution scanning system is needed which is

sensitive to gallium-67. In particular, the scanning system must be suitable for scanning the entire bodies of small experimental animals. Such a system would offer a unique opportunity to study methods of inhibiting or retarding tumor growth.

In response to this problem posed by the National Cancer Institute, the Space Radiation Effects Laboratory (SREL), operated by a contractor with support by NASA's Langley Research Center, suggested a scanning system they were developing. The system uses lithium-drifted germanium detectors to analyze gamma-radiation emitted during the decay of gallium-67.

The excellent resolution of these detectors leads to easy identification of the primary radiation. The collimation procedure is greatly simplified, since scattered radiation will normally be degraded in energy and therefore easily separated from the primary radiation of interest. Investigators at SREL have prepared a three-dimensional computer-controlled scanning mechanism for use in radiobiological experiments. This scanning mechanism can be used to control two lithium-drifted germanium detectors (operating at right angles to each other) to scan a tumorous source in three dimensions. A data acquisition system developed at SREL moves a small animal relative to the two radiation detectors and records the position of the animal at all times during the scanning procedures. The SREL system then produces a map of the activity within the animal.

Tumorous mice have been supplied to SREL by the National Cancer Institute (NCI). Several scans have been performed. The results with a single hole collimator and test sources indicate that a spatial resolution of 1½-2 mm is quite possible. The first scan of a tumorous rat using the simple, single hole collimator produced an initial spatial resolution of about 3 mm. Replacing the simple collimator with a multi-hole focused device will provide improved resolution and/or reduce the time required to perform the scan. NCI personnel are presently reviewing the results of these preliminary studies and have expressed considerable interest in the system.

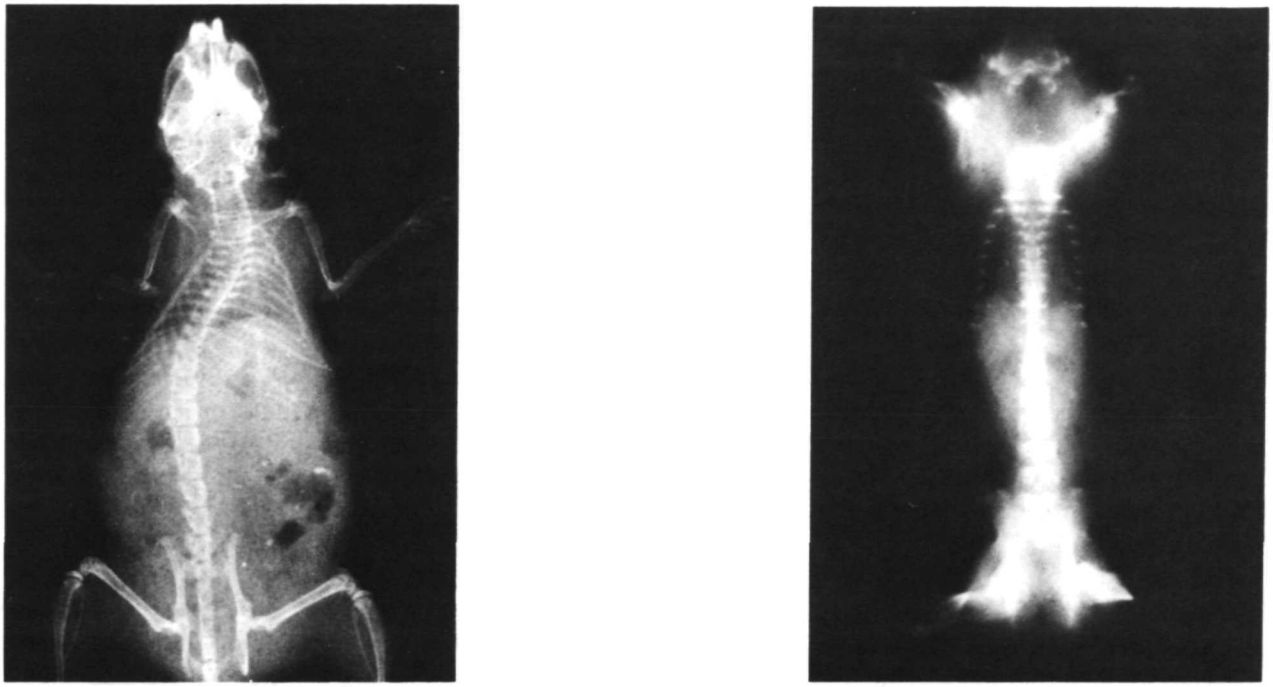
X-Ray Microplanigraph. An aerospace method used for analysis of printed circuit boards is being applied for another use: to obtain improved x-ray techniques for cancer detection.

According to a recent survey, cancer is the second largest cause of death (318,500 in 1968) in this country and is the disease most feared by the American people. In the present state of treatment, only those cancers which are detected early can be treated successfully. Cancers on the surface of the body are easily detected. Cancers deep within the body are difficult to find and an advanced stage of development usually results in the death of the patient.

The chances of patient survival would be greatly enhanced if an instrument could detect these deep-seated tumors and determine whether they are malignant or benign, as well as the extent of spreading. The common method for detecting tumors is by x-ray. Unfortunately, when the entire body is x-rayed, small tumors remain undetected because the background level of the x-ray signal is vastly increased by scattering within the thickness of the body. A more desirable method is a technique whereby x-rays are made of laminar regions only. A basic problem with this approach, however, is to develop a method suitable for making x-rays of thin laminae of regions of a patient's body.

The general technique of making x-rays of thin laminae is called x-ray microplanigraphy. Although this technique is theoretically feasible, it is not actually used for tumor detection. It was employed by NASA to inspect multi-layer printed circuit boards, layer-by-layer, with a resolution of 0.001 inch. The technique, developed by a NASA contractor, involves moving the x-ray source and detector in a particular geometrical arrangement, so that only thin laminae are measured. The Problem Originator discussed this technique in detail with the NASA contractor, and decided that it was highly relevant to his investigation. An example of the use of the technique is shown in Figure 2.

The Problem Originator has submitted a proposal to the National Institutes of Health (NIH) for development of this device. It is highly significant that the entire proposal is based on NASA work. The Problem Originator has already performed some very promising preliminary x-ray studies using this technique, which he plans to implement more fully with the additional NIH funds. A paper on this technique will be presented at the NASA/American College of Radiology Joint Conference in February 1972.



A. Conventional X-ray Image of a Mouse

B. X-ray Planigraphic Image of a Mouse

Figure 2. Comparison of Conventional and Planigraphic X-ray Images

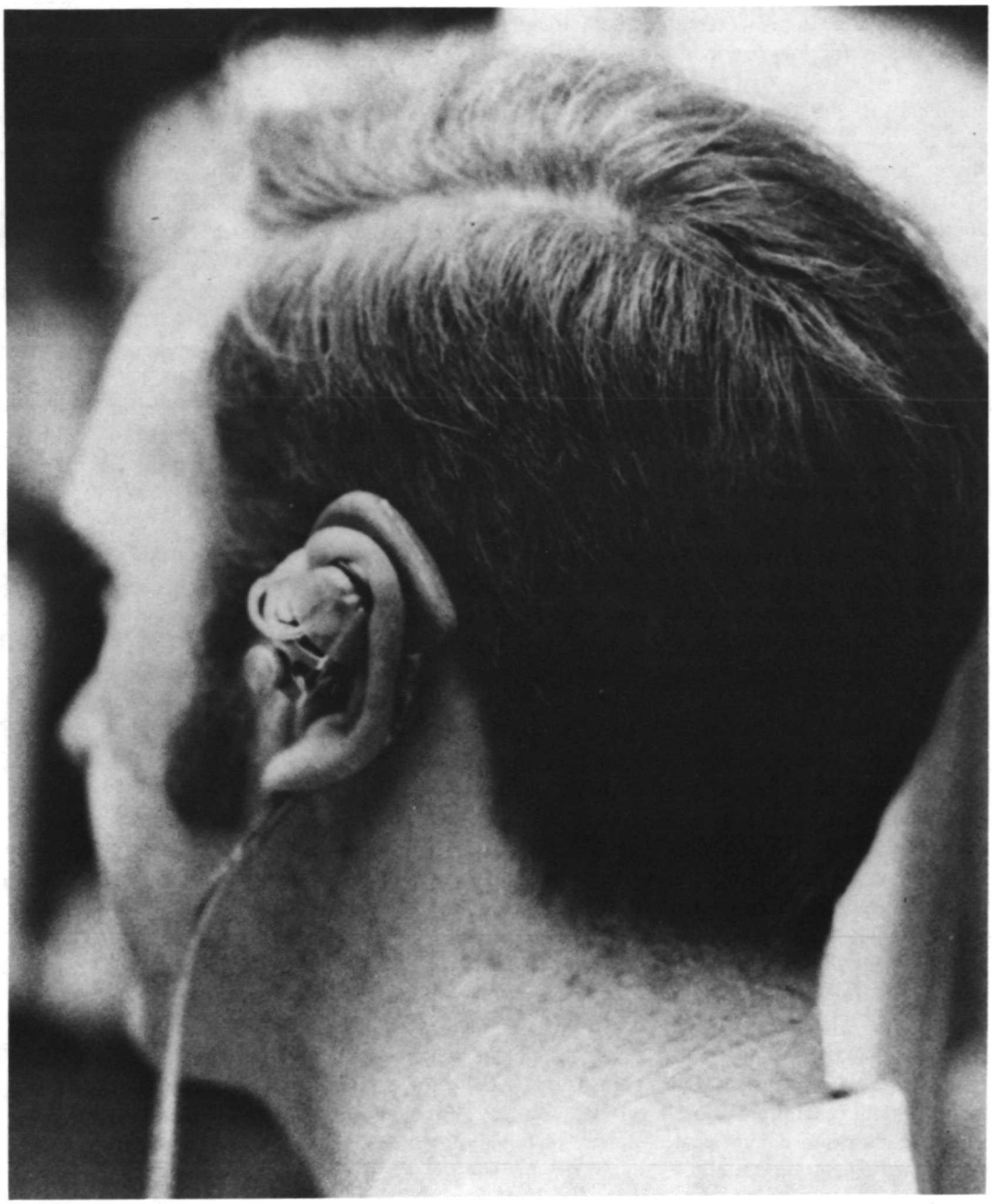
Noninvasive Continuous Monitor Detects Onset of Shock. Leukemia is a disease characterized by self-perpetuating proliferation of white blood cell-forming tissue. An extensive National Cancer Institute program is directed toward finding the causes and cures of leukemia. The clinical phase of this program is concerned with early detection of shock. Shock, defined as the sudden reduction in the volume of circulating blood, frequently results from hemorrhage, or infection, as well as other causes. If it is not recognized early, the damage is irreversible and rapidly becomes fatal. Thus, there is a need for an accurate indicator of the onset of shock, so that corrective measures can be taken in time.

An important measurement of the onset of shock is a reduction in blood pressure. The usual means of measuring blood pressure is with a sphygmomanometer. A cuff is placed around the arm which is then inflated to a higher than maximum blood pressure and slowly reduced. This method is quite inadequate and cumbersome for continuously measuring blood pressure of a critically ill patient, since it disturbs him.

A device for measuring relative blood oxygen content, the ear oximeter (Figure 3), has been identified at Ames Research Center. The device permits detection of the onset of shock without disturbing the patient. The ear oximeter was adapted for use in the early astronaut program; it fits the ear similarly to a hearing aid.

This device is comprised of a small sensor mounted on the ear, and a small electronics package which can be placed at the patient's bedside. The absorption of infrared radiation by the blood is directly related to oxygen content of the blood. The onset of shock is accompanied by a reduction in the amount of blood and oxygen content of the blood flowing through the earlobe. Change in the infrared absorption is detected, and causes the device to set off an alarm that warns medical personnel to take corrective action.

The Ames Research Center has loaned the oximeter to the National Cancer Institute, where clinical evaluation tests are underway. If the evaluation is successful, the unit will provide improved monitoring and care for leukemia patients. A technical paper on this device will be presented at the International Conference of the Institute of Electrical and Electronics Engineers (IEEE) in March 1972.



The ear oximeter was developed to clip on to the ear and measure blood oxygen by absorption of infrared radiation. The output is related to both blood oxygen and pressure so that it may be used to provide for early detection of shock in hospital patients.

Figure 3. Ear Oximeter

Bone-Density Measurement. Neoplasms such as tumors often secrete hormones which leach calcium from the bone. This can produce hypercalcemia (excessive calcium in the blood) and can also produce a site in the leached bone that is vulnerable to cancerous cells. Hypercalcemia affects approximately 20 percent of lung cancer patients and 40 percent of breast cancer patients. Although hypercalcemia can be treated, its fundamental cause is not known. Present studies on experimental animals use x-ray absorption techniques to measure bone density as a means of following the progress of demineralization. This technique is not desirable for humans, since it requires the patient's exposure to repeated, numerous doses of x-rays which must be continued for long periods of time.

A researcher at the Ochsner Foundation, studying the bone demineralization process, inquired whether NASA had developed any techniques for determining the decalcification of bone. The Marshall Space Flight Center had constructed a device (Figure 4) for just this purpose, for possible use in the NASA Skylab program. It measures the propagation time of an ultrasonic pulse across a section of bone. Since conduction velocity is a function of material density, it should provide good indication of any changes in the composition of the bone. This is a noninvasive test and merely requires accurate positioning of two transducers in good contact against the skin overlaying the bone being examined.

The researcher will perform these measurements on rat tibias having bone dimensions similar to the phalange bones of the human hand. It should therefore be possible to extrapolate his data and findings to measurements made on the phalange bones of humans where hypercalcemia is suspected. If the technique proves fruitful, it will be important both as a diagnostic aid and to evaluate the efficacy and progress of therapy. As a result of early clinical tests several improvements are being incorporated in the device and further testing will continue in the spring of 1972.

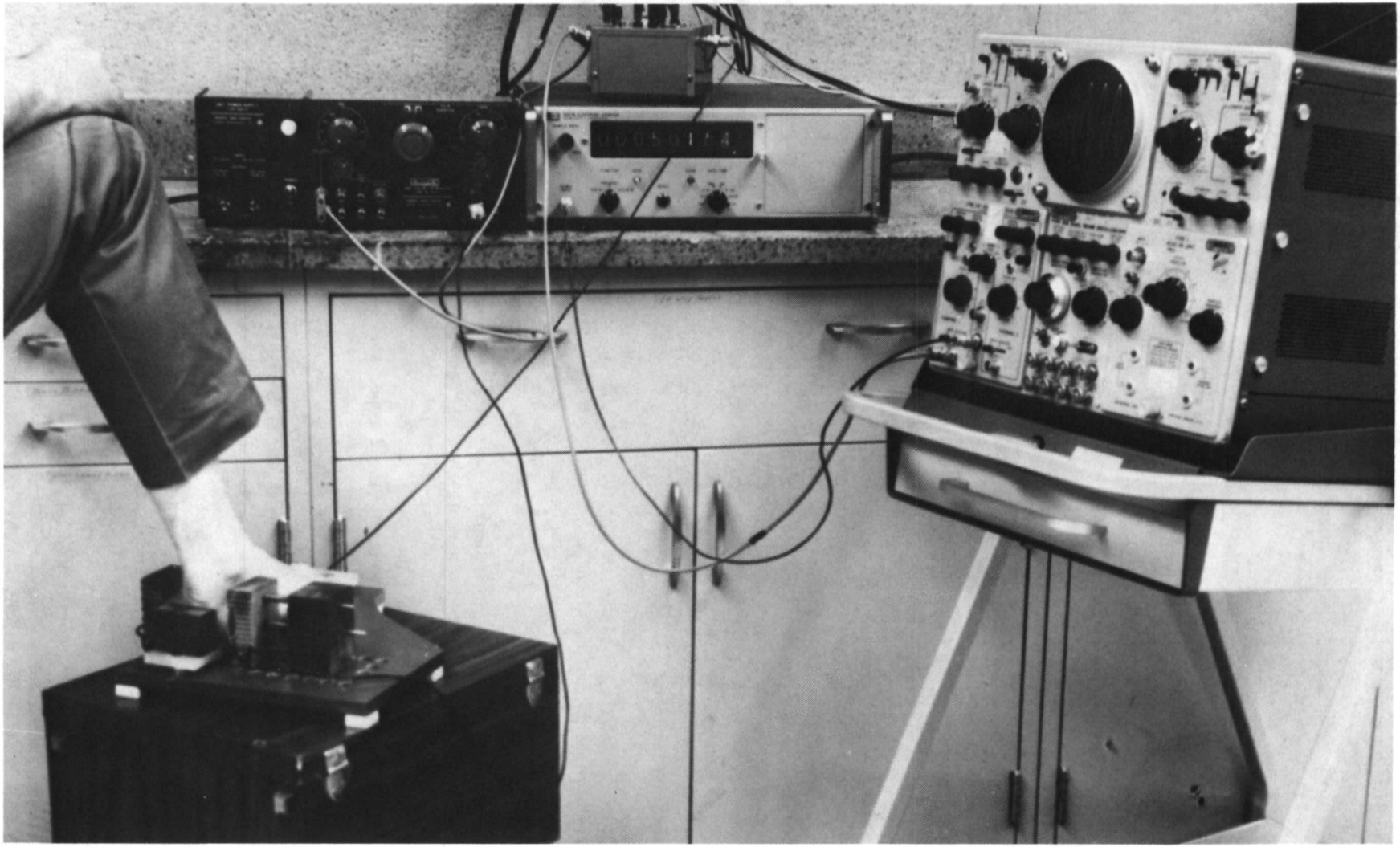
Improved Photographic Emulsion to be Used in Cancer Research. An improved photographic emulsion, developed at NASA's Goddard Space Flight Center for high-altitude cosmic ray studies, is now being prepared for use in the detection of radioactive cancer cells. Cancer study in experimental animals can be facilitated by labeling the tumor cells with radioactive tritium. The tritium attaches itself to the DNA molecule and the division of the tumor cell produces new labeled cells. Autoradiography is used to detect radioactive cells. A film sheet of photographic emulsion is placed over the cells and exposed by the radioactivity. Existing film emulsions require exposure of a month or more. Investigators at the National Cancer Institute (NCI) needed a faster high resolution film so that the autoradiography technique could be used clinically to evaluate the progress of cancer in humans.

A scientist at Goddard Space Flight Center had developed several types of special-purpose emulsions. His original interest in these emulsions had been to reduce the exposure time required to study the composition and energy spectra of low-energy cosmic rays. Space and facilities have been made available for the scientist at NCI, where he will prepare some improved emulsions for testing and evaluation.

Improved Lens for Cancer Research. In cancer research and other advanced medical studies, the basic unit of study is the human cell. Medical science demands fuller information on cellular action, and advancing technologies play a vital role in supplying information on intracellular components. A study being conducted at the National Cancer Institute (NCI) uses an optical microscope controlled by a digital computer to obtain quantitative chemical data on cell mechanisms. This study could scarcely be pursued otherwise, since the human eye cannot detect such minute cell changes. The same system can also be used to delineate three-dimensional architecture of the human tissue.

The study is hampered by difficulty in obtaining sufficient light intensity with the existing unit. This problem could be overcome by using a complex elliptical lens, but the researchers have not been able to locate a commercial source for the needed lens. The National Bureau of Standards (NBS) offered to grind the lens, if grinding specifications for the complex surface were made available.

NASA's Jet Propulsion Laboratory has developed a computer program to design complex optical systems. This program had not previously designed elliptical lenses, but NASA personnel thought that the work could be done. The FORTRAN language computer program was shipped from the NASA-sponsored Computer Software Management Information Center (COSMIC) to the researcher, who has utilized this



Allows noninvasive determination of changes in the calcium content of bones. Previously developed techniques have been dependent on x-rays, making a long series of frequent studies impractical as they would have required subjecting a patient to an excessive amount of radiation.

Figure 4. Ultrasonic Bone Densitometer

program to design the improved lens. The program has been run and specifications for the lens have been fully defined. Now that the complex surface has been defined, it will be ground by NBS.

The new elliptical lens will greatly clarify information derived from the human cell studies. The lens design is a critical element of advanced technology to further cancer research.

CARDIOVASCULAR DISEASE: DIAGNOSIS, TREATMENT AND RESEARCH

Automated Measurement of Coronary Angiograms. The volume of the heart's chambers during various stages of the contractile cycle are now being measured with the use of techniques originally developed at NASA's Jet Propulsion Laboratory (JPL) to enhance television images transmitted by the Mars probes. Researchers at Duke University Medical Center had developed a technique using biplane cineangiography (x-ray movies taken at right angles to each other) to evaluate the heart's contractile action by tracking bifurcation points in arteries located on the external surface of the heart. By measuring the spatial distances between bifurcations in successive frames, the length of epicardial segments and changes in their dynamics could be determined. Thus, the technique could indicate whether an occlusion observed in a vessel also involves damage to the myocardial tissue. NASA's pattern recognition and image enhancement techniques enable a computer to recognize the bifurcation points in successive film frames and measure the changes in spatial distance in successive film frames.

The investigators hope that computer analysis of biplane cineangiograms will be used routinely within the next two years for evaluating candidates for coronary bypass grafts or repair of ventricular aneurysms. It can also be used to check on the results of surgery. Prior to the use of the computer analysis techniques, the bifurcation measurement technique was impractical in terms of time and manpower. The cineangiograph takes 120 frames per second–60 in each plane–so two heart cycles produce about 240 frames. The distance between as many as twenty bifurcation points is measured on each frame, thus requiring nearly 5000 calculations. The computer searches each frame for the predesignated bifurcation points and measures the distances as they change position from frame to frame, presently reducing the analysis time to less than 1 hour.

Through a NASA fellowship, the Duke investigator was able to spend a summer at JPL where he studied the image processing procedures which he has applied to this problem. The system is being used in a research capacity in conjunction with a Myocardial Infarct Research Unit, funded by the National Heart and Lung Institute.

Mechanical Stresses in Aortic Valves. It is desirable to fabricate an artificial aortic valve for a human heart which duplicates the mechanics of the normal valve. The normal aortic valve is composed of three leaflets which come together to close a circular opening. The leaflets are flexible; they flap open and closed on each heartbeat, nearly 40 million times/year. To design and evaluate a prosthetic tri-leaflet valve which can withstand many years of complex flexure, the dynamic stress-strain relationship must be known.

With the development of advanced fiber and composite material knowledge and technology through the National Aeronautics and Space Administration Program and the advancements made in the blood-prosthetic surface interface research under the auspices of the Artificial Heart Program of the National Institutes of Health, the fundamental keystones have been laid for the development of a tri-leaflet prosthetic heart valve.

Use of close-range stereophotogrammetry used by NASA will greatly aid the characterization of stress distribution and permit further explorations toward minimizing point stress.

It is anticipated that about 30 molds or 90 leaflets should be mapped to provide a statistical range of information. By photographing the leaflet motion at various flow pressures and velocities and studying the response of this record of the valve motion, it will be possible to minimize the turbulence of the flow through the valve. By studying the records of valve motion during the closure part of the cycle, it should be possible to design a valve with a flow velocity profile similar to that of the normal human valve.

Quantization of Heart Tissue Hardness. Post-mortem examinations of various organs of the human body can reveal not only the cause of death, but often show other conditions that were affecting the person at the time of death. Research at Tulane's School of Medicine, for example, showed unusual softening of the heart tissue in some patients who did not die of heart disease. The cause of this unusual softening was not known, but a number of factors were considered significant. There seemed to be a critical time period between the appearance of an infarction and a definite softness in the heart tissue. Reasons for this are being studied in experimental work, using rats whose blood is temporarily cut off from portions of the heart in order to determine changes in the heart tissue. Studies to determine whether this soft region can be attributed to any known condition of the human prior to death are also being conducted, but an accurate means of measuring softness of the heart tissue is needed. The researcher's use of a conventional eye tonometer for this purpose had not been successful because the results had not been reproducible.

A computer search of the NASA data bank turned up experiments conducted at the Marshall Space Flight Center (MSFC) on a variety of hardness testing techniques, which appeared to be applicable to the problem. Through discussions with MSFC program personnel, a number of techniques in current use at MSFC were found to be applicable.

NASA personnel indicated the type of instrument required for hardness testing. Of greater importance, they outlined the procedures necessary to obtain reproducible results. This information was then provided to the physician at Tulane's School of Medicine. He purchased the instrument suggested and incorporated the suggestions in his testing procedures. The experiments currently underway utilize the NASA techniques. The researcher has also determined the need for a tester for small areas, and the manufacturer has fabricated a special instrument according to his specifications to allow the testing of very soft, small regions. The results of this experiment are expected to add considerably to present knowledge of the effects of stress and physical trauma.

Bedside Biomedical Computer. The adaptation of the special computer programming techniques developed for the Apollo Guidance Computer will shortly result in the development of the Bedside Biomedical Computer (BBC). The BBC is intended to improve health care delivery to a wide population, and will place emphasis on cardiovascular care as well as biomedical problems which involve the measurement, analysis, and display of subject data in real time.

The computer system will consist of a small digital central processor, a magnetic tape and disc unit, a display/keyboard terminal, and associated electronics. The program structure of the BBC will resemble that of the Apollo Guidance Computer. It is specialized to the tasks of real-time computation and multi-programming, in other words, the computation of several programs on a multi-task, priority-interrupt basis. The program coding will be in assembly language, a single-instruction format which uses mnemomics to describe the computer's basis instruction set and storage locations. In order to conserve core storage and to simplify coding, calculations common to many programs will be combined in macro-programs. These are sequences of instructions that define higher-order operations such as transcendental functions, digital filters, and input-output routines.

The five major phases of the BBC's operation are: initialization, background monitoring, running estimate, batch processing, and hypothetical diagnosis. During initialization, the patient history is taken (or reviewed), the results of laboratory tests and pertinent off-line physical findings are entered, a preliminary identification of possible problem areas is made on the basis of history and laboratory data, the direct channels to be used during the analysis are defined, and the data channels are tested for open circuits, improperly placed leads, and noise artifacts. The background monitor detects and tallies arrhythmias and can provide, if desired, a continuous display of such frequently used parameters as average heart and respiration rates. This monitor continues independent of the major mode of the computer, i.e., the analytical program. Running-estimate programs can provide continuous output which is synchronous with the input. Examples of these programs include transformations of electrocardiogram (ECG) channels to form vectors, band-pass filtering of the phonocardiogram (PCG), and analysis of each carotid artery pulse as it occurs. Batch programs operate on a finite span of input data and do not necessarily produce an instantaneous result. These programs operate for a fixed time interval, providing answers after the fact. Examples

include discrete Fourier transforms of large data arrays, multi-variate correlation, and estimation of indirectly measured parameters. The hypothetical diagnosis is made on the basis of the results of the previous programs.

The goal of the system's operation is the diagnosis of cardiovascular disease in the examination subject, with a confidence level equaling or exceeding that of an experienced cardiologist, and without the use of invasive techniques. To achieve this goal, the BBC will perform a sequence of quantitative steps, displaying intermediate results (as requested) to facilitate the skilled physician's own process of arriving at a diagnostic conclusion. In the hands of a medical technician, the machine will perform an independent statistical analysis of its verbal and objective input. When operated by an experienced physician, the BBC will have the capability to interact with the physician, incorporating his opinions in the diagnosis and supplying him with additional information beyond the technician's understanding.

Bonding of Metal to Ceramic for Artificial Heart Energy Sources. In an effort to achieve an artificial heart system for man, the guiding objective is not only to prolong life per se, but also to provide full rehabilitation to the patient. To the extent that this goal can be realized, the patient should experience a minimum of discomfort and encumbrance. Ideally, the prosthetic heart system should be totally implantable, i.e., all its parts should be contained within the body. To satisfy the many physical and physiological requirements that must be met to realize a compatible, safe, and reliable system for long-term use, the artificial heart must exceed the stringent design and functional requirements demanded of high-performance aerospace systems.

An unanswered problem pertained to the type of energy-conversion system used to carry out the pumping function of the heart. A stack of piezoelectric disks with interspaced electrodes is now a leading candidate for this task. Upon the application of an electric field across the stack, each disk lengthens axially, and the net result is an additive linear movement in the axial direction of the stack. It is this force that will power the blood pump. Various methods of bonding the electrodes to the piezoelectric crystal exist. The rapid determination of the most satisfactory bonding methods can save much time (and occasionally lives) often spent on experimenting with unsatisfactory techniques.

An engineer at NASA's Langley Research Center had constructed several piezoelectric stacks for preliminary NASA-related investigations. He suggested two bonding techniques: one employed epoxy, and the other made use of mechanical loading. These techniques were evaluated by the National Heart and Lung Institute (NHLI) and the NHLI contractor who was investigating the piezoelectric stack concept. It was concluded that the epoxy bond appeared promising and that a piezoelectric stack should be constructed for additional evaluation. The NHLI contractor was put in direct contact with the Langley engineer who suggested the epoxy-bonding method. Following his advice, a piezoelectric stack was fabricated. This stack has good mechanical, as well as electrical, properties, and appears to meet the requirements for use as an energy conversion system in the artificial heart. The epoxy-bonded piezoelectric stack has now become an integral part of the artificial heart program.

Economical Vital Signs Monitoring System for Use with Conventional Nurse Call Systems. An economical, vital sign monitoring system is presently not available for use within nursing homes and rehabilitation hospitals, where high-risk patients are frequently found. An intensive care alarm system could alert patient care personnel when a high-risk patient's vital signs cease, so that immediate remedial action (e.g., external cardiac massage) could be taken to resuscitate the patient. Nursing homes and rehabilitation centers generally are not able to afford intensive care units featuring such alarms, due to high cost. Availability of an economical, reliable, and easy-to-operate alarm system which could be plugged into the existing outlet for the nurse-patient call system, would be a valuable alternative to the more sophisticated intensive-care alarm system. The alarm envisioned could be moved from location to location as needed, since it would merely plug into the conveniently placed nurse-patient call system outlet.

Such a monitoring system was developed at the request of one of the large Southwestern rehabilitation centers. Physicians at the rehabilitation center thought that the availability of an inexpensive vital-signs alarm, which could be used readily outside of the conventional intensive-care setup, would hold great

potential in large medical care institutions where intensive bedside nursing care is not always available. The system is based on a number of aerospace-related electronic physiological monitoring circuits which were applicable to this problem. Funds were provided by the Technology Utilization Program to fabricate a prototype of the cardiac/respiratory monitor (Figure 5) for evaluation in the rehabilitation center.

This device can monitor the EKG signal and by proper placing of the electrodes, it can also monitor respiratory information. When either component of the signal exceeds prescribed bounds, the unit will give an alarm via the local nurse-call system installed in the institution.

The monitor consists of three sections: an EKG Signal Conditioner, an EKG/Respiration Signal Processor, and an Alarm Unit. The EKG Signal Conditioner receives the EKG signal via either leads placed on a subject or through the EKG Isolator. The latter is a device that provides electrical isolation of the subject from the monitor and other equipment. The level of the EKG signal is adjusted to permit proper operation of the processor circuitry. An output is provided for monitoring and recording of the EKG signal. The EKG/Respiration Signal Processor receives the EKG signal and continually adjusts itself to the amplitude of the R-wave of each cardiac cycle. With proper placement of the EKG electrodes, the R-wave amplitude will vary directly with respiration and the processor will provide a signal dependent on the respiration of the subject. A change in the normal respiratory cycle of the subject or severe change in the EKG signal will be reflected in the output signal of the processor. The Alarm Unit will actuate an existing nurse-call system to give notice that some disturbance has taken place either with the equipment or the monitored functions of the subject. The unit will now actuate the alarm relay as long as the signal from the Signal Processor is within certain predetermined limits. The Cardiac/Respiratory Monitor is portable and powered by 115 volts ac (available in all rooms of most hospitals or rehabilitation centers). An adapter can be provided easily to go from the output of the monitor to the input of the existing nurse call panel.

EKG Isolator. Patient safety (especially during screening and monitoring procedures involving electrical equipment) has become of increasing concern. According to some estimates, as many as three patients are killed daily in U.S. hospitals as the result of faulty equipment, with electrical shock being responsible for many of the fatalities which occur.

Research has shown that an excellent means of isolating the patient from the hazards described above can be obtained by optical coupling techniques. However, until recently, such techniques have not been economically feasible—to the extent that manufacturers of medical instrumentation are willing to incorporate them into their equipment designs. An EKG Isolator developed at Marshall Space Flight Center promises to provide an economical solution to the need to be able to monitor a patient's condition without exposing him to possible severe, and potentially fatal, electric shock.

A light beam transmits the biopotential signal from the electrodes on the patient to the medical instrumentation. Whereas the NASA use has been in the area of electrocardiography, the invention is equally applicable for use with other instrumentation. The device employs conventional electrical contacts for connecting the patient to the electrocardiographic apparatus. The EKG signals are amplified and fed into an EKG isolator, which converts the signal from an electrical impulse to a light beam, using a light emitting diode. The signal is then relayed by a light beam from the diode to a photo transistor in the output portion of the isolator and, subsequently, to the electrocardiograph. This system provides complete isolation between the patient and the EKG instrumentation, thereby precluding electrical shock hazards. The device is presently being used in conjunction with the previously described (p. 25) vital signs monitor. Several manufacturers of electronic medical equipment have expressed an interest in the device.

Recording and Playback of EKG Signals via Home-Type Tape Recorders. Researchers at a major southwestern medical school, seeking an economical method for recording and playing back EKG (electrocardiographic) signals via low-cost home-type tape recorders, inquired if NASA had developed any appropriate techniques.

Many components of the EKG signal are considerably below 60 Hz, the lowermost frequency capability of such recorders. Consequently, before such signals can be recorded on the low-cost recorders, they must

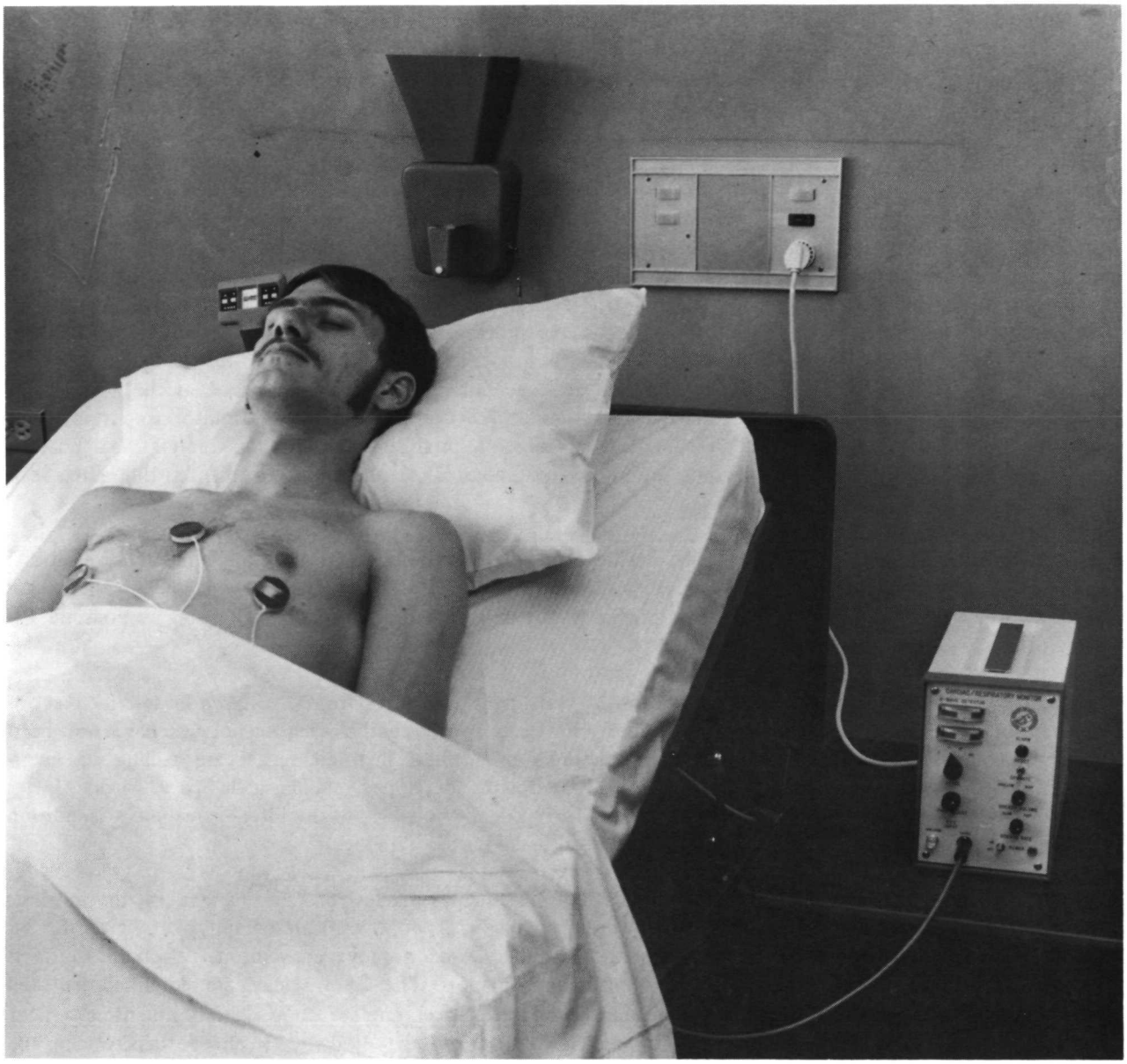
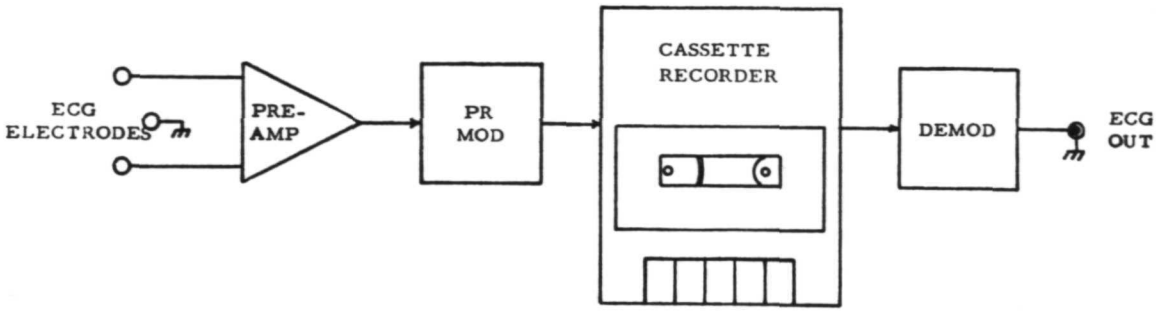
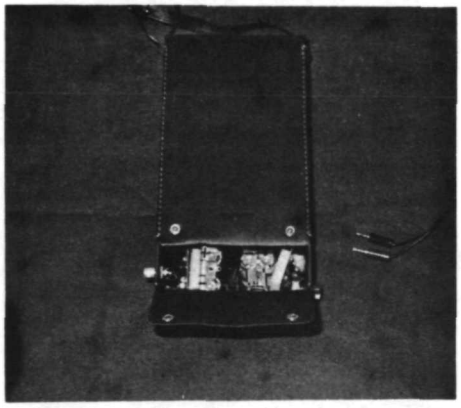


Figure 5. An Economical Vital Signs Monitor

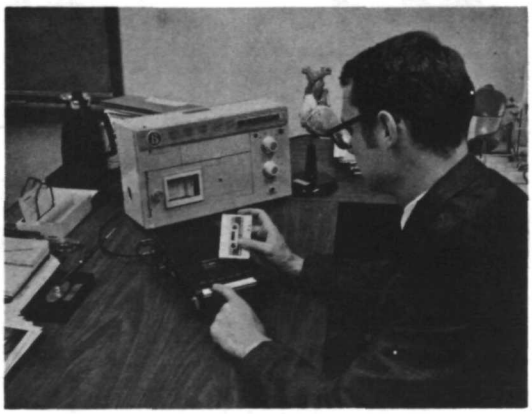


EKG Signal Conditioner

With the modified low cost tape recorder, the physician can record EKG in the patient's home.



A miniaturized version of the signal conditioner shown above is built into a low cost tape recorder.



After returning to his office, the physician can reproduce the EKG signals on the same low cost tape recorder (which has a built-in demodulator), feeding the signals into either a strip chart recorder or EKG apparatus.

The EKG recorder holds great promise for research applications such as monitoring changes in heart activity during exercise, stress, or other routine daily activity.

Figure 6. EKG Signal Conditioner

be conditioned and modulated to higher ranges by means of a subcarrier oscillator having (1) a frequency response from dc to 100 Hz, (2) a low noise figure, and (3) safe, portable battery operation. While there are portable analog recorders on the commercial market which are suitable for the purpose, they are exceedingly expensive ($1625 for one available model). In addition, they require a separate reproducer (at a price as high as $3500) to play back recorded signals into a strip chart recorder or EKG apparatus. This is beyond the financial resources of many physicians. They clearly need a recorder-adaptor which has a built-in signal conditioner/modulator for EKG signal input and a signal conditioner/demodulator for play-back of the recorded signals directly into an EKG apparatus, oscilloscope, or strip chart recorder, within an approximate price range of $100 to $200.

The advantages of having such a device readily available—as part of the physician's kit—are obvious. For example, by using the device (Figure 6), the physician could record the EKG of the cardiac patient within the privacy of his (the patient's) home—then replay the recorded signals into the EKG apparatus maintained in the physician's office and obtain the readout for evaluation at his convenience. The approach also has great potential for medical research. For example, the physician could equip a cardiac patient with the modified recorder and record the EKG as the patient goes about his daily routine, exercises, or undergoes stress. The patient would then send the cassettes containing the recorded EKG signals to the physician at intervals to permit evaluation of the data at his convenience. Since variations from normal EKG waveform patterns are considered good indicators of severity of heart attacks, reactions to various treatment programs, and likelihood of another heart attack, the availability of an economical means for monitoring EKG holds great potential for assisting in the battle to conquer heart disease through research.

A search of the NASA Data Bank resulted in retrieval of NASA Technical Brief no. 64-10171 entitled *Subminiature Biotelemetry Unit Permits Remote Physiological Investigations*. The Tech Brief described a high performance, biopotential monitoring circuit developed at NASA's Ames Research Center. The signal conditioning circuitry described was simple, relatively inexpensive to fabricate, and immediately applicable to the problem.

Telemetry of Electrocardiograms (EKG). Telemetry systems originally designed for monitoring the cardiac activity of astronauts and subjects under severe gravitational stress are now being widely used in civilian medicine. Researchers at Baylor College of Medicine requested assistance in developing a nonencumbering device for telemetering the EKG signals of cardiac transplant patients during the convalescent period. While excellent instrumentation for monitoring such patients' cardiac activity is available during the post-operative period (in the well-equipped coronary care units) an adequate system was not available for monitoring the patients during convalescence, when carefully controlled activity and stress was introduced. What the researchers desired was a small nonencumbering device, similar in size and configuration to a wrist watch, which could be worn by the transplant patient as he pursued daily activities during convalescence—with the device accurately transmitting the EKG signals. Such information permits precise monitoring of cardiac activity under the controlled activity and stress conditions characterizing the convalescent period, and can signal onset of the rejection phenomenon.

Minor modification of the NASA technology used in several other monitoring systems produced the telemetry system required by the Baylor researchers.

The prototype (Figure 7) was built with Baylor funds, successfully field tested, and forwarded to Baylor Medical School for clinical evaluation. The device is useful not only for monitoring cardiac activity for transplant patients, but other cardiac patients as well. The small size and convenience of wearing it on the wrist like a watch minimizes patient discomfort. Long-term application EKG electrodes developed at NASA Ames will also be evaluated as an additional component of the system.

The same circuit is now also being used in a cardiac rehabilitation program. Frequently patients have been conditioned into inactivity during the early recovery phase from cardiovascular disorders in order to avoid additional strain on the myocardium. Psychological rehabilitation and physiological rehabilitation is required to create a healthy myocardium and a healthy attitude. A planned exercise program fits these criteria.

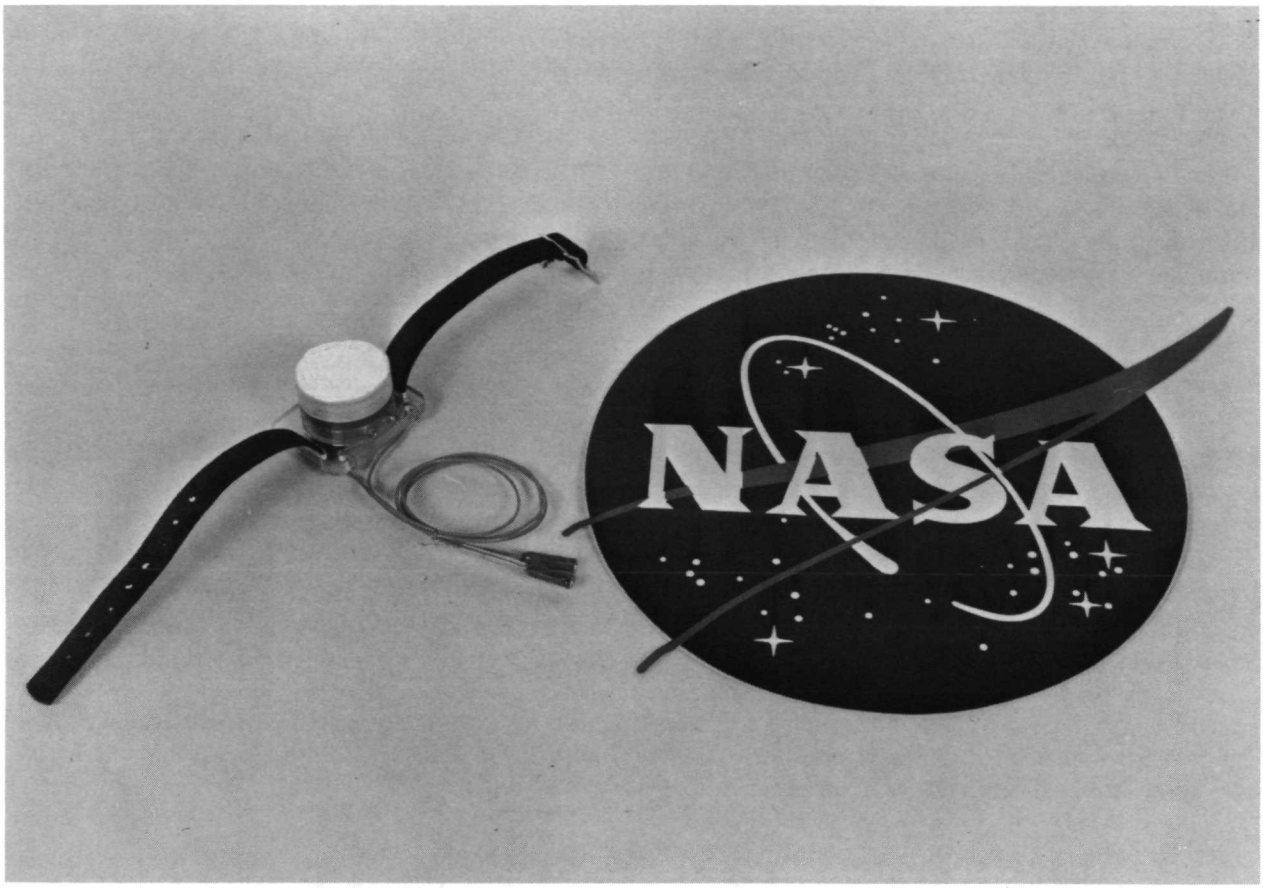


Figure 7. Wristwatch Size EKG Telemetry Transmitter

The physician sought to monitor heart rate and the electrocardiogram waveform from his exercising cardiac patients. Commercially available units did not have adequate low-frequency response to provide the required accuracy of detail in the "S-T" segment readouts. The NASA unit has proven highly satisfactory. Computer analysis of clinical EKG waveforms has yielded significant information on the "S-T" depressions, relating to reactions of a patient during exercise.

The superior resolution of the NASA circuit enables the patient to be warned as changes in the "S-T" segment indicate the patient is reaching his fatigue limit. Thus, the patient can be maximally exercised, yet warned before he overexerts himself.

Surgical Suite Contamination Control. Although improved sterile surgical techniques, careful supervision, and other precautionary measures have done much to reduce infection of patients in hospital operating rooms, contamination by airborne bacteria could not be effectively controlled. It was not until strict contaminant control requirements during the manufacture of aerospace components resulted in significant improvements in air handling technology, that a nearly particle-free environment could be produced. As briefly discussed in a previous section, the division of cardiothoracic surgery of Washington University Medical School and Barnes Hospital in St. Louis, Missouri, was among the first to apply modern, aerospace-developed clean room techniques to operating room use.

Through interaction between NASA and hospital administration personnel, NASA clean room data and commercially available ventilation components were utilized in the design, to achieve a class 100 control of airborne particulate matter i.e. no particles larger than 5μ and fewer than 100 particles per cubic foot ½μ or larger. The capacity of the system is 25 to 100 room changes per hour, a rate range achieved by use

of a special fan blade configuration that permits a wide latitude over the pressure-volume efficiency curve. Maximal flow rate and linear velocity are 7,300 cubic feet per minute and 1.28 feet per second respectively. Net positive pressure relative to the adjacent induction, heart-lung, sterilizer, and monitor rooms is maintained by manually adjustable dampers and back-pressure responsive valves in the volute chamber discharge plenum.

The system contains three graded disposable HEPA (high efficiency particulate air) filters with efficiencies of 40 percent, 94 percent, and 99.97 percent (Figure 8). The temperature and humidity are very closely controlled. The conditioned and filtered air is introduced into a false plenum above the ceiling and distributed through 96 square feet of perforated, epoxied aluminum panels.

Bacteriologic air sampling studies were performed for 3½ months prior to renovation. These studies are now being repeated at different airflow rates. Particle counting has been performed with a Coulter Model 550 monitor. Other special precautions in force in the room's operation are the extensive use of Barbac gowns and drapes to reduce lint; the absence of nonessential tables, hampers, stools, and personnel; and the stationing of the monitoring and blood-gas analysis personnel in a separate room which communicates with the operating room by a sliding pass-through Lexan window. Audio-communication is used for feedback of the test results. All supply cabinets are filled from behind to eliminate unnecessary traffic.

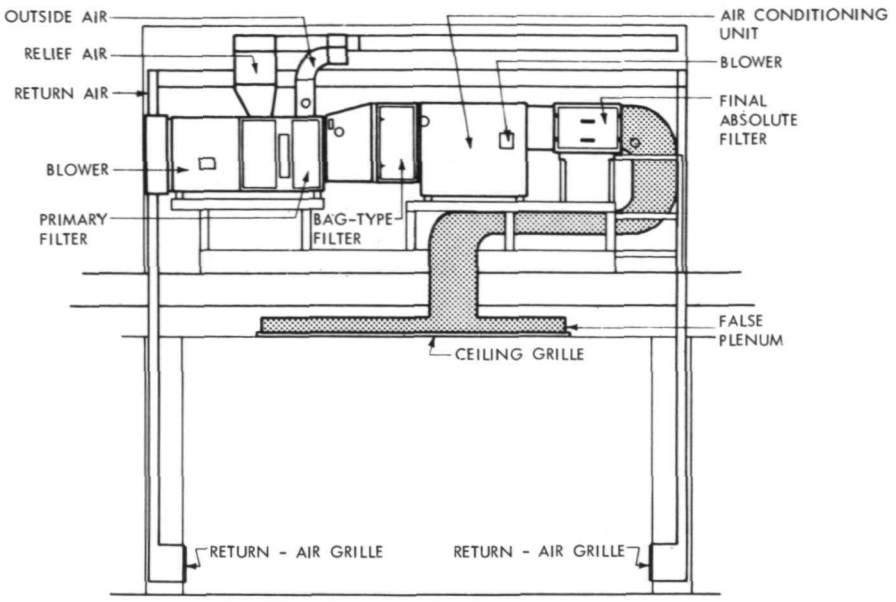
The cardiothoracic surgical suite is used for patients ranging from the newborn to the very elderly, with approximately 75 percent of all operations, open-heart surgery, and the remainder of a "closed" palliative nature. During the first six months that the renovated operating room was in use, no significant wound or prosthetic material infection occurred. The system has yielded high-flow ventilation with superior cleanliness and excellent thermal, humidity, and noise characteristics. There is also a growing conviction among orthopaedic surgeons that the risk of postoperative infection in total hip joint replacement operation is substantially lowered if performed in an atmosphere of HEPA filtered air.

A special conference on the use of clean room technology in surgical suites was held at Kennedy Space Center in May 1971. The proceedings of this Symposium on Clean Room Technology were published in the fall of that year.

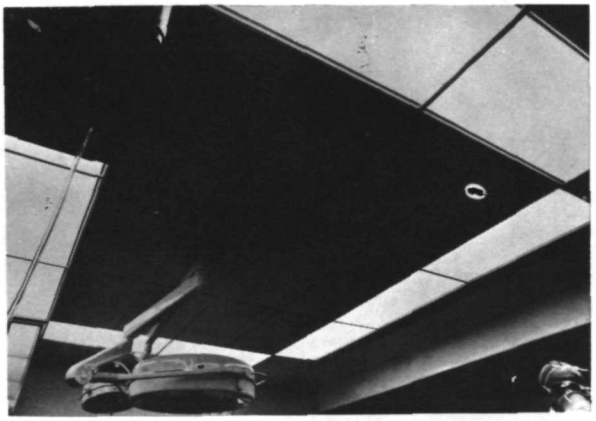
MEDICAL INSTRUMENTATION: GENERAL

Beta-Radiation Catheter Probe to Monitor Cerebral Blood Flow. There is a need for an improved technique to continuously monitor the cerebral blood flow of head injury patients over an extended period of time. Present techniques require inhalation of a radioisotope and the frequent withdrawal of many blood samples for analysis to determine arteriovenous concentrations of the isotope. Monitoring of cerebral blood flow is necessary to determine therapy effectiveness. This current technique produces patient discomfort and requires cumbersome equipment which must be maintained in a sterile condition. It provides few data points for assessing the blood flow, although continuous determinations over extended time periods are needed for optimum analytic effectiveness.

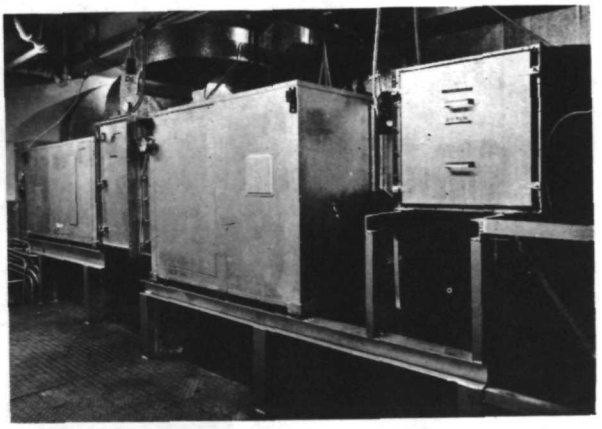
A semiconductor radiation probe capable of continuously monitoring blood flow by detection of weak beta-radiation from the isotope was developed by NASA. It can be mounted in a small double lumen (channel) catheter, making it easy to insert at the proper point in the bloodstream. The probe (Figure 9) has a low signal-to-noise ratio and provides good measurement of the spatial and energy distributions of radiated electrons and protons. The use of this probe will enable the physician to continuously obtain data. One catheter-mounted probe would be placed in the carotid artery to monitor the isotope concentration in the blood being supplied to the cerebral area. (A lumen located near the tip of the radiation probe would allow one blood sample to be taken for blood gas analysis). A second catheter-mounted probe with appropriate lumen would be placed in the jugular vein to get a similar measurement on blood flowing from the cerebral area. From the data collected at these two points the cerebral blood flow is easily determined. The blood flow data are indications of the extent of head injuries, progress towards recovery, and the effectiveness of therapy.



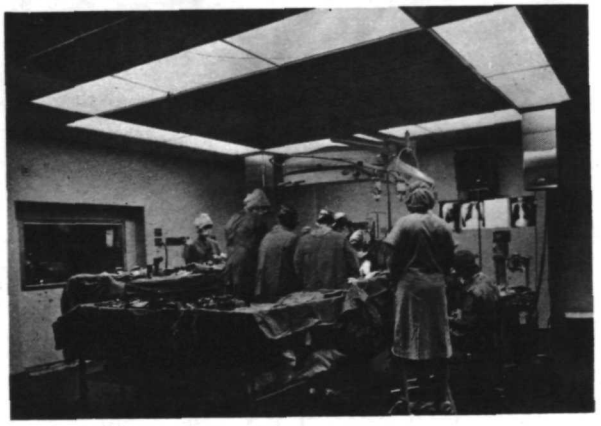
Schematic Side View of Ventilation System for the Operating Room. Capacity is 100 room changes per hour.



Clean air distributes through perforated epoxy-coated panels with a maximum linear velocity of 1.27 ft/sec. A service column is in the upper left corner.



The ventilation system is located in a previous viewing gallery. The 99.97% efficient HEPA filter is on the right.



Ceiling grills cover patient and instrument areas. The monitor room window is on the left.

Figure 8. Surgical Suite Contamination Control by Laminar Flow Techniques

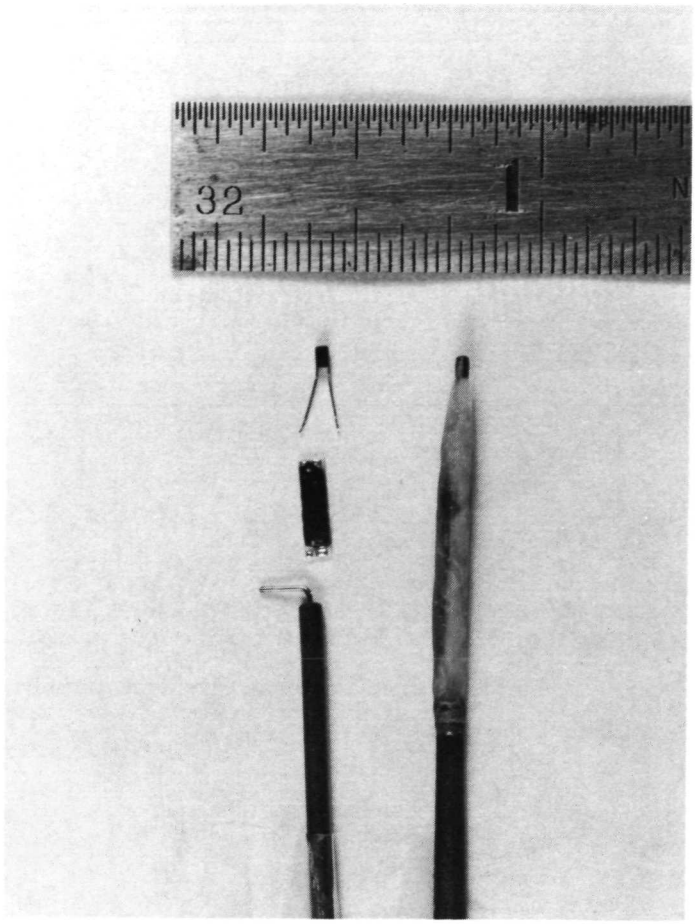
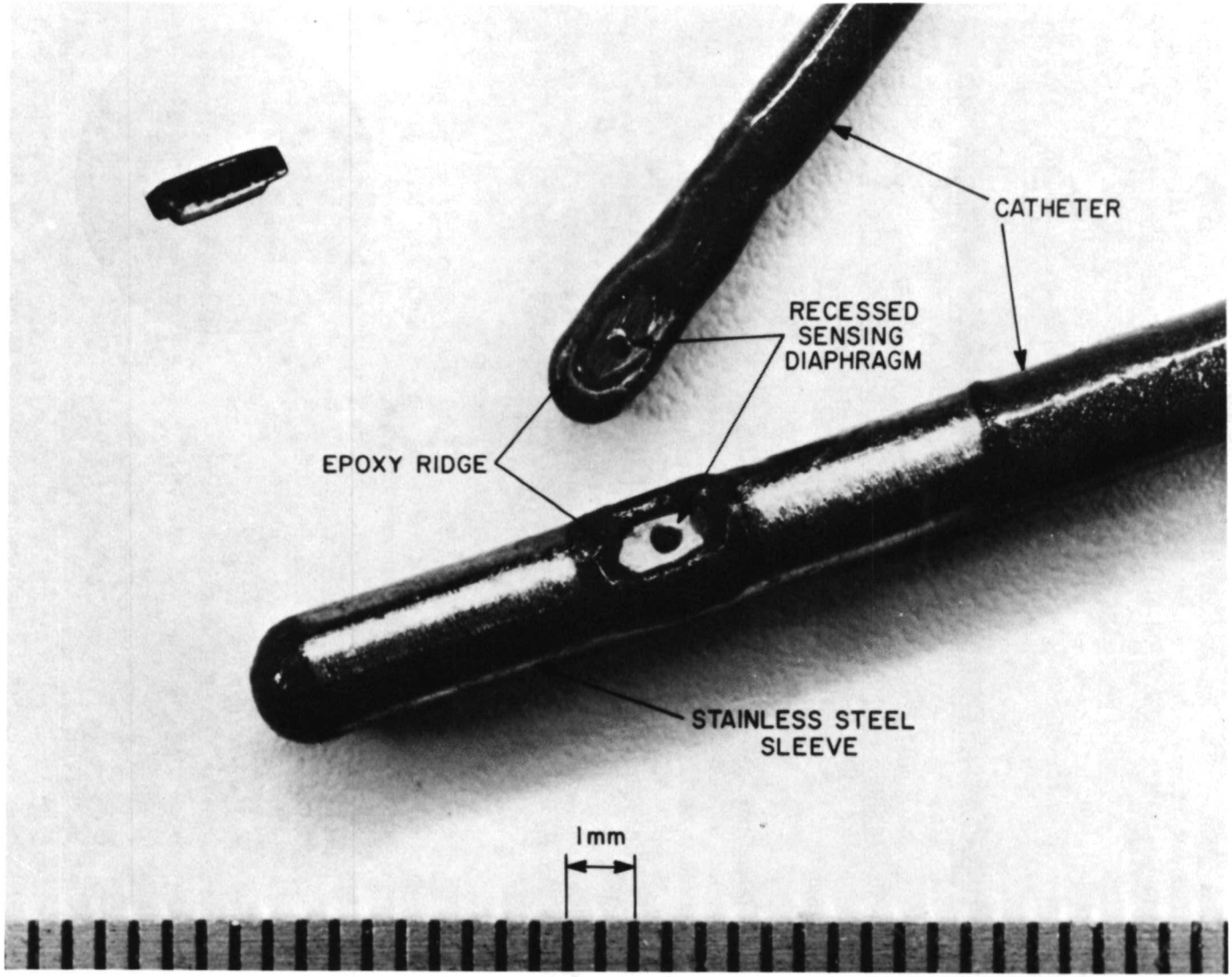


Figure 9. An Exploded View of the Beta Radiation Catheter Probe.

The radiation probes are being mounted in suitable catheters by the Southwest Research Institute which will also provide the investigator with the necessary electronic devices. They are working to develop a plastic coating to separate the radiation probe from the blood while not absorbing too much radiation. The system will then be tested in several animals before being given to the physician for clinical trial and evaluation.

Tunnel Diode Transducer Used as a Biomedical Sensor. The human body is dependent on several fluid transport systems for moving nutrients, gas, enzymes, hormones, and wastes from one part of the body to another. Blockage or excessive pressure within one of the fluid transport systems can result in various pathological conditions. Diagnosis and determination of proper therapy could be improved by a small pressure transducer (diameter less than 1 mm) with the proper sensitivity and range. Inserted into a vein or artery, or any of the other fluid transport systems, it would be valuable in assessing the condition of the circulatory, cerebrospinal, lymphatic, and urinary systems.

Research and development at NASA's Electronics Research Center developed a suitable pressure sensor (Figure 10). New semiconductor fabrication techniques were utilized for a transducer with resolution of greater than 0.1 mm Hg with an overall diameter of less than 1 mm and low power requirements, which has been designed, fabricated, and tested. After the NASA Electronics Research Center closed, the researcher formed his own company, Device Research, Inc. which has made the transducer available commercially. It will greatly aid many investigators concerned with measurement requirements. The frequency response of this device is flat to greater than 4,000 Hz.



Originally developed by NASA/Electronic Research Center and now commercially available, represents a significant advance in the state-of-the-art.

Figure 10. Tunnel Diode Pressure Transducer

The high-frequency response allows the detection of high-frequency heart and valve sounds and permits more accurate measurement of intravascular and intracardiac blood pressure waveforms. Mounted on the tip of 100 cm catheters, the pressure transducer may be introduced into an artery or vein through a standard 17-gauge thin-wall needle (ID=1.1 mm), a size routinely used for humans. It will probably replace techniques which use fluid-filled catheters for measuring ventricular heart pressures and those procedures which require cutdowns on arteries for the insertion of the catheter. Measurement techniques currently in wide use employ a fluid-filled catheter to transmit internal pressures to external transducers. These are subject to distortion and error introduced by the long fluid column through which the pressure pulse must propagate before being measured. The improved device will allow physicians to obtain a more accurate indication of the intracardiac pressure while reducing risk to the patient. Figure 11 illustrates comparative characteristics of the tunnel diode transducer and other commercially available transducers.

Three pressure transducer systems have been made available to medical researchers who have expressed interest in such a device. It is currently being used in studies on an artificial heart, pediatric cardiology and myocardial physiology.

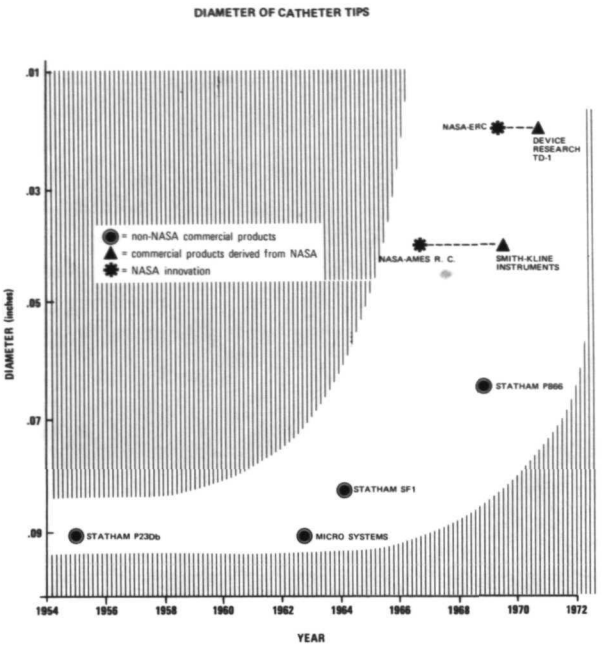
The National Heart and Lung Institute has used the tunnel diode transducer to measure directional stresses within the myocardium (heart muscle) of a calf. The researchers have been able to obtain data which were never before measurable by recording hydrostatic pressure. The measured myocardial stresses are found to vary under conditions such as a local infarction and various drugs. Although these studies have begun only recently, the early results are quite promising and considerable effort will be directed towards further investigations.

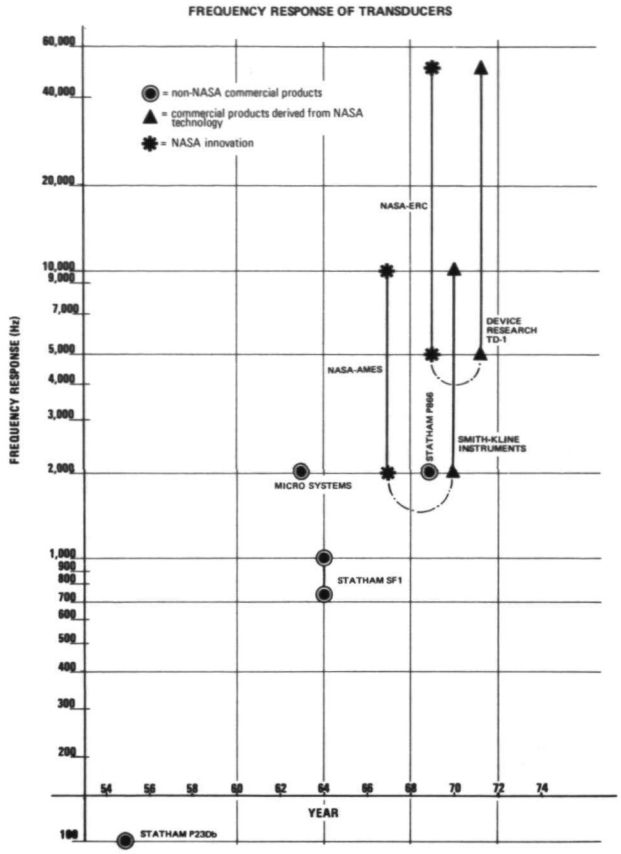
Remote Medical Diagnostic System Via Television. Telemedicine systems for providing physician-monitored medical services in rural areas and in inner-city ghettos are now under active study. A pilot program under the direction of D. Kenneth Bird, at the Logan International Airport in Boston, and the Massachusetts General Hospital (MGH) is now in operation. This system uses a three-mile closed circuit television link between MGH and the airport to provide remote medical services. The federal health agencies are interested in expanding the telemedicine systems to offset the physician shortage and to extend health care facilities. However, a major technical problem is the lack of a television system suitably designed to meet the medical diagnostic needs and also be compatible with existing telephone transmission lines.

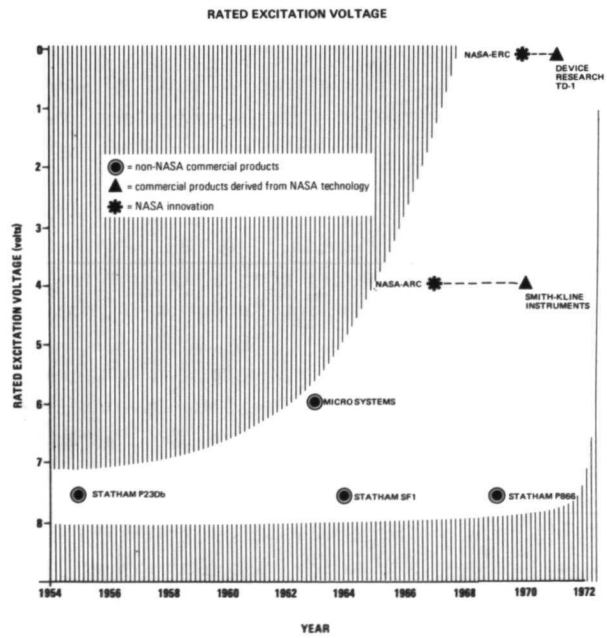
In conjunction with the NASA funded National Academy of Engineering's Committee on the Interplay of Medicine and Biology and its subcommittee on Remote Diagnosis and Treatment, Manned Spacecraft Center personnel were approached regarding possible investigations into the television problem. Subsequent discussions with other medical personnel indicated a communications system study into the commercial transmission links, and medical evaluations or ratings of pictorial data were required before a television system could be properly defined.

A program has now begun to investigate and define the communication and medical requirements for a television system operating between a central medical facility (hospital) and remote clinics. A television system, compatible with existing transmission facilities, and meeting the medical pictorial requirements will be built and tested.

This research study will be divided into two phases: (1) the television requirements will be ascertained through a coordinated program of medical doctors' rating and evaluating pictorial medical data. Such parameters as picture resolution, colorimetry, motion rendition, and video bandwidths will be rated using a representative cross-section of medical patients. In addition, a systems study of the bandwidth capabilities of existing telephone lines, optimal modulation schemes, bandwidth compression techniques, and financial cost tradeoffs will be performed. The results of these studies will define a television system designed for telemedicine systems. (2) The second phase of the program will be to build and laboratory test the television system. Final testing of the television study would be in medical care facilities.







Tunnel diode pressure transducer developed by NASA Electronic Research Center represents a significant advance in the state-of-the-art. Its smaller diameter, high resolution (0.5 mm Hg), broad frequency response, low excitation voltage, and controlled thermal zero shift should improve the quality of data available to physicians and researchers in studies of the cardiovascular, cerebrospinal fluid, and urinary systems.

Figure 11. Characteristics of Miniature Pressure Transducers

Improved Reliability, Quality Assurance, and Safety of Hospital Bioinstrumentation. Hospital medical administrators and other organizations evaluating hospital procedures have indicated that bioinstrumentation in hospitals is not as reliable as the needs of hospitals dictate, nor as accurate as the medical profession requires. The potential for errors in data and the added potential for physical harm to patients dictate that instrumentation used in hospitals should be as reliable, accurate, and of as a high quality as the current state-of-the-art allows.

A subcommittee of the National Academy of Engineering had reviewed the NASA reliability, quality and safety program technologies and was impressed with their potential application to the solution of hospital equipment deficiencies. Accordingly, the subcommittee recommended an effort be undertaken. The American Hospital Association has expressed an interest in this project and will join in a joint cooperative study. A program was suggested which eventually would improve civilian health care by improving the accuracy, reliability, quality, and safety of hospital bioinstrumentation by employing management techniques and control procedures which have been developed for space-qualified hardware.

The Manned Spacecraft Center's experience with the reliability, quality assurance, and safety aspects (R,QA,&S) of bioinstrumentation which has been designed, developed, and space qualified for use in Mercury, Gemini, and Apollo Programs demonstrates that its personnel is qualified to perform this task.

The program will determine the most advantageous way of applying the management techniques and control procedures which have been developed for space qualified biohardware to hospital bioinstrumentation.

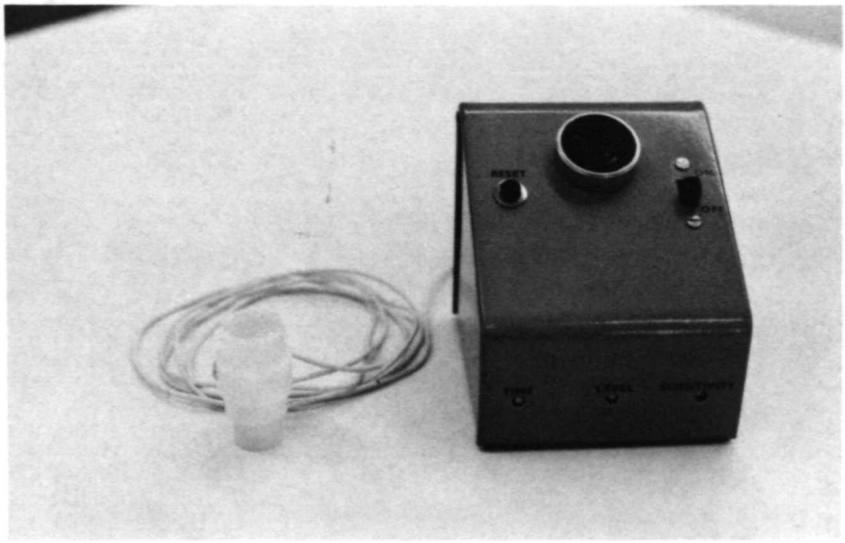
The program will necessarily have to be subdivided into several phases. The first phase will be to identify and study the basic problems which may exist and to develop options in solving these problems by utilizing the various available R, QA, & S disciplines. There will be appropriate coordination among Government agencies, equipment manufacturers, hospital administrators and other representatives of the medical community. The second phase will be to document the existing conditions to the medical community and their comparison with present aerospace practices. This study should result in a series of standards and procedures which, if implemented, would lead to more reliable, higher quality hospital bioinstrumentation.

Newborn Infant Respiration Monitor. Researchers at a West Coast children's hospital asked NASA to assist in the development of an instrument that indicates respiratory arrest in infants. Respiratory arrest frequently occurs right after birth. The infant simply ceases to breathe and death rapidly ensues unless prompt remedial action is taken.

A means of monitoring the respiratory function of newborn infants, particularly of those who are believed to have physiological impairment of the pulmonary system, was urgently needed. The instrument would at the same time relieve nursing personnel of this function and free them for equally urgent duties.

A search of the NASA Data Bank produced several documents describing techniques for automatic monitoring (NASA Tech Briefs 64-10365 and 64-10170). After undergoing modifications, such as replacing the EKG preamplifier described in the latter reference with a thermistor bridge network, the completed system provided a very economical, reliable means of monitoring respiration.

Input to the system is provided by a sensor attached with a microminiature connector to the infant's airway. This permits effective operation of the monitor and allows for autoclave sterilization of the inserted airway. The redesigned transmitter (Figure 12) hangs on the isolette and transmits a pulsating signal to the nurse's station, usually located outside of the nursery. Interruption of the signal indicates the infant is having respiratory problems. In this particular case, the Problem Originator preferred a continuous signal to indicate continued breathing rather than an automatic alarm feature to announce respiratory arrest. The Problem Originator indicated that the quality of the continuous tone transmitted can, to the experienced ear, provide valuable information concerning the infant's respiration. Since several of these units may be used simultaneously in one room, the units have now been modified to provide an alarm in case of respiratory arrest, as several tones were confusing to the monitoring nurse.



The Respiration Alarm detects the thermal fluctuation of the air as a patient is respired. When a failure is detected, an audible alarm is actuated. This will eliminate much of the monitoring which is presently done by a nurse and will free her for other duties.

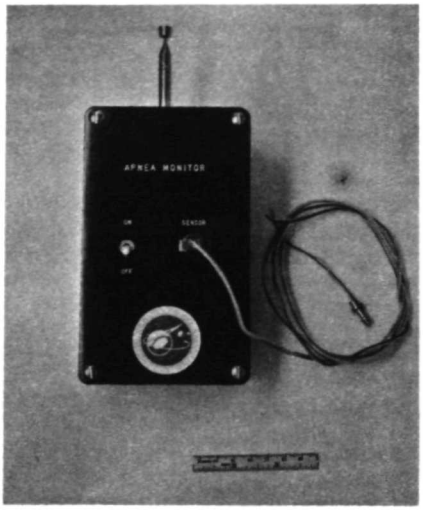
Figure 12. Newborn Infant Respiration Monitor

Breathing (Apnea) Monitor. To ease breathing in infants, comatose children or adult patients, surgical implantation of a tracheotomy tube in the windpipe is sometimes required. If the tube is clogged and cuts off breathing, brain damage or death can result within 2 to 4 minutes. Use of the tube ordinarily requires a nurse to check the tube constantly and take immediate corrective action if necessary. Integrated circuitry, designed and fabricated for aerospace use by NASA's Ames Research Center, has been incorporated in a small device to monitor the temperature of air passing through the tube, and to actuate an audible/visible alarm within 20 seconds of any change (Figure 13). The alarm can be seen or heard at the nurse's station, or in another room if the patient is at home.

The breathing monitor is based on an automatic airflow surveillance system that was developed by NASA scientists. It has a temperature sensor/FM transmitter which is attached directly to the tracheotomy tube so that the inspired and expired air flows directly over a thermistor temperature sensor. Changes in the airflow temperature produce changes in the sensor resistance. An FM receiver records the respiration signal which in turn triggers the alarm system if required. The voltage changes caused by respiration are amplified and actuate an electronic switch. The switch provides a reset pulse for each respiratory cycle of sufficient length, which is determined by setting the amplifier gain control. The reset pulse discharges the capacitor which serves as the timing element of the alarm control. If the capacitor does not receive a reset pulse for a preselected time (arbitrarily chosen as 10 seconds), an alarm control actuates an audible/visible alarm. The device, fabricated at NASA's Ames Research Center, is on loan to the Institute for Rehabilitative Medicine in New York for clinical evaluation.

Measurement of Respiratory Function of Free Moving Children. Respiratory diseases are the major cause of illness in children from infancy through adolescence. Some of the more serious respiratory diseases are asthma, cystic fibrosis, and bronchitis. A great deal of research is presently being conducted into the causes, diagnosis, and cures of respiratory diseases.

One valuable index for diagnosing lung disease in children is their respiratory pattern while engaged in quiet play. If this rate is studied for the same patient over a period of months, much information can be gained about the condition and changes in condition of the patient's lung. The respiration pattern is important because it is directly related to lungs; the body will adjust to the disease by breathing more shallowly and more rapidly. In the case of asthma, a disease which restricts the airflow, the patient will breathe more slowly and more deeply.



The Apnea Monitor

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

Sketch showing the apnea monitor in place. Infants with whom the device will be used are generally so critically ill that they are placed in isolettes and do not require restraining arm straps to prevent removal of the monitor.

Figure 13. Infant Apnea Monitor

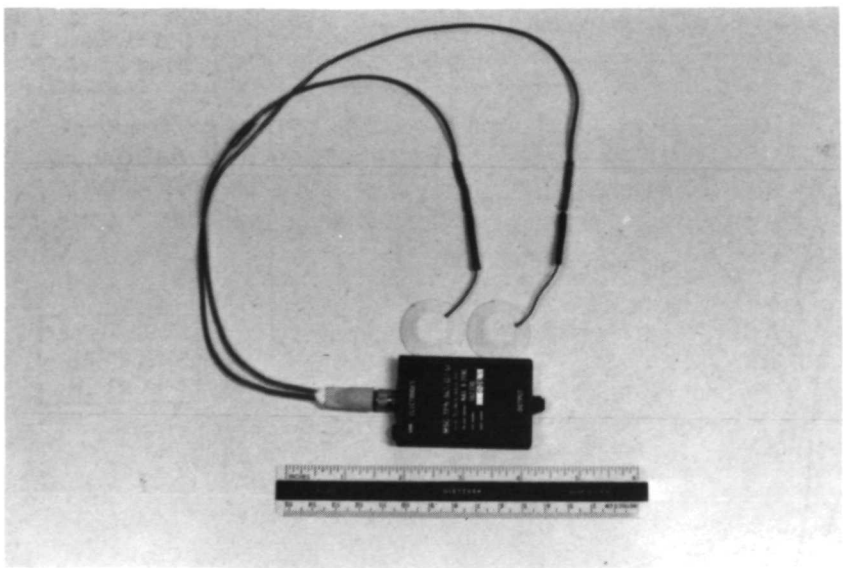
A physician at a southern medical school was conducting a study of respiratory patients ranging in age from infancy to adolescence. It was necessary that the pattern measurement method would not encumber the child so that he would be free to engage in quiet play. It was also desired that the data be transmitted to signal processing equipment by a small unit attached to the child. The respiration rates ranged from 12-80 breaths per minute, and precision and accuracy of 0.1 breaths per minute was required.

The physician posed the problem to the Manned Spacecraft Center (MSC). MSC personnel suggested the use of the Gemini impedance pneumograph (ZPN), which was still available. The impedance pneumograph was designed by NASA to measure respiration rate and respiratory volume during a manned space flight. Although the unit had been slightly modified for the Apollo missions, the Gemini equipment appeared capable of solving the stated problem. A search of the commercial literature determined that, although certain commercial impedance pneumography equipment was available, none was as small as the NASA equipment.

The Gemini ZPN was obtained to test its suitability. When these tests proved satisfactory, it was decided to implement the telemetry portion of the problem with commercial telemetry equipment. During the preliminary tests it was determined that not only was respiration rate information available, but also that the clean waveforms produced by the impedance pneumograph allowed both inspiratory and expiratory times to be determined.

The impedance pneumograph was mated with a commercial telemetry system in a breadboard model. Initial tests on this system allowed the subject a range up to 40 feet from the antenna, and a multiple antenna system was installed which allowed the children to roam freely throughout the clinic area. The unit has now been packaged into a small final unit that will facilitate clinical use (Figure 14).

This application of technology will enable the Problem Originator to obtain valuable clinical information on the respiratory patterns of children who are moving freely and unimpaired in a quiet play environment. This information can be used both for diagnostic purposes and for obtaining baseline information on respiratory rates of small children. Baseline information presently obtained is believed inaccurate because the act of taking the respiratory rate modifies involuntary respiration. The Problem Originator intends to publish the results from his experiments so that they will be available to the medical community.



Allows a physician to record a patient's respiratory rate and inspiratory and expiratory times while permitting the patient to move about freely and unimpaired.

Figure 14. Impedance Pneumograph Signal Conditioner

Lung Sound Detection. A method for studying respiratory diseases in children utilizes a technique developed originally to analyze sounds of aircraft engines.

As previously stated, the major cause of illness in children from infancy through adolescence is respiratory disease. The serious forms include asthma, cystic fibrosis, and bronchitis. Significant research is being conducted both in the causes and cures of respiratory diseases and in better methods of diagnosis.

One useful and simple method to determine whether a portion of the lung is performing properly is to listen to the sounds made by the airflow. This is usually done with a stethoscope, but unfortunately only one section of the lung can be heard at a time. To compare sections of the lung, it would be better to be able to compare the sounds generated by a section of the lung with the sounds generated by the symmetrical counterpart in the other lung.

The basic problem is to detect the sounds from two sections of the chest wall by microphones and to display the sounds graphically. Comparison could then be made on the amplitude, frequency, and time interval between appearance of the two sounds. The frequencies of interest are 50 to 15,000 Hz. Breathing rates normally are 25 breaths/minute, although a range of 12 to 80 may occur. The amplitude of the sounds is not known.

The Problem Originator, a physician, wanted to measure childrens' respiratory performance from infancy to adolescence in a hospital clinic. In the basic description of the problem, he desired a strip chart recorder and microphone combination. However, he was advised that far more information could be gained using spectral analysis such as had been used in analyzing aircraft engines. Unfortunately, there is a difficulty in that real time spectral analysis is required because of the rapidly changing information in lung sounds. Thus, a simple scanning filter spectral analysis technique was insufficient because of the time response required. A computer search of the NASA data bank revealed that NASA had done considerable work in spectral analysis–particularly as pertains to aircraft engines and vibration–for vibration testing of spacecraft. The system, shown in Figure 15, is composed of a microphone, amplifier, and an envelope detector, the output of which can be displayed on a dual-channel strip chart recorder. This dual-channel system would allow time delay measurement for respiratory sounds between similar lobes. In addition, the output of the amplifier could be fed into a spectral analyzer similar to that used in aerospace applications.

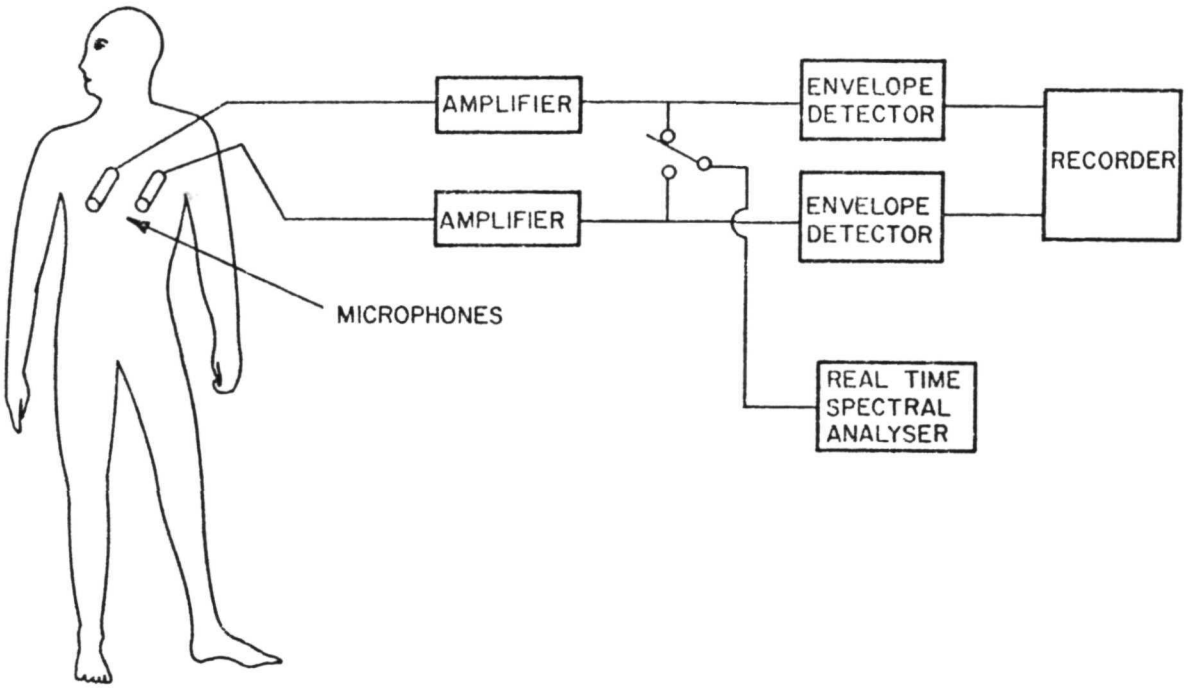


Figure 15. Block Diagram of Lung Sound Analysis System

The NASA contractor who supplies the spectral analysis equipment is presently discussing a joint investigation with the physician on a spectral analyzer specifically configured for respiratory analysis. The contractor has agreed to furnish the equipment at a fraction of the normal cost; in return, the physician will provide the medical consultation necessary to develop this new product. This significant technology application will result in a new diagnostic tool of particular importance in the pediatric field for detection of asthma, cystic fibrosis, and bronchitis. The equipment has been delivered to the investigator and early results are quite promising.

Ultra-low Frequency Bandpass Amplifier for Use in Detecting Gastrointestinal Electrical Potentials. Electrical potentials generated by living organisms have long intrigued medical researchers, since unique electrical depolarization patterns are indicators of organ function and dysfunction. The widespread use of electrocardiograms, electroencephalograms, and electromyograms provide examples of the valuable application of biological electrical potential phenomena to clinical medicine. There is reason to believe that electrical potentials generated by the smooth musculature of the gastrointestinal tract can be equally useful. Researchers at a southeastern medical school are engaged in a large-scale research program designed to investigate possible correlations between various gastrointestinal disease states and electrical potential phenomena centered in the gastrointestinal tract. To date, such potentials have been related clinically to such states as hypothyroidism, hyperthyroidism, and level of morphine ingestion.

Research in this area has been hampered by the nonavailability of a suitable, economical ultra-low frequency bandpass amplifier. Commercially available instruments, having an excess range in filtering and gain, tend to be very costly. A device which provides appropriate signal conditioning in the specific area of interest was needed. A search by the NASA data bank revealed that NASA's Ames Research Center had developed for physiological research a tunable bandpass filter with variable selectivity. The basic circuits were obtained for use in fabricating a stable, active RC bandpass filter having continuously variable noninteracting control of center frequency, Q, and center frequency gain. It was capable of providing reliable signal conditioning for the special application described above. The device has been built and is now being used in an active research program.

Oculometer. Visual performance and behavior studies will be assisted by a device originally developed at NASA's Electronics Research Center for pilot performance studies. The unit, called an "Oculometer", is an electro-optical instrument which measures human eye pointing direction, pupil position, pupil diameter, and blink occurrence. Unlike earlier devices developed for this purpose, the NASA oculometer does not require the subject to wear contact lenses or mirrors on his head, nor does it require the subject's head to be firmly anchored in one place. It is small enough to be mounted in the dashboard of an automobile or in the instrument panel of an aircraft.

The oculometer now seems ideally suited to studying the visual scanning difficulties in one side of the visual field that are often encountered in the hemiplegic patient. (These scanning difficulties interfere in the processing of visual information. They prevent the hemiplegic from singling out pertinent cues that are involved in visual-perception tasks). Some patients tend to ignore visual stimuli located on their impaired side; others render false information on the impaired side; while still others compensate by turning their heads. These difficulties affect the patient's cognitive functioning and have consequences for activities in his daily life, such as reading, dressing and manipulation of his wheelchair. There is also a relationship between scanning difficulties and accidents in the hemiplegic population.

Rehabilitation specialists plan to explore the movements of the eye while the patient is viewing printed matter, geometric forms, and pictures. This information will permit comparison of hemiplegic patients with normals and hopefully will permit characterization of hemiplegic eye movements. The apparatus or measuring technique should permit collection of the following information when the patient is reading a newspaper or looking at a picture:

1. Is scanning initiated on the left or right side?
2. Is the upper or lower half preferred?
3. Does the eye perform horizontal or vertical excursions with greater frequency?
4. Is the excursion distance greater in the horizontal or vertical plane?
5. Is the number of fixations greater on the left or right side?

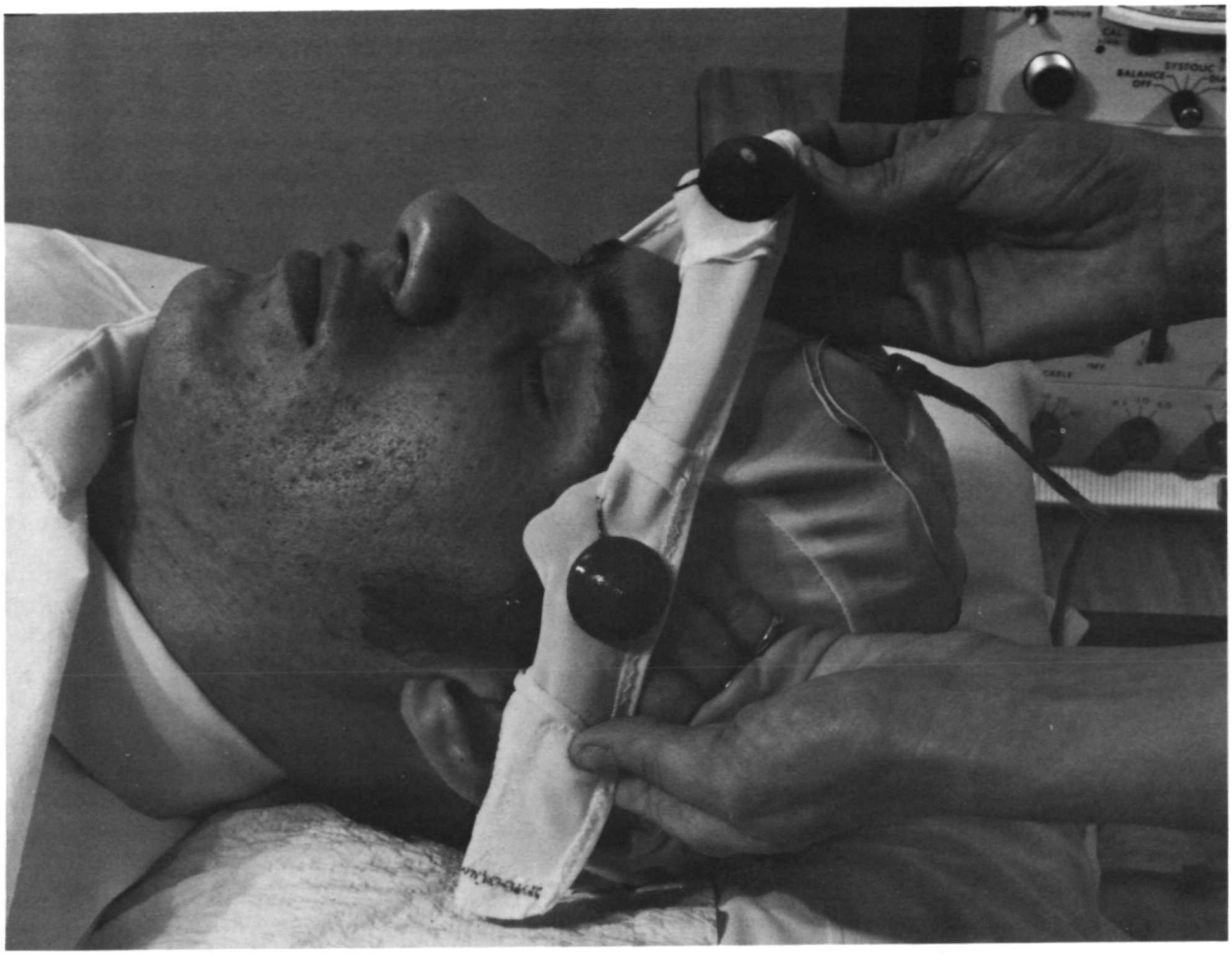


Figure 16. Soft Cap EEG Electrode Assembly

As the apparatus will provide a graphic picture of the hemiplegic's eye movements as a function of time, it will aid in analyzing the specific visual-perceptual difficulties of each patient. It will also assist in devising appropriate individual program of retraining, suitable for each hemiplegic's need.

Brain Wave Sensor as Diagnosis Aid. A brain wave [electroencephalograph (EEG)] sensor and radio transmitter system, developed for space medical research with test pilots, appears to allow major improvements in diagnosis and treatment of schizophrenic mental patients. Scientists at NASA's Ames Research Center and at Agnews State Hospital, a mental hospital of the California Department of Mental Hygiene, are working together on the system. It is comprised of a radio-sensor system with a computer. The new method is under clinical test on mental patients at Agnews Hospital and has shown good preliminary results. Although advances in modern drugs have greatly improved the treatment of many emotionally disturbed individuals, there may be a subgroup of schizophrenics for whom nondrug therapy is better. The problem has been to distinguish these individuals from those for whom drugs are more appropriate.

The headset installed EEG radio-sensor system is light and comfortable and does not frighten disturbed patients. The diagnostic method is based on research in patient brain wave responses to light stimuli. For diagnosis, the patient is fitted with the comfortable, wire-free headset and seated in a darkened isolation room. He watches light flashes of varying intensity, and his responses are then radioed to the computer for analysis. The technique uses differences between a patient's brain wave responses to a series of light flashes as a way of distinguishing between various types of behavior disorders.

Because of the advantages of this system, doctors now believe they can use it to distinguish between schizophrenics needing immediate large doses of tranquilizing drugs, and those patients who can be treated without drugs.

Past diagnostic methods using brain waves have required the insertion of needle electrodes under the scalp, or shaving of a portion of the scalp for electrode contact. With seriously disturbed schizophrenic patients, these disquieting procedures–required immediately on admission to the hospital–usually were not possible. The Ames-developed system, however, employs only a headset consisting of a light wire clip fitted with two small electrodes which sense brain waves with no scalp preparation. The headset also carries a tiny battery-powered radio transmitter to broadcast the brain signals to the computer for analysis. Because data is radioed, the absence of wires prevents undue anxiety about shock therapy by some disturbed patients who have either undergone or fear such treatment. The allaying of such fears is important for good, early diagnostic work.

The sensors and radio were developed at Ames to sense brain waves of pilots riding centrifuges and doing other tests. The 1.22 cubic centimeter, 1.0 milliwatt, high performance transmitter has low internal noise, high sensitivity, and works from a single aspirin-tablet-sized mercury battery. The sensors consist of a silver chloride pellet coated with commercial electrode paste, in contact with a sponge wetted with saline solution. The brain's reaction patterns to the light signals are tiny, brief, and mingled with the constant massive flow of other brain wave signals. However, a computer program has been developed to filter out these tiny electric signals.

The radio-sensor system has promise for other uses. Patients could wear the headsets in their wards. For patients who are unstable or in a very acute state, moment-to-moment monitoring and intensive care could be provided similar to that in intensive care units in general hospitals. The data on their EEG activity could be radioed to the computer as they engage in a variety of activities, or are presented with different situations.

The NASA Technology Utilization Office has funded the fabrication of several additional EEG telemetry headsets and will make them available to qualified users for additional clinical trials.

EEG Sleep State Analyzer. The Veterans Administration is conducting a large-scale program in the Antarctic to investigate various psychophysiological phenomena manifested under extreme environmental conditions. An important phase of this research is the recording and analysis of sleep data to help advance existing knowledge on the processes of adaptability and inadaptability to extreme environmental conditions. Efforts to study sleep and sleep patterns have relied largely on trained specialists for proper interpretation of EEG recordings. This is time-consuming and expensive. The Veterans Administration learned that NASA had developed an electronic sleep analyzer system, capable of automatically determining the stages of sleep in a human subject. It was developed to determine the effects of weightlessness on brain activity. Its use precludes need for a professional to interpret thousands of feet of EEG recordings. The NASA instrument uses selected aspects of the total available EEG signal, to continually assess the subject's state of consciousness. It can make a decision concerning the level of sleep, thus eliminating the need for time-consuming interpretation by a human of hundreds of hours of EEG tracings. A soft, comfortable, EEG electrode cap, originally developed for NASA will also be used in this study. This cap eliminates the need for the time and scalp preparation required by conventional individually applied electrodes (Figure 16).

KIDNEY FUNCTION DISORDERS: TREATMENT AND RESEARCH

Urine Transport System for Postoperative Fluid Maintenance. A system to improve the postoperative maintenance of body fluid levels is seen to be clinically tested. Based upon the urine transport system developed for the Biosatellite program, this new urine transport will accurately record urine volume output versus time. The output of this system may then be used to control the rate at which additional fluids are administered to the patient.

One of the essential indicators of a postoperative patient's condition is his fluid intake-output record. Additional fluids must be administered to a patient passing a large amount of urine, so as to maintain a proper electrolyte balance. Excessive retention of urine or unusually high rates of urine output are indicators that specific action must be taken. The present practice is for a nurse to manually record the amount of urine in a calibrated container at specified intervals. This leaves much to be desired, as a patient could easily slip into electrolyte imbalance, with scant note being made of his increased urine output.

The urine transport system originally developed for the monkey in the Biosatellite program provided a solid basis for the further development leading to a clinical urine transport system. The patient's urine is collected in a holding tank and accurately measured in 3cc increments. It is then pumped into an analysis bag so that it may either be collected for further laboratory tests or discarded. It provides a direct digital indication of the patient's urine output. Connected to a monitoring computer, it will provide information on the patient's rate of fluid output and immediately notify nursing personnel of unusual conditions. Through the computer, it may also be used to control the rate at which additional fluids are administered to the patient, thus permitting precise maintenance of body fluid content.

A less sophisticated version of this device has already been in clinical use for over a year. Used to maintain the fluid levels of cardiac patients during the first 24 hours after surgery, it has proven itself of considerable value in patient care. Maintenance of constant fluid levels places less stress on the patient than the depletion-restoration cycle normally encountered, and less time is required of medical personnel.

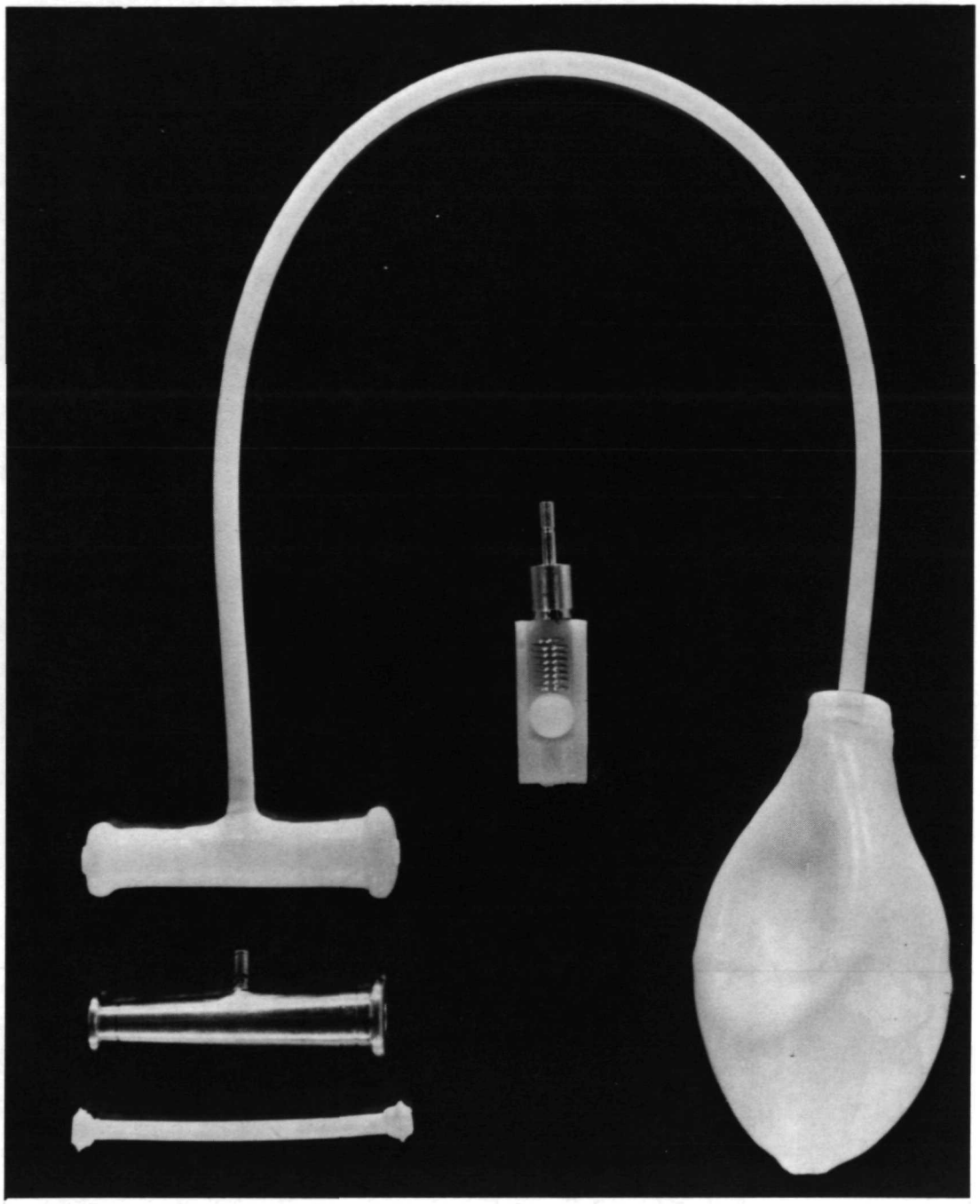
The first prototype of the new Biosatellite based system will be delivered for clinical trials by the end of February 1972. Following successful demonstration of the first unit, four additional prototypes will be released for further clinical evaluation.

Aerospace Valve for Urinary Control. Certain injuries and diseases cause the loss of voluntary control of the urinary function. In addition to obvious social and hygienic implications, the inability to control urine flow can result in kidney tissue deterioration, infection, and in some cases, kidney damage and death. Electrical stimulation of the flow-controlling muscles has not been wholly successful because of insufficient muscle response and painful bladder pressure.

A medical researcher treating paraplegics found that there was a need for a simple, reliable, and totally implantable urethral valve which could be easily controlled by the patient. A NASA engineer suggested that a valve similar to one used in manometer tubes might solve the problem. The valve has been included in the design of an implantable control system. This system will enable the patient to mechanically control urination by applying pressure to a small air-filled bulb located under the skin. Biocompatible materials such as silastic, normally used for long-term implants, were unsuitable as they react adversely to continuous exposure to urine. A material has been found by the NASA Applications Engineering Project and preliminary tests indicate it is biocompatible and capable of withstanding constant exposure to urine. Difficulties were encountered in fabricating tubing and bulbs of the material but these techniques have been mastered. Five prototype urinary control systems (Figure 17) have been fabricated and delivered for laboratory testing.

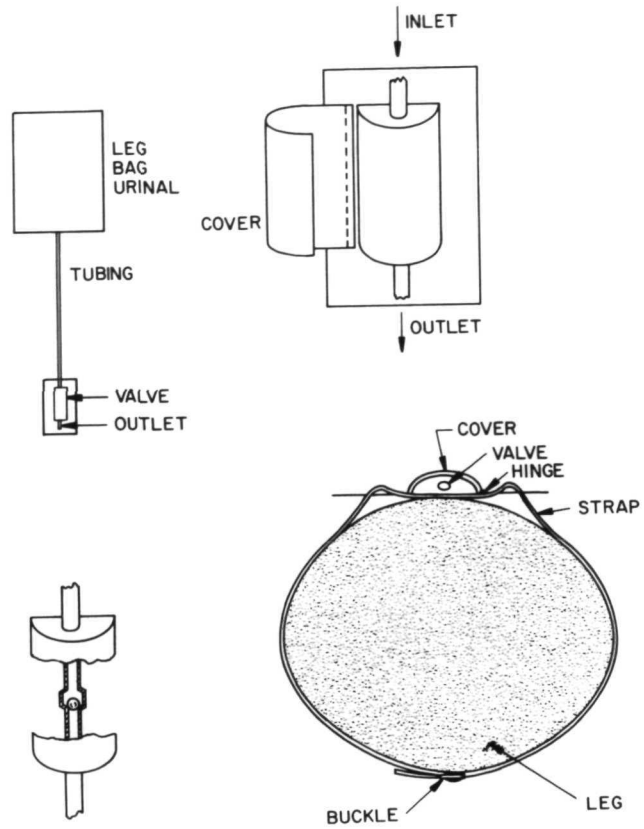
These prototypes will be implanted in dogs to determine if there are any unfavorable long-term interactions between body tissue, the tubing and valve material, and urine. If the prototypes prove satisfactory, the design would be inexpensive to manufacture and could benefit as many as 15,000 patients per year.

The pressure bulb controlled valve may also be useful as a drainage valve for leg bag urinals. Many spinal cord injury patients, who often must wear a leg bag urinal, lack the muscular coordination necessary to open and close a rotary valve to drain the urinal. Their dependence on others to perform this task could be reduced by using a pressure bulb controlled valve to control drainage. Since the ability to make a fist and to push on an object are among the few controlled muscular actions these patients can perform, the bulb-controlled valve would appear to be an ideal solution to the problem. As these valves will not be implanted they may be manufactured at a low cost using common, readily available materials (see Figure 18).



Complications resulting from the loss of voluntary control of urinary function are the most common cause of death of paraplegic patients. Based on a NASA manometer tube valve, this prototype, consisting of a flow valve, a check valve, and a pressure bulb has been constructed and is being tested. Voluntary pressure applied to the bulb which is also implanted under the skin allows the bladder to drain completely in a normal fashion, thus preventing the development of bladder or kidney infection or the development of pathological high pressures within the urinary system.

Figure 17. Prosthetic Implantable Valve for Urinary Tract



Many neuropathic patients lack sufficient muscular control to operate a rotary valve, thus increasing their dependence. The NASA-designed valve merely requires that a force be exerted on the valve cover to operate it.

Figure 18. An Improved Drainage Valve for Legbag Urinals

Liquid Flowmeter for Use in Kidney Research. Better diagnosis and treatment of kidney disease requires an improved understanding of the total urological system. Urine flow measurement in the ureters, tubes that connect each kidney to the bladder, is complicated by the flow being pulsatile. Small gas bubbles are also present in the liquid. The bubbles make accurate volume measurement difficult. The existing technique for measuring flow in the ureters requires collecting urine samples at definite times and can only provide average flow rate information.

Instantaneous flow rates can, however, be measured by a liquid flowmeter developed for the Skylab mission. The system uses a thermal dilution probe and two phase flow separation techniques to get accurate liquid mass flow measurements regardless of the air or gas trapped in the liquid. The ability to accurately measure the liquid flow patterns from the kidneys will be particularly important to a better understanding both of kidney function and of the bodies response to specific clinical drugs.

Scanning Electron Microscope for Analysis of Surface Morphology of Kidney Stones. Research techniques at NASA's Marshall Space Flight Center have been used to extract information on the structure of kidney stones. A researcher at Bowman Gray School of Medicine has been engaged in a long-term study of kidney stones, their occurrence, causes, and related surgical techniques. The overall objective of his research is to prevent the formation of kidney stones. Specifically, he is seeking to understand the mechnisms which cause kidney stones to form in some people and not in others. To this end, he has undertaken a number of research programs and techniques which have yielded much useful information.

However, there is no precise theory for why kidney stones form in certain people and not in others. For example, it appears that concentration of the chemical components in the urine may not be the critical factor, because stones form in certain people who have lower concentrations of the chemicals which seem to be the basic ingredients from which urinary calculi are formed. Tiny crystals are often formed in the tubules of the kidneys in many people, However, in certain people these tiny crystals grow and form kidney stones. As a result of the researcher's work, he suspects that there may be a difference in the surface structure or in the surface energy between those crystals which grow and form urinary calculi, and those which remain in the tubules and do not grow.

A significant portion of the population is affected by kidney stones. Passing kidney stones is extremely painful, and those which are not passed can frequently cause severe problems and necessitate surgery. The researcher is seeking a means to examine the surface morphology of renal calculi, which will yield more useful information on the surface structure than that presently obtained from light microscope techniques. He wishes to determine whether or not surface morphology is a factor in kidney stone formation.

An excellent scanning electron microscope facility was found at Marshall Space Flight Center (MSFC). The potential usefulness of the scanning electron microscope for performing the surface structure studies was discussed with the researcher.

In subsequent arrangements made to use the facility, four samples of representative kidney stones with identification numbers were sent to the MSFC. Forty scanning-electron micrographs were made of the surfaces of the kidney stones, and of the cross-sections obtained when the crystals were fractured. One of these electron micrographs is shown in Figure 19.

The immediate benefit of this effort is the availability of an analytical technique for the researcher to determine the applicability of his theoretical hypothesis. Neither the analytical technique nor the instrumentation required were available at Bowman Gray.

If the relationship between surface morphology and kidney stone formation is established, significant strides will be made in understanding the formation of human kidney stones. If a fundamental understanding of the mechanisms involved is determined, methods to prevent kidney stone formation could soon follow.

Rapid Detection of Bacteria in Urine. One of the principal missions of a neighborhood health clinic that serves approximately 25,000 inner-city residents is the delivery of preventive medical care. One part of the clinic's program is to visit residences periodically to measure blood pressure. In addition to high incidence of hypertension, clinic personnel found a high percentage of bacteriuria in hypertensives given a more thorough examination. As a result, the clinic has been looking for a rapid means of making in-the-field urinary bacteria counts.

The clinicians were informed of an instrument developed at the NASA Goddard Space Flight Center. Based on the presence of ATP (a high energy compound present in all living cells) it utilizes the firefly bioluminescent luciferin-luciferase reaction for detection and counting of bacteria. The device (Figure 20) is basically a semiconductor photometer which detects the light radiated by the luciferin-luciferase reaction in the presence of ATP.

Figure 19. Electron Micrograph of a Kidney Stone

The clinicians were informed of an instrument developed at the NASA Goddard Spaceflight Center. Based on the presence of ATP (a high energy compound present in all living cells) it utilizes the firefly bioluminescent luciferin-luciferase reaction for detection and counting of bacteria. The device is basically a semiconductor photometer which detects the light radiated by the luciferin-luciferase reaction in the presence of ATP.

This instrument can make the bacterial detection (in urine) in 20 minutes rather than 3 to 5 days required by former methods. Testing at the Johns Hopkins Medical School showed that the device permits the accurate screening of many patients in relatively little time. Rapid bacterial identification and diagnosis can forestall serious urinary tract infections and complications and reduce the costs of manpower and numerous chemicals required by older methods. A joint proposal has been prepared and funding arrangements for fabrication of the device are underway.

Liquid Crystal Sterilization. The kidney is supplied with blood by the renal artery which consists of at least two major branches. A large anterior branch supplies the anterior part of the kidney exclusively, and a smaller posterior branch supplies the posterior part exclusively. In a line, called Broedel's line, which passes between the two main arterial divisions, there are no large blood vessels. It is best to make an incision along this line when surgical opening of the kidney is necessary. But it is difficult to locate the boundary line visually. A researcher raised the question of the applicability of liquid crystals to determine these boundaries. Samples of encapsulated liquid crystals were obtained from a commercial supplier by the researcher and from Marshall Space Flight Center (MSFC). It was then necessary to establish sterilization methods for the liquid crystal films prior to use in regular procedures which would not impair the effectiveness of the liquid crystal films.

MSFC has been using liquid crystals for nondestructive testing of metal structures. The encapsulated liquid crystals developed under NASA contract were considered ideal for use in renal surgery. Also,

This automated urine bacteria detection system is based on the light flash produced when living bacteria encounter the substance luciferase obtained from firefly tails.

Figure 20. Automated Urine Bacteria Detection System

personnel at Marshall, experienced in work with liquid crystals, suggested gas sterilization. Evaluation proved this to be the best solution to the sterilization problem. The researcher performed several surgical experiments on the kidneys of dogs, using the liquid crystal material obtained from MSFC, and the technique proved to be very effective. After surgical exposure of the dog's kidney, one of the arteries leading to the kidney was ligated. The kidney was then placed in a cooling bath, and upon removal from the cooling bath, the artery not ligated furnished blood to the kidney, heating that portion of the kidney. Using small strips of liquid crystals, the researcher was then able to trace out the line of demarcation between the two arterial supplies (Figure 21). The juncture between the light and dark areas of the liquid crystal strips indicates the location of Broedel's line. This permitted incision into the kidney without severing any major arteries.

The advice on sterilization and the encapsulated liquid crystals supplied by the Marshall Space Flight Center were vital to the accomplishment of this transfer. The researcher and a commercial supplier are currently discussing the possibility of obtaining prepackaged sterile liquid crystal strips for general use in this surgical application.

Kidney Dialysis Matrix. A kidney research group at the University of Utah Medical School inquired of NASA concerning techniques for fabricating a matrix essential to the operation of artificial kidney machines. An improved technique was sought which would support the material which separated the blood from the washing fluid in an artificial kidney machine.

Figure 21. Liquid Crystal Tapes Aid Kidney Surgery

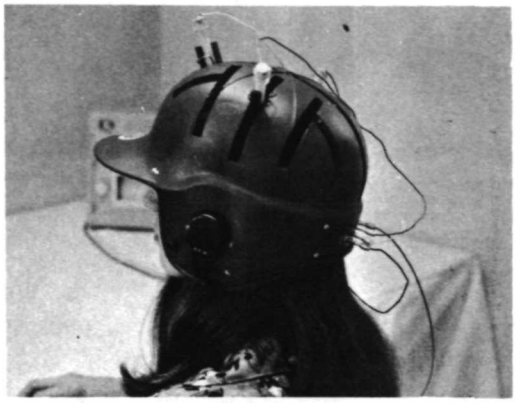
Due to the current high cost of kidney machines they are not yet available to all persons who need their assistance. Many people have died due to the lack of access to this dialysis treatment. The Utah Medical School group is attempting to design a kidney machine that will be low enough in cost that patients requiring it can afford to have one at home. To build this machine they needed a technique to deeply photo-etch a matrix of points to form a mold. The mold would then be used to cast a plastic matrix to support the interface material between the blood and the washing fluid.

Personnel at NASA's Langley Research Center have had extensive experience with the photo-etching of printed circuit boards. They fabricated a sample of the matrix which appears to present an ideal solution. The Langley technique provides more usable surface of dialyzing membrane, thus improving the machine's performance. Langley is presently awaiting dimensional specifications for the matrix plate and will fabricate several for test in the machine.

REHABILITATION MEDICINE: PATIENT TESTING, EVALUATION, AND TRAINING

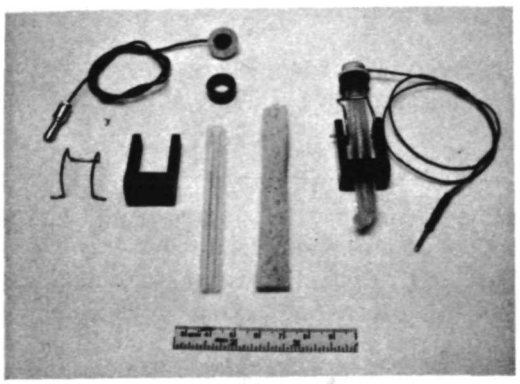
EEG Helmet for Early Detection of Hearing Defects. Based on a system used originally to record changes in the brain waves (EEG) of astronauts and pilots while under gravitational stress, this EEG helmet (Figure 22) is now part of a system to test the hearing abilities of small children by recording their brain waves. Thousands of children classified as mentally retarded are believed to be suffering not from mental retardation, but rather from hearing difficulties which have cut them off from the environmental interaction which is essential to the development of their intellect. If these hearing defects can be identified early in infancy and appropriate remedial measures taken, many youngsters can be prevented from becoming functional retardates. Thus, the entire system is intended to assist in identifying hearing defects in young children who cannot verbally communicate information regarding whether, and to what degree, they hear an auditory stimulus.

Mounted on the helmet are three electrodes, a low noise, high gain amplifier, and a pair of earphones for administering the auditory stimulus. The helmet-mounted electrodes have several advantages over the more conventional, individually attached type. No prior scalp preparation is required and, as all three electrodes are simultaneously placed, the time required to prepare a child for testing is significantly reduced. No special electrode paste need be applied to the child's scalp and later removed as in the conventional recording method. The electrodes and leads are held firmly in place by the helmet so that the child cannot tear off or dislodge electrodes by a mere swipe of his hand, which is a problem frequently encountered in the conventional technique. All of these considerations would be quite valuable in terms of time and cost reduction in a large-scale screening program. The low noise amplifier (based on Ames Research Center design) built into the helmet amplifies the signal by a factor of 1000. By reducing the length of the wires carrying very small signals, the possibility of extraneous electrical noise pickup is significantly reduced.



The EEG audiometric helmet in position on the subject. The electrodes can be adjusted to a variety of head sizes, do not require shaving of the head, and do not require use of electrode paste. Used in a hearing testing program, evoked response audiometry uses changes in the brain waves to determine an individual's threshold of hearing. This makes it possible to determine hearing deficiency in infants and young children. By identifying and applying proper treatment to those children with a hearing problem, they may be prevented from becoming functionally retarded.

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



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

Figure 22. NASA EEG Audiometric Helmet

Thus, with this system, auditory signals (tone bursts or clicks) are fed into the helmet via the built-in earphones. If the child "hears" the signal, it is indicated by a change in the brain wave pattern. The child does not have to tell the researcher that he hears. If he does in fact hear, his response will appear in the processed and displayed EEG tracing.

The Marshall Space Flight Center's Astrionics Laboratory has designed an appropriate signal-generating and processing unit. The necessary electronics instrumentation required to make this technique readily portable and economically practical has been built, and four of the prototypes are being made available for clinical evaluation. The block diagram of the total system is shown in Figure 23.

Diagnosing Gait Abnormalities. A specially instrumented suit developed at NASA's Langley Research Center (LRC) may prove quite valuable in studies of human locomotion for patient rehabilitation. Techniques for studying the motion of limbs during normal locomotion and for diagnosing gait abnormalities have been previously dependent on visual observation. Two and three dimensional information on limb motion has been acquired by using a system of grids and cameras. Data taken by these techniques is unsatisfactory because of the complexity of the installation, the fragmentary nature of the data, and the difficulty of extracting position information from such visual data. In addition, visual techniques require that the desired position measurements be taken in a laboratory or other "artificial" environment in order to maintain the patient within the field of view of the camera and grid system.

A specially instrumented suit for the Crew Vehicle Disturbances Study in the Skylab Mission was developed at the Langley Research Center. The suit (Figure 24) essentially consists of a partial exoskeleton which is fitted to the individual by means of a suit. Potentiometers are used at the various joints and also on rings located on the arms and legs to provide information on the angular relationships between the joints. This unit is lightweight and compatible with the overall requirements. The results at LRC indicate that precision of measurement of rotation of one member with respect to the other using this technique approaches plus or minus 1 percent. It is anticipated that some difficulty may be encountered in affixing the exoskeleton to the patient. However, it is felt that this difficulty can be overcome as a result of the light weight and relatively small size of the exoskeleton. For these preliminary studies it is anticipated that only the lower half of the exoskeleton unit will be required since the studies are primarily concerned with gait analysis. The present suit developed at LRC uses an umbilical cable to transmit data from the potentiometers on the exoskeleton to the data processing equipment. A study has been made at Langley of the requirements involved in instrumenting a telemetric system. The design of the telemetry apparatus has been completed. Should evaluation of the exoskeleton prove that this approach will provide the necessary data, it is expected that telemetric techniques will be required to obtain the greatest utility and versatility in the use of this technique. The suit is presently on loan to the Rehabilitation Research Center at Emory University and following that, it will also be evaluated by the Veterans Administration Hospital in Miami.

Testing of Neuropathic Patients. Many people suffer from neuromuscular disorders which result in the loss or impairment of muscular control. The cause of these disorders is damage to the nervous system which controls the musculature. One symptom of this disorder is uncontrollable tension and relaxation of muscles.

Modern therapeutic treatment allows many thousands of patients to improve the degree to which they can exercise voluntary control over their muscles and, therefore, to assume a more active and useful role in society. Therapeutic treatment, however, is presently hampered by the difficulty of measuring the improvement that individual patients make during the course of therapy. As an example of a currently employed technique for measuring a patient's progress, the patient is presented with a drawing of a thin-lined geometrical pattern and is asked to trace the pattern with a pencil. From this experiment, a subjective judgment can be made regarding the degree to which a patient is able to control the movement of his hand. It was felt that more quantitative measurement of a patient's progress could lead to refined therapeutic techniques which, in turn, could bring about more rapid and more complete recovery for the many patients suffering from neuromuscular disorders.

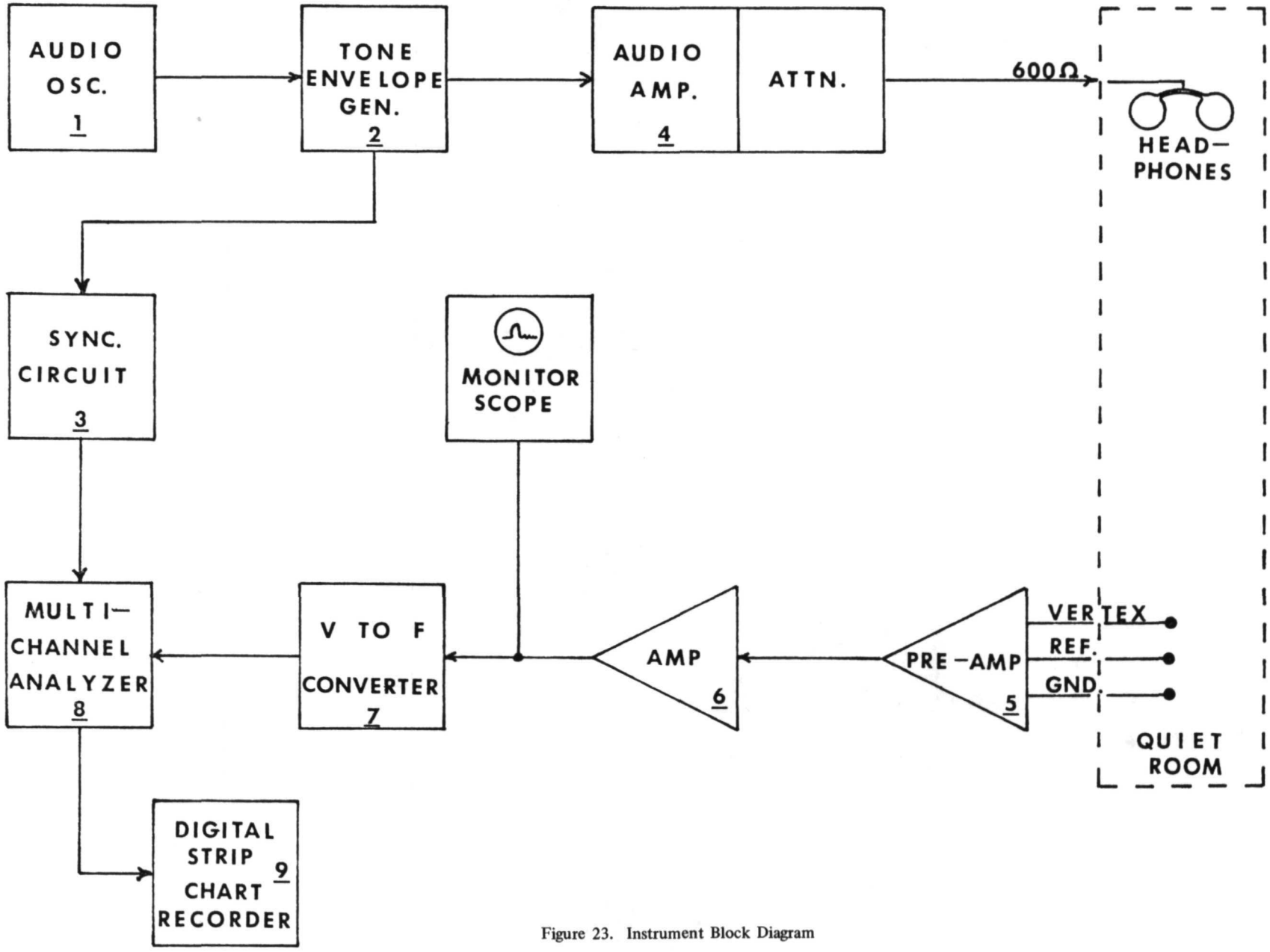


Figure 23. Instrument Block Diagram

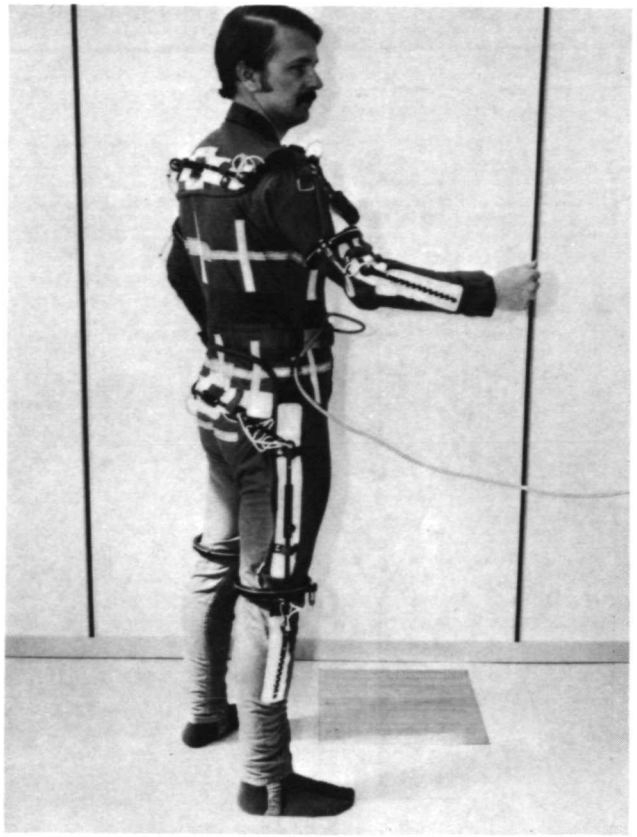


Figure 24. Partial Exo-Skeleton for Locomotion Studies

In the design of highly reliable aircraft and space systems which are to be operated under direct manual control, the problem of the man-machine interface becomes critical. Scientists at NASA's Langley Research Center (LRC) have been working for many years on these problems. Of major importance is the understanding of the motor and perceptual characteristics of the human pilot. To measure limb-control response time, rate of movement, etc., Langley researchers developed a variety of tests and testing apparatus. This research resulted in a mathematical model of the human pilot.

The problem of testing neuropathic patients was discussed with two of the pioneers in pilot modeling at Langley. It became evident that the tests devised to determine pilot characteristics had much in common with the requirements for testing patients with motor disorders. In a demonstration tracking task given to aircraft pilots at Langley they were required to track a random disturbance by positioning a joystick so that an oscilloscope trace is maintained in the zero position. With this configuration, it was possible to record both pilot response and instantaneous error in tracing random disturbance. The task included model stick and aircraft dynamics. This configuration is illustrated in Figure 25 for a single axis tracking task. The Langley researchers suggested that the stick and aircraft dynamics be removed from the task, in order to acquire better motor performance measurement in neuromuscular patients.

The LRC tracking task with the suggested modifications, shown in Figure 26, was implemented and demonstrated to the Problem Originator to evaluate the technique. A detailed evaluation is expected within 2 or 3 months.

Human Voice Analysis. An aerospace technique for improving speech transmission from aircraft is being applied in analyzing speech defects.

Approximately 6 to 7 percent of the population is considered to have either temporary or chronic speech defects. One such speech defect is characterized by pitch that is either too high or too low and can be caused by either contact ulcers, polyps, polypoid degeneration, or chronic laryngitis. In chronic cases, inadequate understanding of the causes of speech defects hampers treatment.

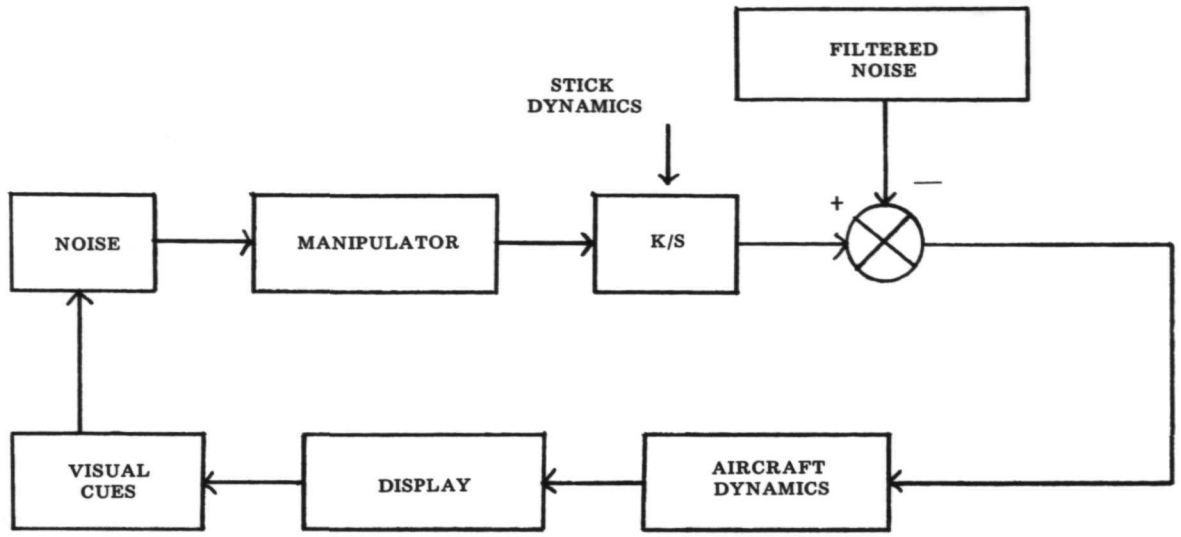


Figure 25. Single Axis Tracking Task for Testing Neuropathic Patients

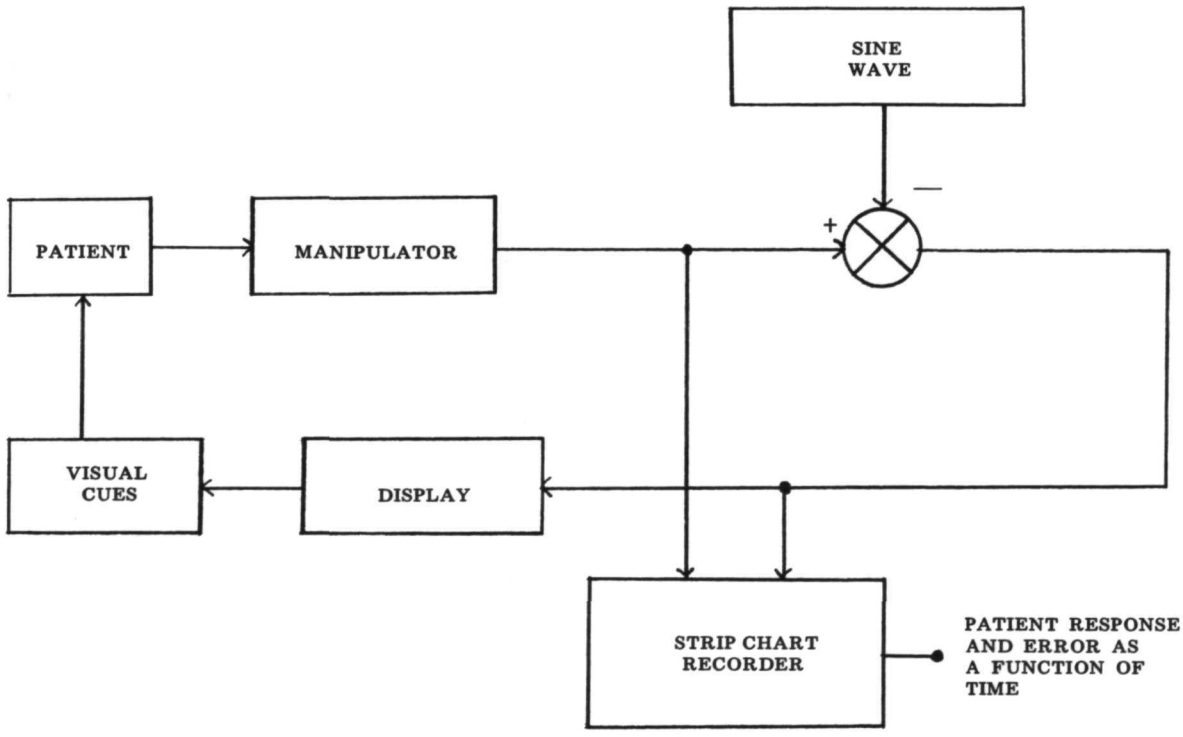


Figure 26. Single Axis LRC Tracking Task

There is a technological barrier to the analysis of speech defects due to the inability to precisely quantize characteristics of the human voice. This is further complicated by the fact that many changes in the human voice are easily detected by the ear, but are often quite subtle in their spectral density or frequency changes. A number of techniques have been employed in an attempt to quantize the human voice, but to date no technique has been found which permits the therapist to measure changes before and after therapy.

Speech consists of a broad fundamental frequency range and many harmonics. Small shifts in the fundamental frequency and amplitude cause large changes in the human voice. Frequency spectrum analysis must be able to detect fundamental frequencies ranging from as low as 50 Hz for low-pitched male voices to more than 400 Hz for high-pitched children's voices. The technique must measure fundamental frequencies to a precision of 1 Hz and amplitude to a precision of 1 decibel, and must take into account both fundamental frequency and harmonics and their relation to the fundamental frequency. Although not required, real time analysis is desirable.

The relevant documents produced by a search of the NASA data bank dealt with the determination of spectral differences between several languages and with voice detection from a noisy environment (for example, spacecraft). The techniques discussed appeared to be directly applicable to speech therapy, and the Problem Originator expressed strong interest in pursuing this approach. The use of the fast Fourier transform and a digital computer for analysis was of exceptional interest mainly because such a computer (capable of handling the fast Fourier transform analysis) was available at the Tulane University School of Medicine. Although the computer was in their Neurology Department, arrangements were made so that it could be used by the Otolaryngology Department.

At the present time, the fast Fourier transform techniques, outlined in Figure 27, are being implemented on the digital computer for analysis of tape-recorded speech, and for comparisons before and after therapy. The initial portion of the study is to establish a baseline of information from which changes can be documented. The physician has indicated that the initial results are favorable, and that an advance in speech therapy can be anticipated.

Cleft Palate Airflow Monitor. The severe difficulties associated with cleft palate and the effects of corrective surgery can be evaluated by measuring the amount of air passing through the nasal opening during speech. These measurements reveal changes in the palatic fissure history, response to treatment, and other characteristics. The measuring device must not restrict nasal passages, which would alter the normal nasal airflow in the child. If an apparatus either disturbs the child or makes him uncomfortable, it can render inaccurate measurements.

The NASA respiration monitor using a thermistor bridge (as described in NASA Tech Brief B68-10438 and supplemental information) should prove useful for gross measurements, to estimate the amount of air flowing out of the nasal openings. A duplicate model of the NASA respiration monitor was forwarded to the investigator at the University of Minnesota Dental School. Since the original monitor configuration would not measure air volume directly, the investigator recalibrated the device to approximate the volume of airflow.

Electrodes for Hand Rehabilitation. An important aspect of the physical therapy of patients who have experienced damage to their hands involves the repetitious exercise of certain muscles. It is general practice in the treatment of hands in which muscles have been damaged or have become atrophied to implement a program of exercise and therapy aimed at permitting the patient to regain use of the hand. These therapy exercises are frequently prescribed following surgery to correct and improve hand function. In such therapy programs, specific muscles in the hand must be exercised by the patient. It is frequently difficult for the therapist to determine if the patient is performing the exercise pattern by using the proper muscle instead of some other combination of muscles. This is especially true when a single therapist is working with a number of patients and the patient has to perform the exercises essentially unattended. The damaged muscle is frequently favored by bringing into play some other combination of muscles to produce the motions prescribed by the therapist. As a result, an EMG muscle trainer is employed to determine whether or not a specific muscle is being used by the patient. This muscle trainer consists of two electrodes, an

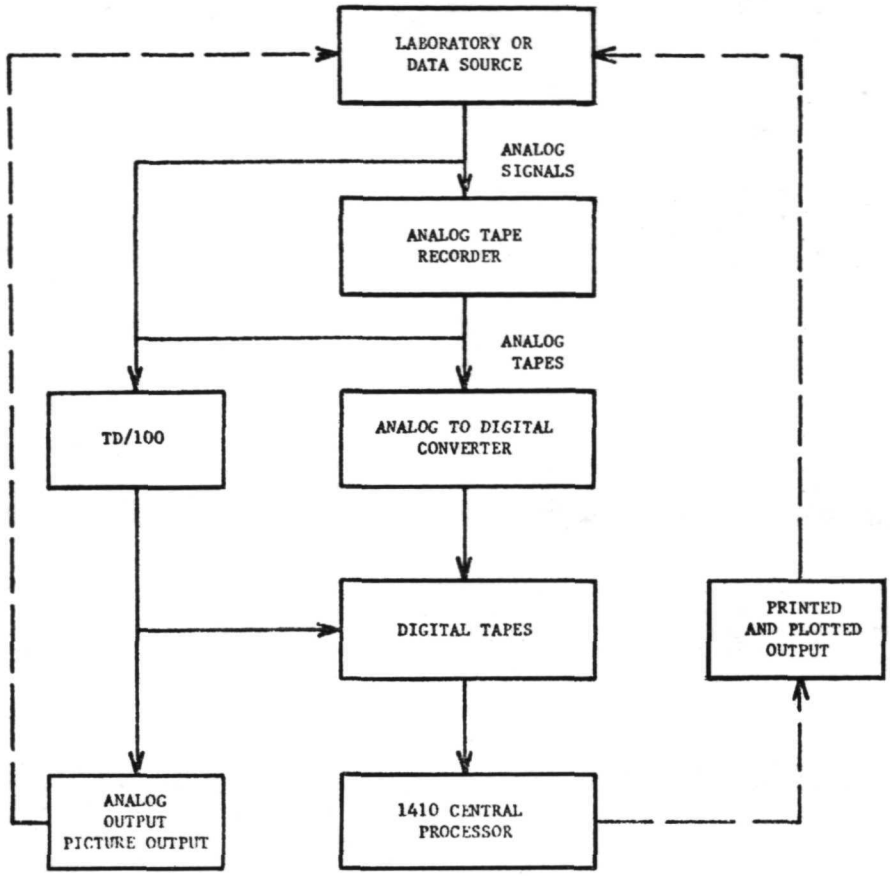


Figure 27. Block Diagram of Voice Analysis System

EMG amplifier, and a speaker to permit audible recognition of EMG signals. If the electrodes (Figure 28) are properly placed, the therapist can then determine audibly whether the desired muscle is being used by the patient in the exercise.

Conventional electrodes used in this procedure consist of stainless steel cups approximately 5/16" in diameter which are filled with electrode paste and attached to the muscle with masking tape. There are some difficulties with these electrodes: they are too large, and the attachment method along with the size of the electrodes obscures the muscle being exercised. Frequently, it is desirable to perform other therapeutic procedures on the muscle while it is being exercised. The present electrodes and associated attachment tape prevent this because in most cases the muscle is completely covered. In addition, the masking tape does not maintain the electrodes in proper position during exercise which can result in artifact or complete loss of the EMG signal.

A search of the NASA data bank had previously revealed a NASA technical note, TND-3414 (Dry Electrodes for Physiological Monitoring). This document discussed a dry electrode technique which used a spray-on method of application. The spray-on electrode application procedure was changed to "paint-on" so that very small electrodes could easily be attached to the surface of the skin. Preliminary tests made in the clinical environment using these small "paint-on" dry electrodes were completely satisfactory. The electrode could be made very small, no further attachment mechanism was needed for the wires, and the electrodes provided extremely satisfactory input signals to the EMG muscle trainer. Motion artifact was no longer a problem, and there was no tendency for the electrodes to become dislodged during exercise. In addition, there was almost complete visual and physical access to the muscle being exercised, thus permitting the use of other therapeutic procedures during exercising, leading to an overall improvement in patient care. In addition, therapists have found that the "paint-on" electrodes are much easier to apply to

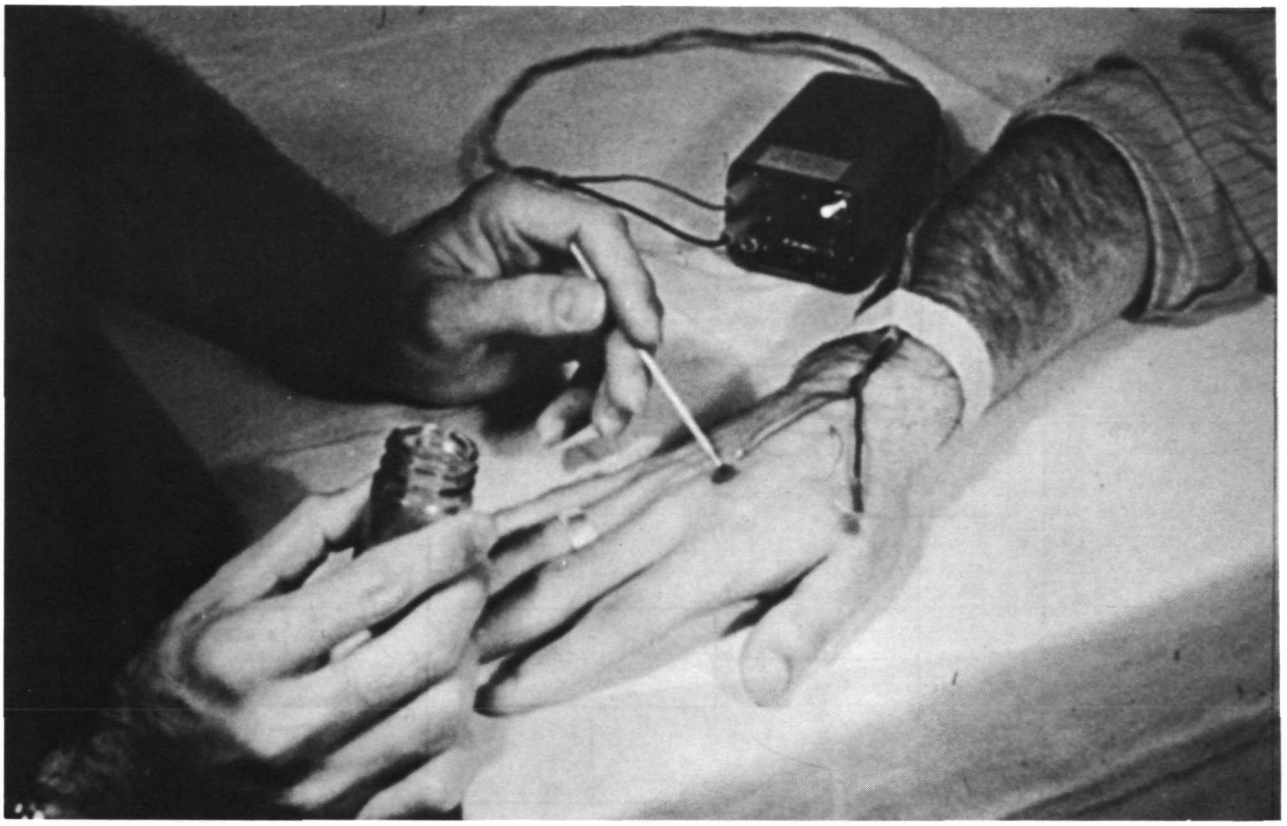


Figure 28. Paint-On Electrode for Hand Rehabilitation Training

the specific area on the skin, leading to increased convenience and more exact electrode placement. Since the paint-on electrodes are essentially a thin film, they are very flexible and remain in intimate contact with the skin as the muscles are being exercised. The paint-on electrodes have been evaluated now for a number of months in the clinical environment and have been found to be satisfactory and effective solutions to the original problem. The paint-on electrode has been adopted by several other rehabilitation agencies and is now recommended by the designers of the EMG muscle trainer.

A Simple Method of Obtaining Electrical Connection to 25-Micron Wire. In EMG (electromyograph) studies of the spinal musculature, fine wire (25-micron) subcutaneous electrodes are placed through a hypodermic needle into the muscle whose EMG signal it is desired to monitor. The end of the electrode wire not in the muscle protrudes through the skin approximately 1 to 1½ inch. The external end of the electrode wire must be electrically connected to the input of an integrated circuit preamplifier strapped or taped nearby. Soldering, welding, or other bonding techniques which pose a real or psychological danger to the patient cannot be employed. The technique in use when this problem was defined employed a coil spring which is attached to the input terminal of the preamplifier as the connector. Connection was made by pulling the spring apart, inserting the bare electrode wire, and allowing the spring to compress back down on the wire. Although handy and easy to use, electrical connection was essentially accomplished by means of "smeared" point contacts with this method so that reliability difficulties have been frequently experienced. A better method of connecting the electrode lead to the preamplifier was desired. The new connection technique had to be easy to use with this fine wire, provide reliable and low impedance connection, and could not be hazardous or threatening to the patient.

A connection technique employing a conductive adhesive based on the NASA-developed dry electrode techniques was suggested as a potential solution to this problem. The terminals to the preamplifier are constructed by forming two tabs or "lands" of copper separated by a small distance on a chip of printed

circuit board (see Figure 29). These terminals are attached to the preamplifier, and connection from the preamplifier to the terminals is accomplished by soldering. Because of the small size of the electrode wire and resulting difficulty in handling, it is necessary to fix the wire in place before the electrical connection can be made. To accomplish this, a small double-backed adhesive template shaped as shown in the illustration is applied to each terminal tab. Next, the electrode wire to be attached is stretched across the tab and pressed into the adhesive at each end of the tab. This holds the wire in a fixed position so that the conductive cement can be easily applied. The conductive adhesive is applied using a camel's hair brush, a Q-tip®, or other convenient applicator. Using a small hand-held hair dryer blower, the cement can be dried in less than 15 seconds. Then to obtain additional mechanical strength, a piece of transparent adhesive tape is applied over the terminal. This technique has provided excellent electrical connection between the preamplifier and the electrode wires and has been very reliable. In addition, because of its ease of attachment, technicians have quickly learned the technique and become proficient in its application. Tests have been conducted clinically with human subjects and also in a research program in which gorillas were used as test animals. In both cases, this connection technique was highly successful. The researcher considered the connection problem completely solved and is now using this technique routinely as a part of his standard procedures. It has been demonstrated at several medical conferences and has been enthusiastically adopted by other rehabilitation centers.

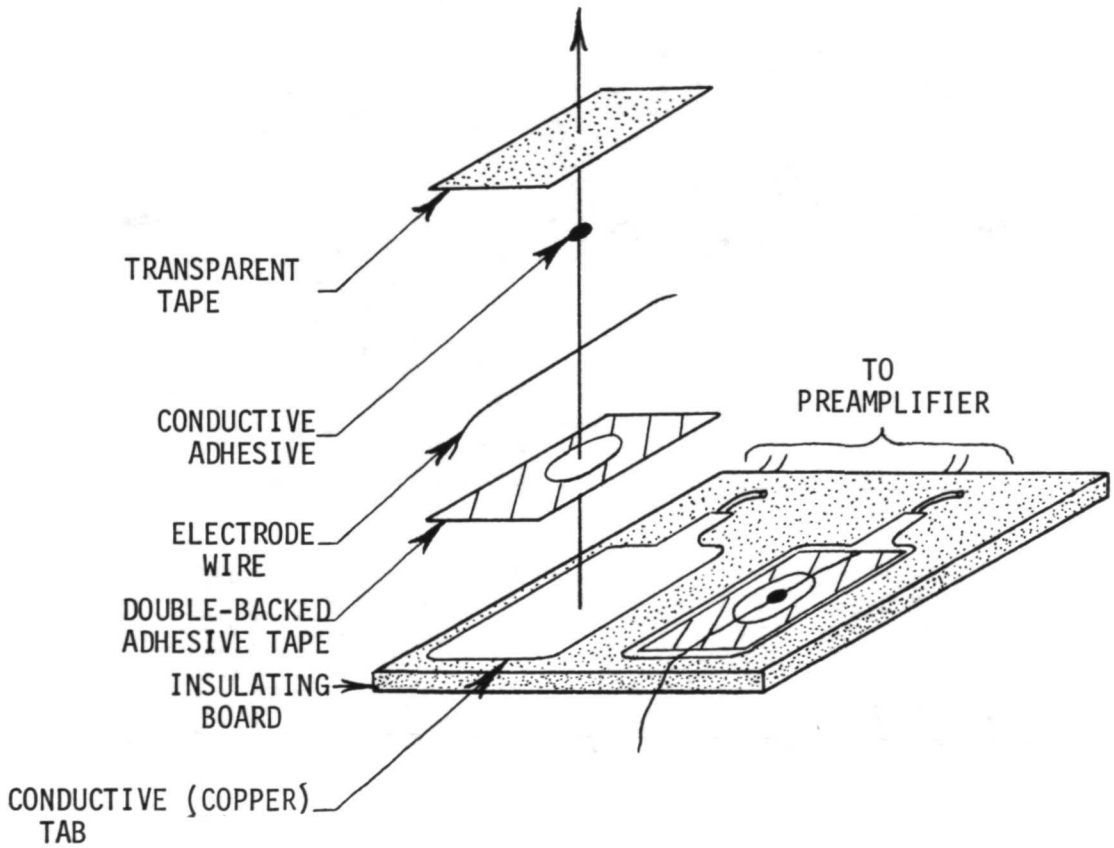


Figure 29. Connection Technique for 25 Micron Electromyograph Wire

Polymethane Foam as a Padding Material. Patients with spinal cord injury frequently develop decubitus ulcers (open bed sores) caused by continuous pressure applied to weight-bearing points of the body. Easily infected, these sores often become quite serious, exposing muscle, tissue, and occasionally bone. Surgery is often required to close the wounds. High-pressure points are more common in these patients, since their musculature and other padding tissues atrophy from lack of use. Sensory deficiencies prevent the patients from feeling any pain; a person in normal health would reposition himself before an ulcer would form. Motor paralysis prevents injured patients from moving. Pressure sores cause much suffering and are difficult and expensive to cure. The high cost (up to $15,000 per case) is attributed to hospital-staff time which must be devoted to the patient, to special medication, surgical correction, and postoperative care.

A group at NASA's Ames Research Center investigated a number of padding materials developed for use in space vehicle couches to absorb vibration and shock. For the medical problem, the Ames group suggested the use of a NASA-developed polymethane foam. This foam (Figure 30) has many unique viscous and elastic properties, plus temperature and compression-rate sensitivities. It absorbs mechanical energy, cushions to a comfortable, flow-fitted support, and distributes high pressure areas into uniform lower pressures. It can be easily formed while maintaining stiffness, and it functions as rigid foam at low temperatures or as elastic foam at high temperatures. It is now commercially manufactured.

The material is available in several densities and has proven useful in many rehabilitation applications. When used as a wheelchair pad, patients note relief of pain and considerable increase in comfort. Although

Decubitus ulcers tend to develop over the bony areas of the bodies of spinal cord injury patients who experience sensory loss. The average estimated cost for treatment of a decubitus ulcer is $15,000. Researchers have been seeking a cushion material which will prevent formation of these ulcers. A polymethane foam developed for space vehicle seat cushions may result in a significant improvement in bedding for these patients. It may also be used as an improved padding material for wheelchairs and prosthetic or orthotic devices.

Figure 30. Polymethane Foam

no ulcers have been evident with the use of the polymethane foam, this cannot be stated as an established fact, because of insufficient experience. Patients using these pads previously had hip pains while sitting, and feel that the polymethane foam pads are preferable to others. No sweating or heat problems have been experienced with the polymethane foam.

When polymethane foam was used as padding for below-knee prostheses, the results were excellent. The below-knee amputee usually has discomfort on the anterior distal end of the stump, because of clapper action against the prosthesis on extension of the knee. The rehabilitation center reports that the use of ¼-inch strips of this foam has relieved this pain immediately. In one case, the foam was placed on the distal end of a stump on which a blister had formed prior to the placement of the foam. The patient continued to walk and to use the stump bearing weight on the foam. The blister healed without complication.

When the conventional felt padding on knuckle bender splints of patients with burns was replaced with polymethane foam, it provided adequate support without damaging the thin scar tissue as the felt padding had done.

The polymethane foam has also been used to pad 4-post neck braces and various prosthetic devices. Patients report far more comfort and experience far less pain.

The results of these early applications of polymethane foam have been highly encouraging and it is currently being evaluated for other uses.

On-Line Fabrication of Orthotic Support Devices. Physicians at rehabilitation centers feel that patients could be relieved from a certain amount of pain and discomfort by means of rapid custom-fabricated orthotic devices, such as arch supports. Since most rehabilitation centers do not have in-house fabrication facilities, the usual procedure is to measure the patient for the device and then order it from a commercial source. This results in loss of much therapeutic time, since 2 weeks customarily elapse between order and receipt of the finished item.

The Problem Originator at a Southwest rehabilitation center desired to obtain a lightweight material, that would be both resilient and tough, which could readily be poured "in-house" to form a suitable temporary orthotic support.

A search of the NASA data bank revealed several alternatives. The most promising was the foam-in-place technique developed at Wright-Patterson Air Force Base for use in customized, form-fitting helmet liners. After testing for fabricating orthotic support devices, it appeared very promising (Figure 31). Indications are that this will prove to be an effective, economical means for providing immediate custom-fitted temporary orthotic support aids.

There has also been interest in using this material to form molds for positioning and immobilizing patients during radiation therapy. Accurate repositioning of a patient is essential for effective therapy, and the casting techniques currently used are both time-consuming and expensive.

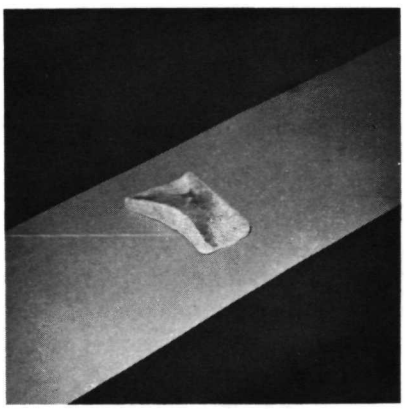
Effective radiation therapy requires that a patient be accurately repositioned each time to receive a specifically directed radiation dose. For this accurate repositioning, as well as immobilization of limbs or a hand, casts must often be made to withstand months of repeated handling. The foam-in-place mold-making technique is being evaluated for this purpose, as its rapid fabrication and curing properties are quite favorable.

Biocarbon Implants. High purity, high strength forms of carbon, developed for space capsule heat shields, are being tested and evaluated for the fabrication of prosthetic devices. Devices such as bone substitutes, teeth and replacement heart valves which are intended for long-term implantation in the human body must be highly compatible with body fluids and tissues. Until recently, however, the available carbon was not sufficiently strong for prosthetics use. Materials of lesser biocompatibility had to be used.

In place foaming of arch support provides the patient with a custom fitted support device which can be used immediately. Shown here is the arch support foamed to the contour of the foot.

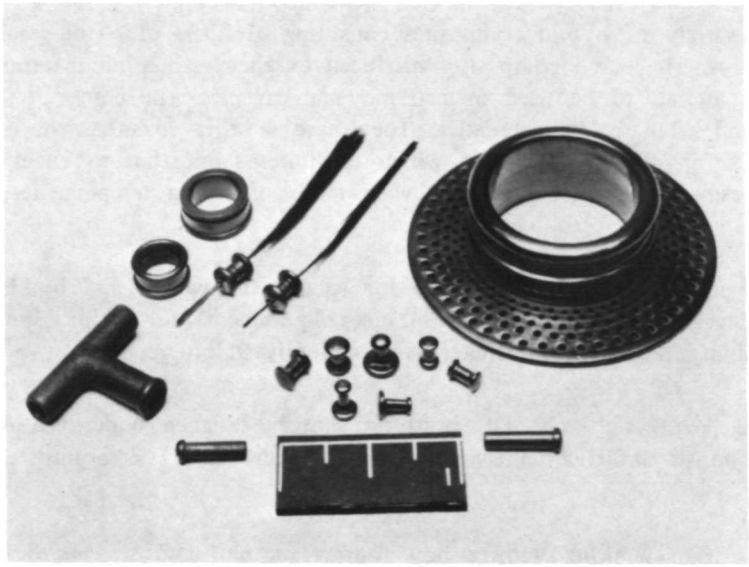
Trimming free foam arch support to fit patient's shoe.

Arch support trimmed and ready for insertion into patient's shoe. The entire process from foaming the arch support to placing it in shoe takes only ten to fifteen minutes.



Temporary arch support in place in shoe, ready for immediate use.

Figure 31. Helmet Liner Foam for Rapid Fabrication of Support Devices



High-purity, high-strength forms of vitreous carbon, form prosthetic devices intended for long-term implantation in the human body. Vitreous carbon is the material originally developed as an ablative heat shield for reentering space capsules.

Figure 32. Biocarbon Implants

Studies have shown that vitreous carbon developed for aerospace use is now sufficiently strong to be fabricated into prosthetic devices (Figure 32) and pure enough to be biocompatible. Vitreous carbon combined strength with chemical inertness. In comparison with other materials used for implantation, it is notably light and hard enough to permit low mass implants, and has a low coefficient of linear thermal expansion. Being a pure carbon, it is highly resistant to body fluids since it cannot oxidize (corrode) at body temperature. The advantage of not being metal is that it should be free of the adverse tissue response such as inflammation, swelling, pain, sepsis, and body resorption initiated by the release of metallic ions and particles. It also has an advantage over polymers such as acrylic, PVC, Teflon, and nylon, in that vitreous carbon contains no impurities or additives, such as stabilizers, antioxidants, and low molecular weight components. With polymers, adverse tissue reactions arise from leaching of these various constituents which can be toxic. Also, although these polymers offer high resistance to industrial chemicals, they are often metabolized by the body, resulting in a loss of strength. Studies to date indicate that vitreous carbon exhibits excellent chemical resistance and high strength and rigidity. This suggests that its use may prove to be a major advance in implantation materials, both for surgical and oral implants. Technology Utilization funds have been made available through the Marshall Space Flight Center for a special project at Rancho Los Amigos Hospital to further develop and test biocarbon materials in cooperation with interested medical specialists.

Lightweight Prosthesis and Orthosis Materials. Prosthetic and orthotic devices have been improved and refined by incorporating new ideas and materials in highly sophisticated developments. Orthopaedists almost uniformly have standardized on using stainless steel as the preferred supportive material for its characteristics of durability, dependability and stress resistance.

Steel reinforced artificial hands, feet, arms, and legs have been extremely helpful in rehabilitating the amputee, the paralyzed, the neuromuscularly weak, and the patient who has birth defect anomalies. The stainless steel supports also introduced substantial weight and bulk factors for these devices.

Men, women, and children with neuromuscular weakness have experienced considerable difficulty when they tried to manage the weight and bulk of their devices while adjusting during rehabilitation and in later activities. The physical difficulties and aesthetic objections affected a large segment of those receiving rehabilitation medicine treatment.

NASA developed a variety of hybrid composites consisting of fibers of boron-graphite-glass embedded in a matrix of epoxy resins. The cured composites produced excellent structural materials to satisfy aerospace needs for lightweight materials to be used in airframes and capsules. The composites are equal or superior to steel in stiffness and strength characteristics. They have another advantage in contouring and shaping since they are cloth-like in the precure state which facilitates fabrication to exact specifications. Adjustments in the epoxy resin components provide a wide range of curing temperatures, to include curing at room temperatures.

These composites appear to hold great promise for solving the weight and bulkiness problems without sacrificing durability, dependability, and stress resistance requirements for orthotic/prosthetic devices. Fabrication design and feasibility testing of the materials is presently in progress.

Motor For Powering Prosthetic Unit. DC brushless motors designed under NASA contract to position satellite solar panels and to unfurl antennas now appear ideally suited as a motive source for prosthetic devices.

A rehabilitation physician working with a boy four years old who was born without legs and arms approached NASA for assistance. With prostheses and intensive training the boy was able to stand up and walk independently at the age of 19 months. He is now using both leg and arm prostheses. In addition to walking, he can eat, drink, and draw using his prostheses.

The basic problem was to design a prosthesis that will permit the boy to go up and down stairs. The physician had contacted many specialized prosthetics and rehabilitation centers both in the United States and Europe. Unfortunately, little practical experience was available to draw upon in the rehabilitation of one so severely handicapped. The physician has evolved a design in which the prosthetic legs can be made to telescope by means of a drive motor in the leg. Such a telescoping prosthesis would allow one of the legs to be lengthened to the height of the stair tread so that the other foot could be placed on the next step. The boy would then transfer his weight to the upper leg, and the extended leg would be shortened to the proper height to permit him to stand on the level with both feet on the upper stair tread. The process would then be repeated, thus allowing the boy to traverse the stairs.

The basic problem in the design was to locate a motor that was small and lightweight enough to fit into the prosthetic leg while at the same time powerful enough to lift the entire weight of the boy. Hard and fast specifications on the motor performance were somewhat difficult to assign. As a result, information on the smallest and most lightweight motors that could be obtained and which could provide the power to lift approximately 50 pounds a distance of eight to ten inches within a time span of five to ten seconds was sought.

Brushless DC motors designed under NASA contract to provide motive power in positioning satellite solar panels and unfurling antennas were the most likely to fit this particular application. Information on the motors was obtained and forwarded to the Problem Originator. After reviewing the motor characteristics with his technical staff, it appears that these motors are well-suited for the prosthesis for the young boy. As soon as detailed motor requirements are completed, a motor will be requested from the manufacturer.

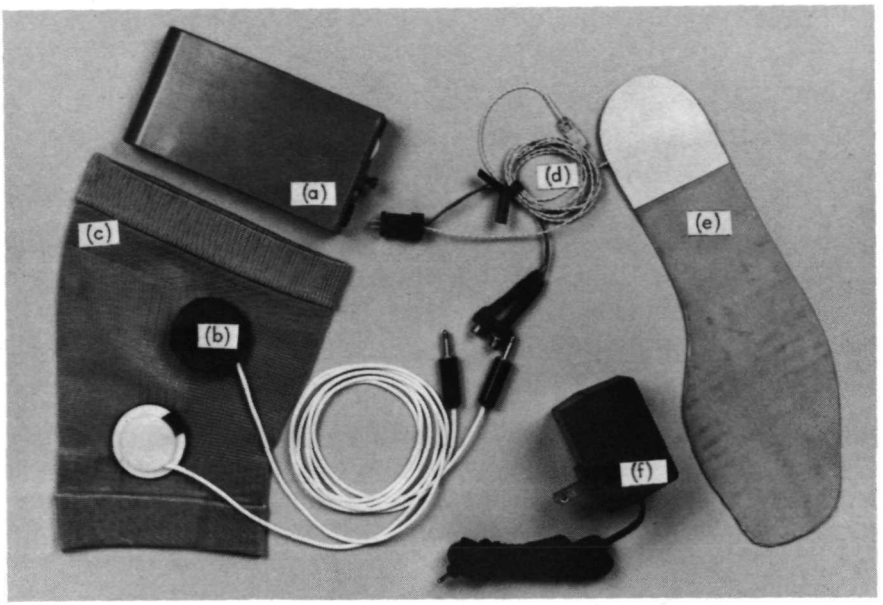
The Rancho Los Amigos Hospital, a West Coast rehabilitation center, is also working with NASA Jet Propulsion Laboratory to define specifications and design compact, lightweight motors specifically for powering artificial limbs.

Electronic Peroneal Nerve Stimulation Via Flexible Electrodes. Ultraflexible electrodes being developed at NASA's Ames Research Center for long term monitoring during prolonged space flight are suitable for many rehabilitation and patient monitoring problems. The electrodes are made of an elastomeric material saturated with a fine suspension of conductive metallic particles. The material may be formed to any shape and can be stretched to 40% greater than its original length while maintaining excellent conductive properties.

(a) Electronic Stimulator

(d) Cable Assembly

(c) Fixation Device



(e) Innersole Footswitch Assembly

(b) NASA Electrodes

(f) Battery Charger

The use of special ultraflexible electrodes developed at NASA's Ames Research Center permits more effective functioning of the device.

Figure 33. Electronic Peroneal Nerve Stimulator

In the patient with hemiparesis or hemiplegia[Δ] functional electrical stimulation (FES) of the peroneal nerve may be indicated rather than the mechanical peroneal brace or splint to achieve effective dorsal flexion and eversion of "drop foot." The impairment of the peroneal muscle group, resulting in "drop foot," appears to be the most common permanent residual. This produces a major interference with walking. Marked improvement of the impaired gait of the hemiparetic patient may be achieved by electrical stimulation (Figure 33) applied to the peroneal nerve. This stimulation can be applied by surface electrodes connected to a stimulator triggered by a heel switch in the last third phase of the walking cycle. The stimulator affords adjustable frequency, duration, pulse width, and intensity of the train of stimuli.

With the use of functional electrical stimulation, it is not only possible to prevent "drop foot," the goal of classical mechanical peroneal braces, but also to control dorsal flexion and/or eversion of the foot in specific phases of the walking cycle. At the same time, the active processes of nervous activity involving related muscle groups (i.e., excitation and inhibition of them) which are necessary for any organized movement can be influenced. The technique described represents a useful aid for the hemiplegic patient in the control of simple defects of locomotion and other stereotyped, semi-automatic motor activities. However, a limiting factor has been the nonavailability of suitable electrodes. In this connection, since the area of attachment for the electrodes undergoes considerable adjustment during movement, ordinary electrodes and attachment methods were inadequate.

[Δ]Partial or complete paralysis of the muscles of one side of the body following damage to the upper motoneurons from any of a variety of causes such as brain injury, inflammation or tumor, and most frequently, cerebral occlusive disease.

The rehabilitation center researcher was placed in direct contact with Ames Research Center researchers who were undertaking advanced developmental work in ultra-flexible electrodes and wires technology. As a result of this contact, the Ames researchers fabricated specially shaped flexible electrodes for external attachment to the leg. The Problem Originator has evaluated them and has expressed his satisfaction with the electrodes.

Another rehabilitation center is presently evaluating these electrodes for use in a fully implantable nerve stimulation system. A conductive cuff of elastomeric material will provide a soft, nonabrasive contact with the peroneal nerve.

Tendon Mender. A NASA-developed technique for butt-welding fine gage wire (NASA Tech Brief 70-10136) is being evaluated for placing barbs on fine wire pins (Figure 34). These pinds will be used to hold the severed ends of tendons together while they are healing. The technique was originally developed by the Langley Research Center for welding thermocouple junctions using fine gage wire 0.001 inches in diameter.

Surgical restorations are required to regain mobility functions after tendons have been severed by accidents and injuries. Wire and other suturing materials have been employed to bind the tendon ends in close proximity to permit healing to anatomically join them again. These procedures required followup surgery in many instances for the purpose of exposing and removing the suture materials following the healing. Cosmetic and plastic surgery frequently was necessary to repair the area as a result of the scarring.

The University of Utah Problem Originator sought the means to butt-weld barbs along the shaft of a fine gage wire so that it could be inserted as a pin into both of the cut ends of the severed tendon. His idea was to so angle and place the barbs that they would present minimum resistance by flexing as the

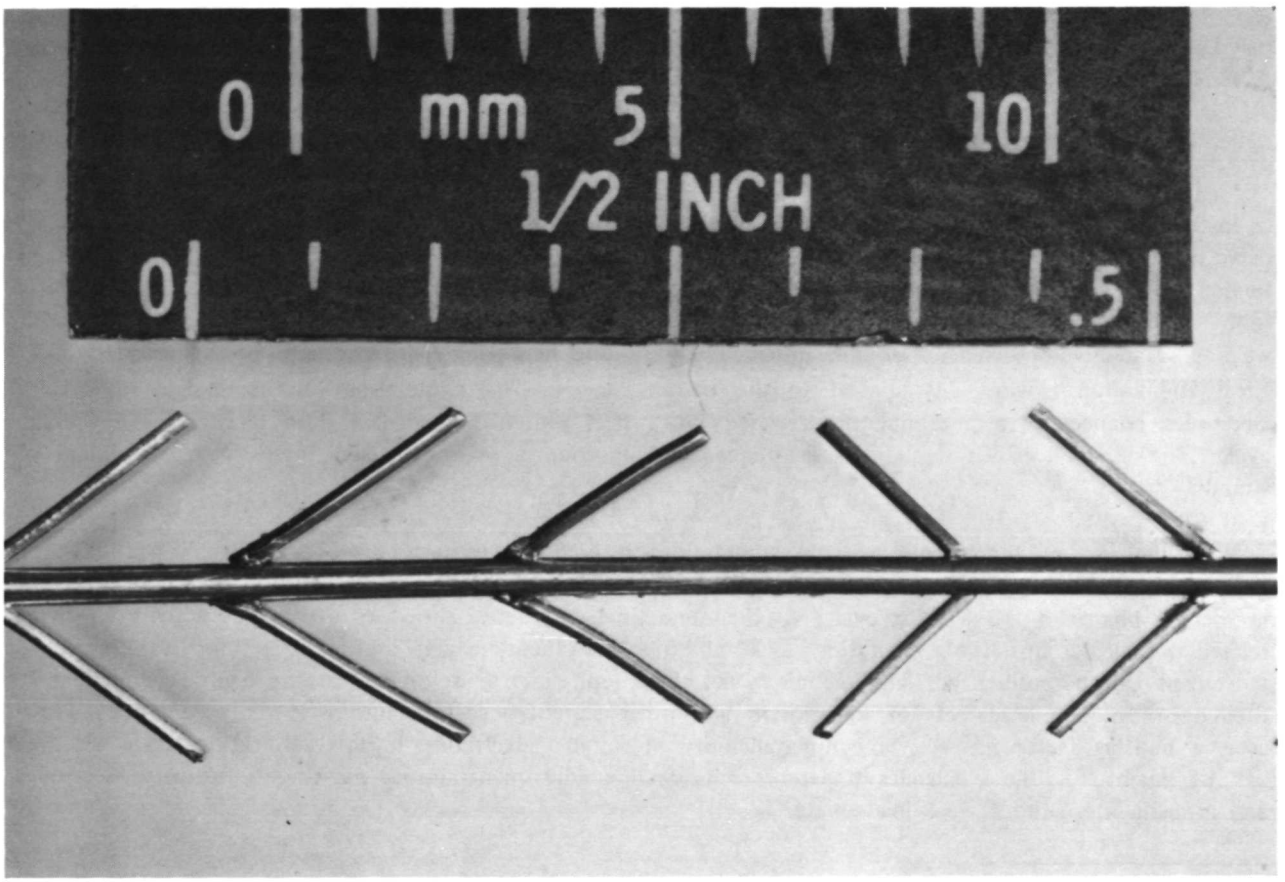


Figure 34. Tendon Mender Pin

pin is inserted. Any outward pull by either cut end could cause the barbs to catch into the tendon material without inverting to present maximum resistance to pullout. This pin could remain in place after healing since it would resist any tendency to migrate in the tissue and would present no biocompatibility problems.

A number of these pins have been fabricated at Langley Research Center and will be tested in dogs in the near future.

Battery State-of-Charge Indicator for Powered Prosthetic Device. Powered hand prosthetic devices presently manufactured use rechargeable nickel-cadmium batteries. A University of Michigan group wanted to measure the total current drain on the battery pack during normal daily activity. They wanted to minimize the size of the battery pack, since excessive batteries would contribute added weight, yet excessive discharging would damage the batteries.

The group was familiar with the electrochemical coulometer circuit that was used by NASA to monitor the condition of spacecraft batteries. The NASA Technical Note NASA TN D-5773, "Mercury Electrochemical Coulometer as a State-of-Charge Indicator," was sent to the investigator. He used the ampere-hour type state-of-charge indicator for a dc system as described in the technical note. This circuit measures the total battery current.

The batteries in the prosthetic power pack are charged to full capacity and the coulometer set to zero each night. During the day, while the patient pursues his daily routine, the total current from the power pack is monitored. At the end of the day, the amount of power used is recorded. This information is used to size the power pack so that there will be sufficient capacity for this individual's activity but not enough excess to cause unnecessary added weight and bulk. The state-of-charge coulometer will provide better design data for prosthetic power packs and will facilitate the modification of power packs to individual requirements.

REHABILITATION MEDICINE: PATIENT ASSISTANCE DEVICES

Anti-g Suit to Control Hemophiliac Bleeding. Hemophilia is a physically and psychologically crippling disease which, according to National Hemophilia Foundation figures, affects more than 60,000 Americans. Afflicted children rarely reach adulthood without disabling joint deformity, contractures, and muscle atrophy due to recurrent hemorrhages following even minor trauma. Maternal over-protection, fear of injury, and recurrent hospitalizations isolate the hemophiliac child from his peer groups and often lead to severe psychoneurosis. Employers are reluctant to hire the adult hemophiliac because of exaggerated fear of work related injury and excessive sick leave. The cost to society of hospitalizing and supporting these otherwise normal individuals is enormous.

The current treatment of hemophilia consists of the administration of fresh blood or plasma to replace the deficient antihemophilic globulin factor (AHG). The use of AHG concentrates and cryoglobulins gives promise of prevention, but is limited by the development of neutralizing antibodies in 10 percent of the patients, frequency of injections required, and excessive cost (of AHG). Clearly, any technique or procedure which could prevent or minimize initial bleeding into the muscle or joint (which can sometimes exceed one quart) would be a valuable adjunct in the treatment of hemophilia. Not only would the subsequent crippling effects be reduced, but equally important, the afflicted child or adult could interrelate more normally with his peers.

The use of external body counter pressure, as exemplified in the modern anti-g suit, seems ideally applicable for use by the hemophiliac. A garment containing a system of inflatable bladders could be worn as an outer coverall which would appeal to a child or as an undergarment under regular clothing. Immediately after a fall or suspected injury, the child could inflate the suit by simply activating a compressed gas cartridge attached to a belt or other easily accessible area. This would result in immediate immobilization of the injured limb, and by forced extension of the joint, a reduction in the size of the joint space into which potential bleeding could occur. The current design concept (Figure 35) provides that the

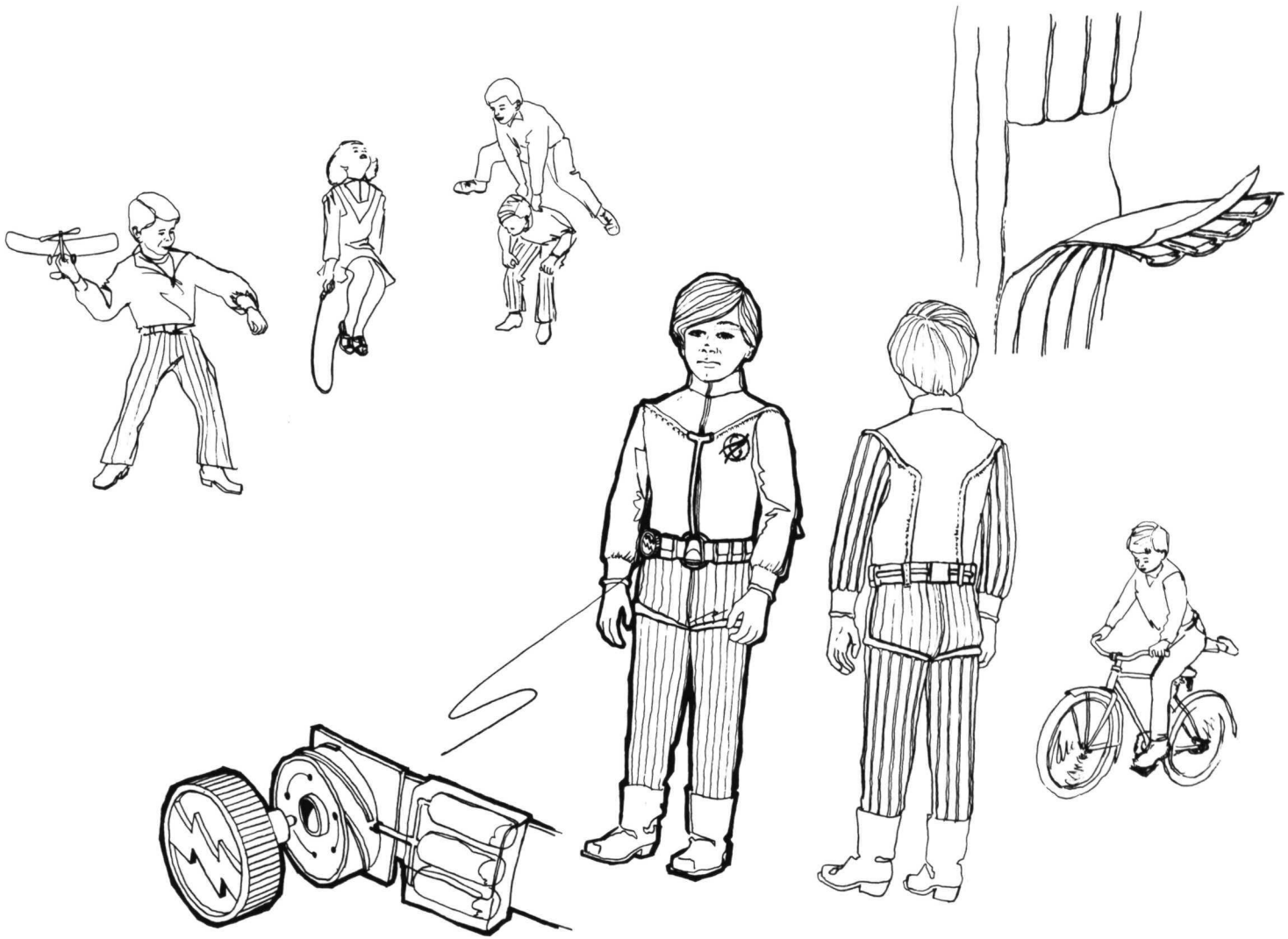


Figure 35. Concept for Application of Anti-g Suit to Hemophiliacs

bladders be inflated to prevent pooling of blood in the extremities. Also, the bladders can be removed to permit laundering or interchanging of garments. The use of the anti-g suit in clinical medicine is not without precedent. Physicians and researchers at NASA's Ames Research Center and Stanford University Medical Center recently reported a case in which an anti-g suit was able to arrest life-threatening hemorrhage in a young woman on whom standard techniques were unsuccessful. The dramatic response in this case prompted the researchers to consider the possible application of the g-suit concept in hemophilia. Their report contains a theoretical discussion of possible mechanisms by which external counter pressure is able to control internal hemorrhage.

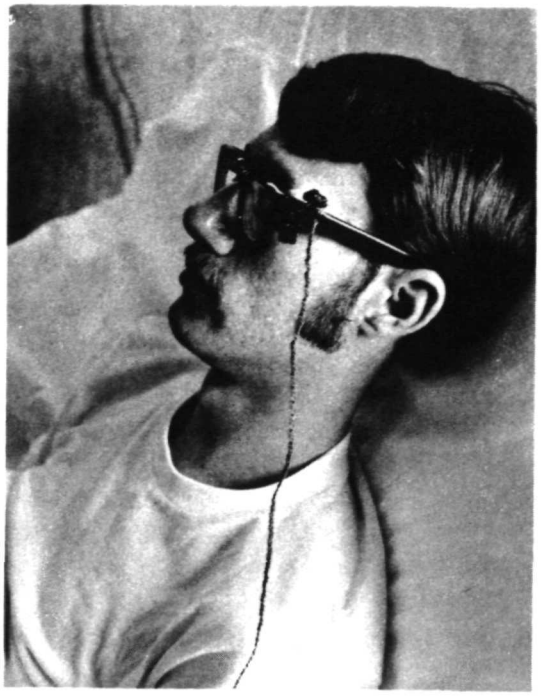
The Technology Utilization Office is presently funding the fabrication of a prototype "antihemophilia g-suit" for evaluation on suitable patients in a controlled clinical setting. As of January 1972, two suits have been built and are presently being worn by children who are patients at the Kaiser Hospital in Santa Clara, California.

Assist Device for Totally Paralyzed Patients. The Vietnam conflict, plus the increasing incidence of serious automobile accidents on the Nation's highways, have resulted in a large number of totally paralyzed (quadriplegic) patients. These patients are confined to hospitals and extended care facilities. Depending upon the level of spinal cord injury sustained, some may have limited use of, for example, the fingers. Others, however, cannot even move their little fingers or move their heads. Obviously, such patients must of necessity depend upon others for everything that is done for them–from feeding and bathing to turning off the lights when they wish to sleep. Rendering the matter even more difficult is that such patients–having no control over their extremities–cannot activate the call system to summon the nurse for assistance when needed. The result for those quadriplegics who survive (many do not for extended periods) is an unending succession of long hours at the complete mercy of others.

The Veterans Administration Regional Office in San Antonio had placed a quadriplegic veteran in one of the local nursing homes and, having learned of the NASA efforts in rehabilitation during a recent state-wide rehabilitation conference, solicited help in devising some means for helping the veteran perform such simple functions as turning the page of a book or magazine, or turning on a radio or television set–to help add more meaning to his daily life. The veteran, despite the severity of his affliction, remained exceedingly alert and desperately wanted to do something other than continually watch the television set in his room–unable to change the station or turn the set off. He particularly wanted to be able to read books and magazines. This presented quite a problem, because, even with the utmost effort, the individual could not move his arms or hands to activate a control mechanism. The matter was complicated even more by the inability to move the head, which motion could perhaps have been used to activate a control device.

It appeared that an ideal solution might well be provided by using the NASA-developed sight switch (Figure 36), presently being evaluated as a control mechanism for electric wheelchairs. Accordingly, arrangements were made to obtain one of the sight switches for trial (a unit was obtained with the help of TUD, NASA). The sight switch was found to work exceedingly well with a standard mechanical page turner and required only a modest adaptation to put into use. This adaptation involved designing a circuit that could complete the page turning (or other action) sequence–without the patient having to keep his eyes turned towards the switch while the action sequence was underway. With the modification, one brief glance activates the page turning mechanism which completes its cycle automatically, allowing the patient to return his eyes to the normal forward position, thus avoiding undesirable eye strain.

The eye switch is considered superior to possible alternative control methods, such as intra-oral switches. These are subject to deterioration in saliva and, in addition, present sanitation problems. A further advantage of the eye switch is that it can, by adding simple logic components, control other functions designed to help give the totally paralyzed patient some measure of control over simple daily activities. The activities include turning on or off his room lights, calling the nurse or attendant when he needs help, turning on a special "talking book" phonograph when he tires of reading and–if interaction with the Southwestern Bell Telephone Company proves successful in adapting a telephone instrument–being able to call family and friends when he wishes, without the intercession of a nurse or attendant to place the call for him.



The Sight Switch Set is a unique switching device, which requires only movement of the eyes to actuate, and provides a "hands free" mode of control. It is small and suitable for mounting on a normal pair of eyeglasses or eyeglass frames. It consists of a low intensity light source and a photodetector to sense variations in light reflected from the sclera of the cornea of the eye, which can then be used to actuate control mechanism.

The NASA switch (with amplifier) interfaced with a mechanical page turner. To turn the page, the paralyzed patient need only turn his eye slightly towards the eye switch. Light reflected from the eye is picked up by the sensing unit built into the switch. In turn this energy, upon amplification, actuates the page turner. This eye operated switch can also be used to control a television set, a radio, the room lights or other devices.

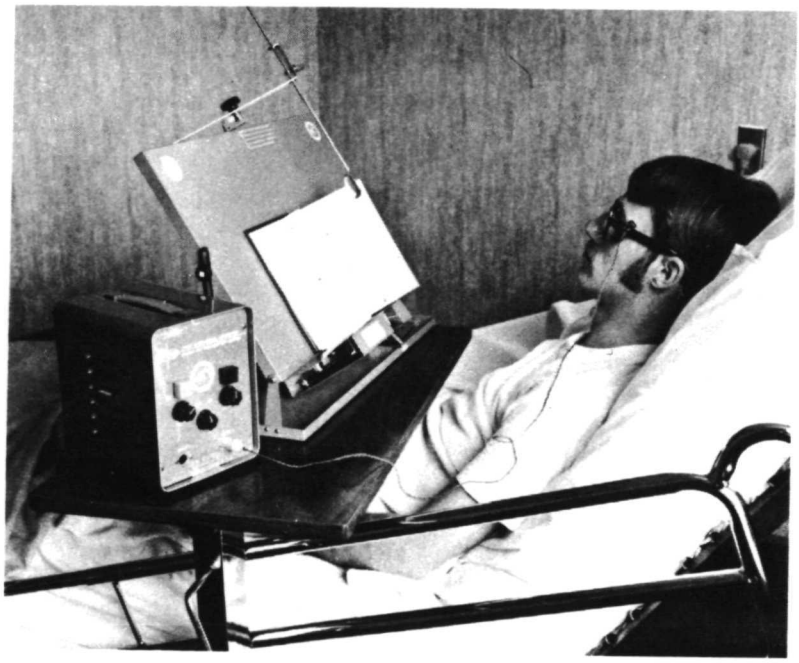


Figure 36. The NASA Eye Operated Switch in Use

Eyeswitch Operated Wheelchair. Quadriplegics, who are denied the use of both arms and legs, can now use their eyes to operate a motorized wheelchair (Figure 37) with a mechanism called a Sight Switch. The Sight Switch uses sensors mounted on eyeglass frames to start, stop, reverse, and turn a wheelchair by eye movements alone. The device was developed originally so that astronauts could control the flight of their space vehicle while immobilized under high gravitational forces. The switch is now being manufactured and is undergoing tests at rehabilitation centers. It is estimated that, in addition to more than 100,000 quadriplegics in the U.S., other handicapped persons will benefit from the new mobility achieved from use of the Sight Switch.

Sight Switch Control of Prehension Devices. Some partially paralyzed and amputee patients could utilize orthotic support device assistance for self-care or productive work rehabilitation. Prehension devices are a class of orthotic support devices which have proved extremely useful in restoring functions that this group of handicapped has lost. The prehension devices are becoming increasingly more sophisticated as better modes of operation are developed and limits of control refined. The devices have been particularly useful in restoring these patients' mobility and self-care.

Typically, movements of various muscles and body parts are used to activate the drives and linkages which permit the person to control positioning of the device, or to control the degree of pressure applied. However, there are some patients, particularly those afflicted with a disease involving spasticity and muscle tremors, who are unable to utilize this method of control. The Problem Originator needed an alternative method, one that is relatively easy to operate such as a basic on-off, all-or-nothing activating switch. This type of switch is expected to facilitate the training required for patients to learn to operate the orthotic device and improve the capacity of individuals to use the device for various tasks.

Several alternative control devices were evaluated and it was determined that the sight-operated switch would, again, be a suitable control device. A sight switch has been obtained and is presently being incorporated into the control mechanism of several orthotic devices being fabricated at a rehabilitation center. It is expected that the technology application outlined will have considerable application throughout the nation in hospitals and extended care facilities caring for quadriplegic patients who are unable to perform even simple functions for themselves. For this reason, special material that outlines this technology is being prepared. This will make others aware of what can be done, at a most modest cost, to add a great deal of meaning to the daily lives of totally paralyzed patients.

Improved Control Mechanism to Improve the Self Sufficiency of Quadriplegics. Logic circuitry and microswitches used extensively in aerospace instruments have been applied by NASA Langley Research Center engineers to develop a device to substantially improve the self-sufficiency of quadriplegics.

Patients who are paralyzed in all four limbs (quadriplegics), multiple amputee patients, and patients with severe neurological disorders are almost totally dependent upon support from patient care personnel for any activities or interests in which they can participate. The morale of such patients is markedly improved and the demands on patient care personnel are greatly relieved by any device or procedure which aids self-sufficiency. The extreme limitations of the quadriplegic and the shortage of patient care personnel have become significant medical problems.

The Problem Originator had evaluated the self-sufficiency potentials for the NASA-developed eye switch. That technology application benefited the situation, but it also introduced irritations of the eyes when the cornea was exposed to the light for extended time periods. Some patients felt encumbered because they had to wear the eyeglass frames up to 24 hours each day. Some disorientations were encountered when they repeatedly looked away from what they were doing to actuate the eye switch. The glass frames tended to obstruct their already limited viewing area. The Problem Originator sought an alternate means to replace the eye switch, still within the capabilities of these patients to operate them.

Some of the quadriplegics are able to make limited head and neck turns to either side. Some are able to control the movement of a finger or a toe. Most of them could produce a directed puff of air. These factors were carefully considered and applied to the search for an alternate system.

The sight switch, originally developed to permit astronauts to control space vehicle flight under high gravitational force by the movement of their eyes, has been adopted to permit paralyzed patients to control the motion of the wheelchair.

Figure 37. Eyeswitch Operated Wheelchair

Scientists and engineers at NASA Langley Research Center proposed and outlined a complete control system which could be actuated by a puff of air directed against a paddle to contact a microswitch.

NASA Langley Research Center coordination was provided through the Technology Utilization Office to design a breadboard model for a prototype system (Figure 38) using a breath-actuated microswitch.

The original prototype system was produced and has been modified to expand the capabilities to accept input from a variety of actuating sources. It will respond to the eye switch, a breath-puff switch, a toe or finger switch, and a pneumatic pressure switch which the patient can actuate by slightly turning his head. Additional circuitry was built into the electronic control box to permit the patient to selectively activate any one of six electrically operated appliances.

Extensive testing has proven the feasibility and operational capacity for each of the alternative actuating control devices and the coupling to selectively control the activating switches, within the capabilities of the patients who would use them. The system has been installed in a rehabilitation center and patient response has been quite favorable.

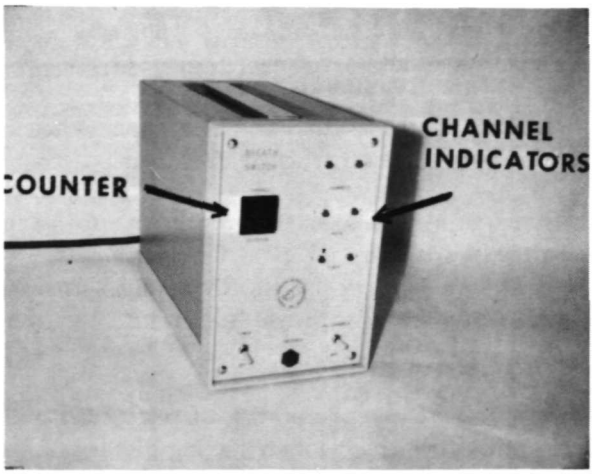
Pressure-Sensitive Device for Use in Tongue-Operated Control Systems for Assist Device and Wheelchairs. Severe neuromuscular disabilities are frequently fatal. Improved patient care, however, has increased the number of patients who survive severe paralysis. Such patients are continuously bedridden with severe functional limitations. But their dependency can be lessened through technological devices and improved methodologies that develop and encourage self-sufficiency. Without it, total care for paralytically disabled patients is not only difficult but also very expensive.

Researchers at the Rancho Los Amigos Hospital have had long experience in developing a variety of specialized new orthopedic methodologies and devices. They work with severely disabled neuromuscular and amputee patients to develop self-sufficiency through added mobility. A basic wheelchair, for example, has been modified through the addition of an electric motor, switches, and other attachments. It can now be operated forward and backward, turn, and go up and down inclines or stairs. The researchers have also been successful in refining chair control and operation so that it can be used by paralyzed or amputee patients whose muscular use is limited to control of the eyes, mouth, and head. Such chairs have now become commercially available.

Considerable progress has also been made in developing control systems for externally powered orthotic devices. Extra-oral, tongue-operated switch controls provide sequential off-on control of the orthosis, and show promise as a means of providing control. The Problem Originator at the Rancho Los Amigos Hospital requested assistance from NASA personnel for technology adaptable to incorporation in a reliable, saliva-resistant switch that is small enough to fit the lingual area of the mandible, and sensitive to tongue pressure operation. A pressure sensitive semiconductor device, identified in a NASA Tech Brief, appeared promising. The device is an insulated-gate field effect transistor that performs strain sensing and amplification functions in one hermetically sealed, integral package.

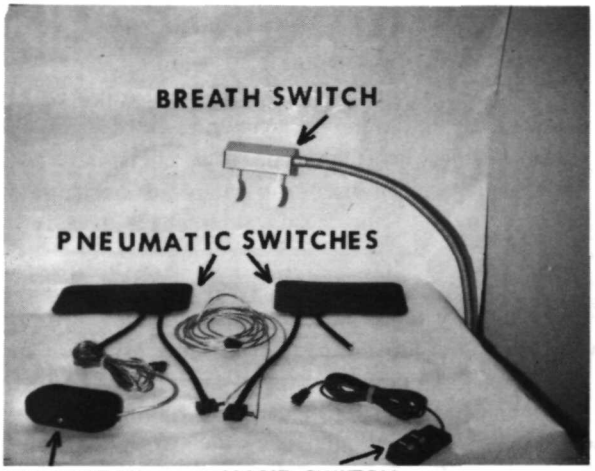
The Problem Originator plans to incorporate the device into a switching unit to vastly improve the control devices currently in use. It will, for instance, permit the chair operator to achieve controlled gradual accelerations (and decelerations), a feat not possible with current on-off control systems. The Applications Program has funded the custom fabrication of several of these devices for clinical evaluation.

Paper Transport for Vocational Rehabilitation. As the result of a request of the Woodrow Wilson Rehabilitation Center to NASA for assistance, an engineer at NASA's Langley Research Center has developed a device (Figure 39) which may enable a severely disabled quadriplegic to be financially self-sufficient. The number of vocations available to severely disabled quadriplegics is extremely limited. Many such patients maintain so little control of their musculature that the only basic proficiency which they can acquire is to punch pegs or to depress keys on a keyboard. The Training Division of the Woodrow Wilson Rehabilitation Center is constantly seeking vocations for which these patients can be trained.

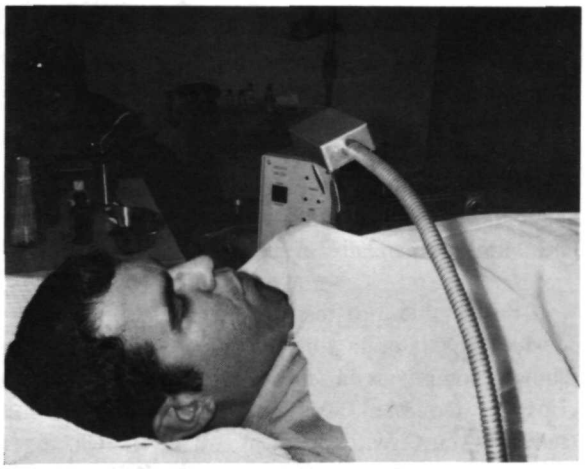


Logic unit for the automated patient environment control unit. The channel indicators light up when a given channel is activated, permitting the patient to know at any given instant which channels are activated. The counter (or digital display unit) permits the patient to follow the channel selection sequence so that he knows precisely what channel he is on at any given time during the channel selection operation.

Rear view of the logic unit showing the outlets where patient assist/comfort items are plugged in (such as lights, radios, television, page turner, electric bed adjustor, etc.). Each outlet corresponds to a particular channel on the logic unit.

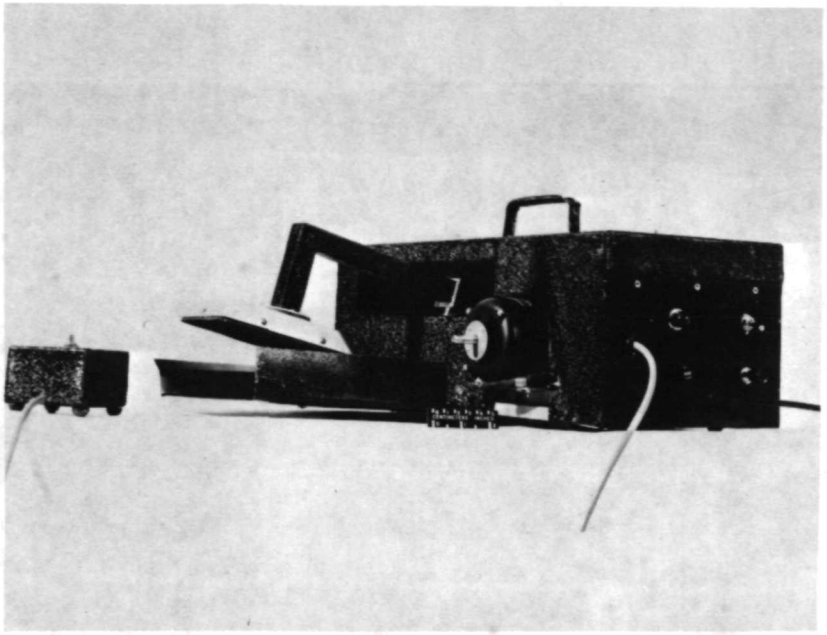


Various types of switches available for use with the logic unit. Not shown is the NASA-developed eye switch, which can also be used. The pneumatic switches are placed adjacent to the patient's head. A slight pressure activates the logic unit. One switch functions as a channel selector; the other functions to turn the channel on or off.



The automated patient environmental control unit in use with the breath-actuated switch. The innovation permits totally paralyzed patients to control assist/comfort devices merely by gently blowing on the breath-actuated switch. For the lesser disabled patients, other types of control mechanisms (see illustrations to the left) can be utilized as inputs into the logic unit.

Figure 38. A Patient Assist System Featuring a Variety of Control Switch Capabilities



The first prototype of a paper transport system which would permit disabled patients to perform bookkeeping and clerical tasks.

Figure 39. Paper Transport

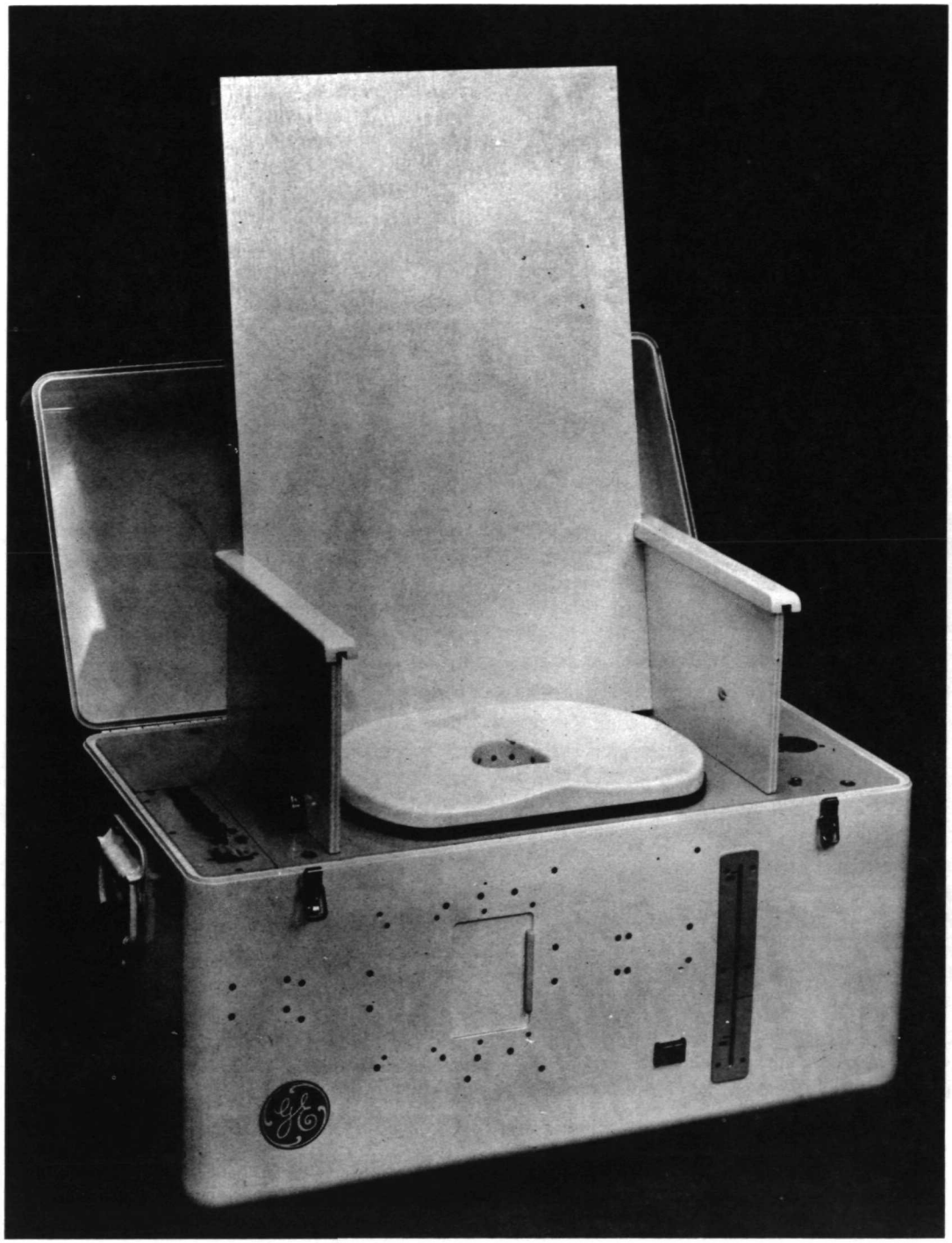
Quadriplegics can operate a specially designed bookkeeping machine so far as entering the data is concerned, but generally the data is not in a form which is readily visible to them. In most instances, businesses which would employ a quadriplegic to do this sort of activity (perhaps in his home) would bring a stack of tickets to the quadriplegic for him to enter into the machine. This poses a difficulty since the quadriplegic cannot reach over and remove the tickets from the stack. Consequently, he cannot gain access to the tickets underneath the top ticket unless someone is present to transport the top ticket off the pile and into another pile as he enters the data. A simple device which could be remotely controlled by means of a single button was required to pick up or attach to the top ticket on a stack and remove that ticket to another location nearby. Stacking from one tray to another was desirable. The person who delivers the tickets would be able to stack them in the tray as needed by the pick-up device.

The device uses a vacuum pick-up with a transport mechanism operated by an electric motor. A working prototype has been fabricated and is being evaluated at the rehabilitation center. It is expected that a refinement of this model to reduce size and mechanical complexity will be undertaken should this prototype model prove acceptable. The cost of the design is quite low so that acquisition of the machine would not impose an economic burden on quadriplegics wishing to use such a device.

Hydro-John. Persons afflicted with cerebral palsy sometimes have difficulty controlling the processes of urination and defecation. This can be a serious social and psychological problem for the individual, particularly during rehabilitation classes. The use of volunteers in rehabilitation and training makes the problem even more difficult because of their lack of experience and the somewhat objectionable situations that may occur.

A potential solution to this problem was found to be the "Hydro-John" developed for the "Skylab" (Figure 40). Features of the unit that are particularly favorable are its self-contained, automatic sanitation of the anal area, and the containment of objectionable odors.

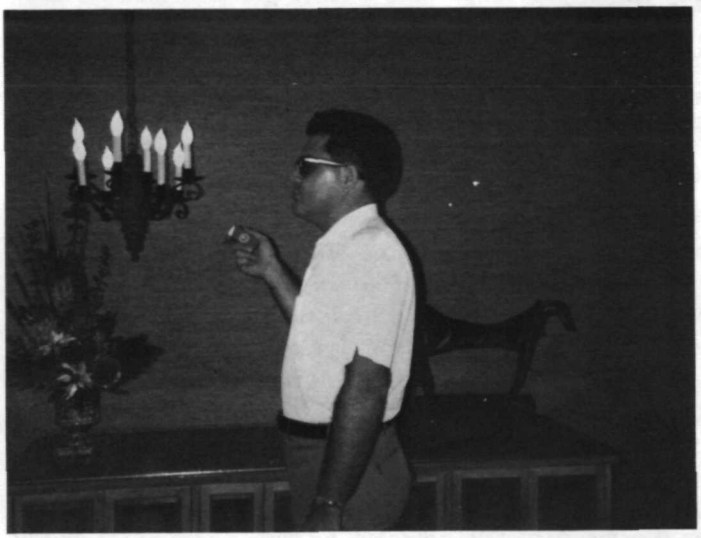
The unit was loaned to the United Cerebral Palsy Association Center for evaluation. Based on the experience then gained, several modifications were suggested to be incorporated in a unit specifically for handicapped individuals.



Persons affected with cerebral palsy and spinal cord injuries have difficulty controlling the processes of urination and defecation. The Hydro-John built for the "Skylab" may provide a partial solution in that it is completely self-contained and provides for automatic sanitation of the anal area and containment of objectionable odors.

Figure 40. Hydro-John

The light detector can indicate to the blind whether it is daylight or dark outside, or if interior lights are on.



Portable light detector emits an audible tone which varies in amplitude and frequency to indicate to the blind the presence or intensity of a light.

It can also indicate when automatic cooking devices (coffee pot with pilot light) have completed a cycle.

Figure 41. Light Detector System for the Blind

Specifications have been drawn up for a small portable urinal that could be mounted underneath the seat of a wheelchair. A number of physicians have shown interest in the washing, wiping, and drying seat which seems superior to currently available commercial units and would be of great benefit to stroke and paralysis patients. The basic "Hydro-John" system has been demonstrated to several agencies responsible for physical rehabilitation, such as the Veterans Administration and the Social and Rehabilitation Services of HEW. Discussions are currently underway to explore the construction of additional prototypes and the possibility of commercializing the product.

Portable Light Indicator for Use by Blind Persons. Though lights are of no value for the blind, they are used nevertheless, particularly when the blind individual is being visited by those individuals who have use of their sight. Knowing when lights are on or off presents a problem for the blind–particularly in the case of ceiling lights which cannot be touched to feel the heat associated with an illuminated light bulb. Lights unnecessarily left on are not only wasteful but are safety hazards and tend to alarm neighbors who sense something may be wrong when left on at night. In addition, it is important for the blind persons to be able to know when lights are illuminated in areas presenting safety hazards to visitors–such as stairways during the hours of darkness. The Texas Commission for the Blind requested NASA assistance in developing a small handheld device which would activate an acoustic signal when it was pointed towards a source emitting light. A search of the NASA data bank revealed technology directly applicable to the problem. Four prototype light indicators (Figure 41) were fabricated under NASA sponsorship and are now undergoing testing in conjunction with the Texas Commission for the Blind. As a result of these preliminary field tests, future units will be made more directional and more rugged.

Portable Sound Meter for Use by Deaf Persons. The person with normal hearing has little difficulty with the values of ambient sound and the amplitude of his own voice output in learning to speak, because they are automatically assessed by his hearing abilities. The deaf person can be taught to speak effectively although unusual difficulties are encountered because he cannot realistically gauge the levels of sound. He has no way to estimate the noise level in any surroundings and can only estimate the acceptable level of his own speech amplitude by observing reactions of persons in that vicinity. Deaf persons are very sensitive about offending others with extraordinarily loud or unusual speech sounds, and they encounter many psychological problems when it is necessary to talk with others in public or in private. The problems are severe when teaching deaf persons to speak and exist in interrelations for the rest of a lifetime. Deaf persons need a simple and portable means for assessing amplitudes of sound. A solution to this problem, posed by the Texas Rehabilitation Commission, was proposed by an engineer at Kennedy Space Center. The solution involved a battery-operated device containing a microphone, amplifier, potentiometer, and meter.

The problem was nominated as an applications engineering candidate and a prototype unit developed. By observing the meter (Figure 42) as he speaks, the deaf person can maintain his voice within calibrated ranges.

New Type of Tracking Cane for the Blind. Blind individuals do not have at their disposal an economical cane which they can use to "track" a previously laid out course, as a means of providing a greater measure of self-sufficiency. The more sophisticated canes developed as aids to the blind (laser canes, ultrasonic devices, etc.) are not within the economic reach of the typical visually handicapped individual. A more economical, but effective alternative is needed, particularly for use in rehabilitation centers, homes for the blind, etc., where the number of blind persons present make it worthwhile to lay out a guidance track. A flash sheet prepared at NASA's Marshall Space Flight Center (ATTS-TU MSFC October 9, 1970) describes a new type of cane (Figure 43) for tracking. This concept involved a grooved track which was not very practical to lay down due to cost. However, by adapting the MSFC cane to include the optical sensor used in the NASA sight switch, it is possible to have an effective tracking-sensing system which meets the needs described above. Use of the optical system permits a track to be laid down quite readily with paint, a durable adhesive tape, inlaid tile, or conventional carpet. The system will allow incorporation of coded information such as right or left turn, stairs ahead, or other hazards, so as to permit the visually handicapped person to negotiate the track with greater speed and assurance.

The NASA-developed miniature portable sound meter (on the right) compared to the conventional portable sound meter. The miniature unit will enable a deaf person to gauge the surrounding noise level and the loudness of his own voice so that he may speak loudly enough to be heard yet not be shouting.

Figure 42. Portable Sound Meter

An optical sensor built into the tip of the cane permits a blind person to follow a track marked on the floor with paint or tape. Installed in rehabilitation centers or homes for the blind, the track can contain coded information warning of turns or hazards, enabling a visually handicapped person to move around more easily in unfamiliar areas.

Figure 43. Tracking Cane for the Blind

Improved Powered Prosthetic Device. Notwithstanding the sophisticated nature of presently available artificial hand prostheses, amputees and paralyzed patients have to use both artificial hands to manage a single power tool. Rehabilitation researchers have been seeking improvements for the manipulating capabilities to expand the limitations for self-help and job performance.

NASA had developed several powered terminal devices and appropriate control systems to operate a manipulator device in outer space and to remotely control vehicles. Spinoffs from those programs were combined to produce an upgraded, proportional control system which vastly increases the range of dexterity and the case with which a totally paralyzed or amputee patient can use a prosthesis, arm or hand.

Using this powered, prosthetic, terminal hook device, a patient is enabled to single-handedly operate power tools such as electric drills, soldering guns, etc. Control of the device is positive and delicate enough to avoid danger when picking up and drinking from a hot cup of coffee. Another version permits the individual to write and perform many complex tasks. Women are able to use the technology to apply makeup to their faces, unaided.

The rehabilitation hospital that collaborated in the original development of the device for NASA is presently making extensive evaluations of it. The preliminary reports indicate they believe it will prove to be a significant breakthrough and contribution in the field of rehabilitation.

OTHER PUBLIC SECTOR EXAMPLES

HOUSING & URBAN CONSTRUCTION

Fire Retardant Coatings–Intumescent Paints. Intumescent paints, which swell when heated to form an insulating carbon char, have been commercially available for some time. However, many of these commercial paints tend to be deactivated in high-humidity conditions, lack good color stability, have poor mechanical properties and poor pigmentation qualities. NASA's Ames Research Center has developed a new class of intumescent paints which eliminates these undesirable properties (Figures 44 and 45). These were developed essentially for use on the interiors of aircraft and spacecraft.

Significant advantages of the NASA paints over commercially available coatings are their hydrolytic stability, superior optical and mechanical properties, and greater heat stability of their char. Disadvantages of NASA's coatings include a toxicity problem resulting from SO_2 given off from the film upon expansion, and ultraviolet degradation of the binder upon exterior exposure.

The intumescent agents developed by NASA are monomers based on p-nitroanaline and sulfuric acid, which undergo a complex series of condensation reactions when heated to temperatures above 350°F. Gaseous products are produced (H_2O, SO_2, N_2) simultaneously with a black, char-like, heterocyclic oxidation-resistant polymer. The polymer is blown into a low-density surface foam by the escaping gases. This char is stable to temperatures of 1000°F, and with low density (0.1 to 0.3 lb/ft^3) results in a closed cell structure; the resultant very low thermal conductivities provides excellent heat protection

The National Association of Home Builders identified a new use for these paints. Fibre Reinforced Plastic (FRP) shower stalls and tubs have been sources of fire in buildings under construction. Plumbers, accustomed to working with metal fixtures have, on occasion, inadvertently set fire to the FRP with pipe-soldering torches. The manufacturers of the FRP fixtures saw a need for protecting the areas that the torches might burn; so the International Association of Plumbing and Mechanical Officials and the National Association of Home Builders (NAHB) Research Foundation developed a test procedure for these fixtures. The test involves placing a 1-inch flame from a propane torch on the FRP for 30 seconds and timing the duration of the resulting burn, waiting 2 minutes, then repeating the test at the same spot. In no instance may the FRP continue burning more than 30 seconds after removing the flame, or it fails the test and is unacceptable.

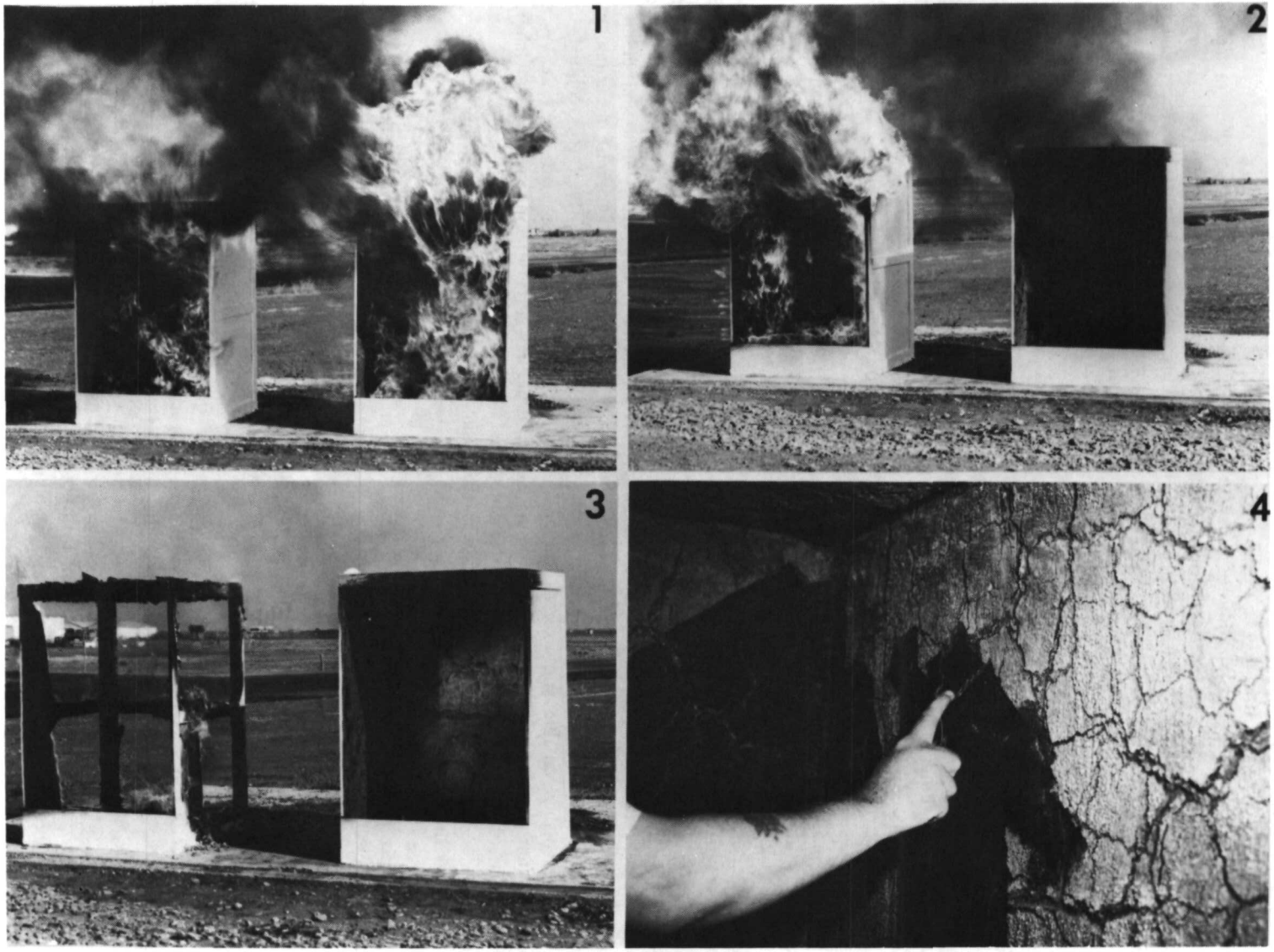
The AVCO Corporation is producing intumescent paint under a NASA license to determine its commercial applications. When samples of FRP fixtures were coated with the intumescent paint and tested at the NAHB Research Foundation Laboratories, durations of burns were under 10 seconds with indications that less than 5 mil thicknesses of the paint would provide adequate protection. The company is currently surveying other potential markets and applications for the intumescent paint.

Intumescent Mastics. Mastics are high-viscosity pasty materials used as protective coatings or cements. Because steel loses its structural strength early in a fire (strength of structural steel at 950°F is 40% of strength at 70°F), some building codes require compensating protection. For example, the State of Michigan requires 1-hour protection for structural steel in school buildings, and New Jersey requires 30 minutes. Mastics are generally applied with spray equipment to a one-half inch thickness. Concrete is a commonly used mastic material.

NASA, as a result of its interest in heat ablation, for a variety of purposes, has developed a new, highly stable class of intumescent materials which can be formulated as mastics by the addition of short fibers of glass. The Ames Mastic 313 was developed by the Chemical Projects Research Office. Currently, a sample of the mastic has been prepared by Ames, and tests are being conducted by the AVCO Corporation to compare the efficacy of the NASA mastic with two commercially available materials. When the tests are completed, the New York Urban Development Corporation will evaluate the utility of the NASA material for use in its program for building a great number of housing units in New York State.

NASA-developed fire retardant coating, recently advertised in technical magazines, exhibits improved weathering properties.

Figure 44. Intumescent Paints



Test of fire retardant intumescent paints, showing coated and uncoated structures. Photograph 4 shows the heavy layer of char which acted as insulation.

Figure 45. Intumescent Paints

Fire-Retardant Foams. Fire-retardant foams are needed in the construction industry for use in thermal insulation and fire-resistant paneling for buildings. NASA's Ames Research Center has developed a class of fire-retardant foams which might meet this need. The NASA foams are based on isocyanurate (ICU) chemistry, and were developed principally for use in military aircraft.

Isocyanurates, formed by the trimerization of isocyanates, are flame-retardant because their molecular bonds have been modified to become inherently more temperature-stable. The performance of ICU foam in the presence of fire has been tested in a NASA fire simulation facility designed to reproduce the radiative and convective heat fluxes in large fires. The time taken for a thermocouple to reach 200°F when it is located 2 inches below the heated specimen surface is a measure of the fire performance of commercial foams, with which the ICU foam was compared. ICU is available from the AVCO Corporation in containers up to 55-gallon capacity.

The Department of Housing and Urban Development (HUD) has received samples of the ICU foam, and arrangements have been made to have the Ball Corporation, an Operation Breakthrough winner, evaluate it. The evaluation will be both for difficulty of fabrication and fire retardation. So far, fire-retardancy tests required by the National Bureau of Standards and the American Society for Testing Materials (ASTM) have not been met by the reported NASA test data. The Ball Corporation will test the foam in a practical configuration, with the intention of utilizing it in their project if the evaluation is positive.

It has also been proposed that the New York Urban Development Corporation (UDC) consider the foam for areas of great fire danger (kitchen range, furnace, etc.). The UDC is particularly interested in this usage because of a fire in a modular housing unit in upstate New York; the module used polyurethane extensively, which proved to be a major problem in the fire. UDC is also considering the ICU foam as a possible panel core material for lightweight fireproof partitions.

Ultrasonic Torque Wrench. Rivets are no longer used in building construction. Unless a bolt is tightened into its elastic region, normal vibrational forces can loosen the connection and cause structural failure. Excessive torquing stretches the bolt into its inelastic region and rupture may result. Accurate measurement of the clamping force of a bolt is complicated by the frictional forces present. The force required to overcome friction is highly variable and exceeds the force required for axial extension of the bolt. As a result, architects often overdesign structures, resulting in added structural costs in both material and labor. A former chairman of the Research Council on Riveted and Bolted Structural Joints has stated that "... the tightening of high strength structural bolts is the main problem area of the structural engineer, the steel erector and the field inspector."

In response to this problem, the Marshall Space Flight Center described an ultrasonic wrench, designed by a NASA contractor, which is used to ensure leaktight connections when assembling fluid distribution systems.

Marshall Space Flight Center held a meeting in late 1971 with a commercial company interested in developing the torque wrench. At a second meeting in January 1972, the best technical approach to the torque-tension problem will be discussed. There will be representatives from the commercial company, Marshall Space Flight Center, and from Bethlehem Steel. One of the leaders in high-strength structural bolting technology, Bethlehem Steel is one of the largest U.S. steel erection companies. An applications engineering plan for the wrench will be drawn up at this meeting.

Organizations that have been consulted in order to determine the need and importance of the torque-tension problem in industry are: American Institute of Steel Construction (AISC), Industrial Fasteners Institute (IFI), and the Research Council on Riveted and Bolted Structural Joints.

Low-Voltage Switching and Flat Conductor Cable. The switching circuit commonly used in conventional electrical wiring of residences and buildings is expensive. Standard wiring practice uses a switch in series with the fixture to be switched. This necessitates bringing the power circuit from the fixture to the switch location.

Several problems are associated with switching circuits that are installed in walls. In some new systems of construction, walls are very thin, leaving little room for conduit and switch boxes. In panelized and prefabricated construction there is still significant on-site labor associated with fishing wires through conduit, and, of course, in case of a malfunction it is very difficult to repair embedded wires. Rewiring can be a significant cost during the rehabilitation of older buildings.

An investigation of alternative (and less costly) methods for the installation of electrical switches on walls was requested by the New York State Urban Development Corporation (UDC). The low-cost solution includes a low-voltage switching device developed with NASA technology and flat conductor cable developed at Marshall Space Flight Center (MSFC) (Figure 46). The system, called "Switchpack," will realize savings by eliminating the conduit network required for the switch leg of conventional circuits and by surface mounting the switching circuits. The flat cable is adhesive-backed, mounted to effect a low profile (only 7 mils thick), and is obscured by paint. The simple, inexpensive switch that accepts the flat cable can also be glued to the wall. New buildings designed to accommodate Switchpack need only provide "in situ" horizontal power runs, going up or down for outlets and/or fixtures.

Several meetings were held with large manufacturers to interest them in adapting low-voltage switching devices to the flat conductor cable. But they chose not to pursue the project. A small innovative manufacturer, Non-Linear Systems, that produces electronic parts and equipment for the aerospace industry, expressed, on the other hand, strong interest in this adaptation and developed with its own funds the necessary low-voltage solid-state switching device.

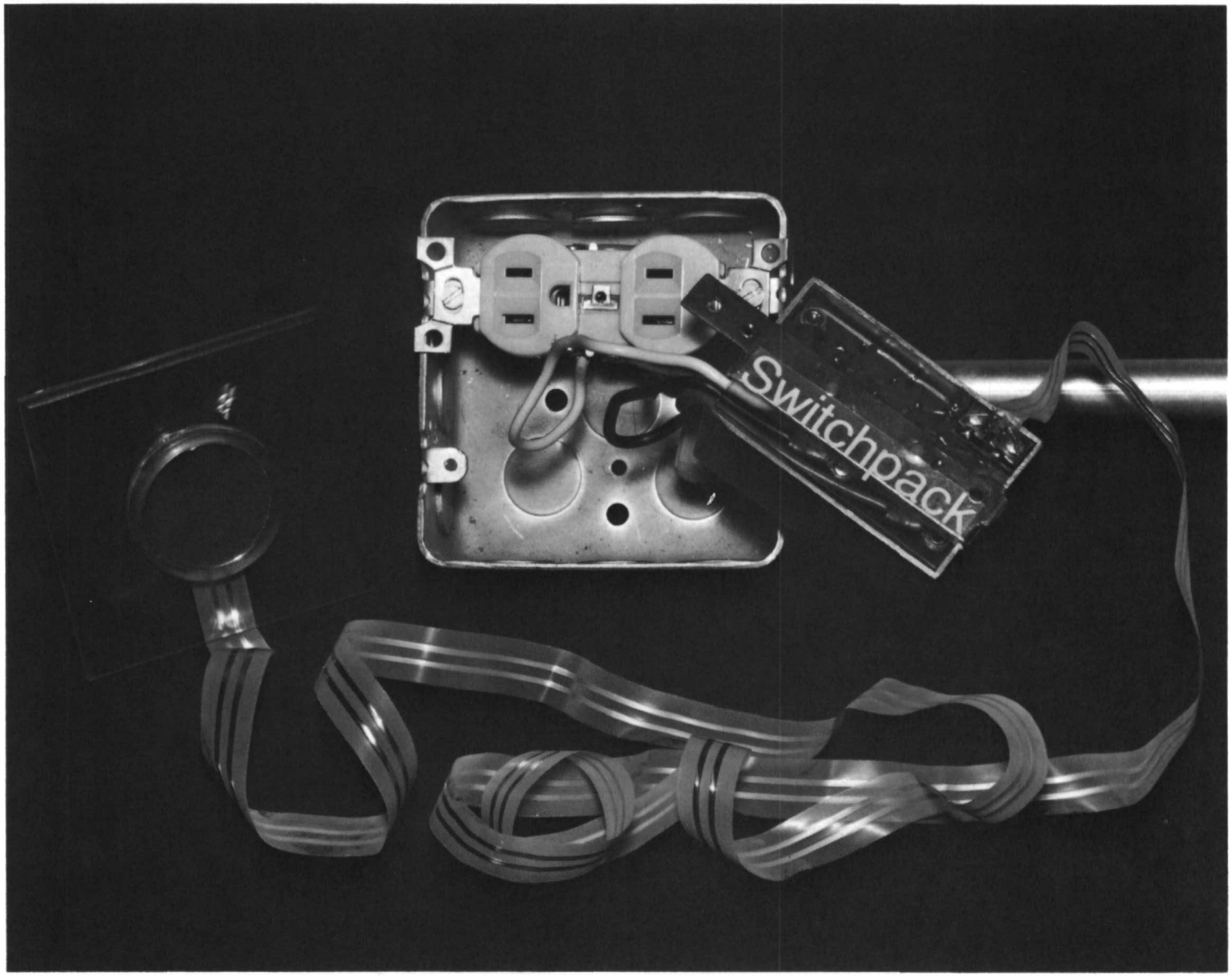
Because of the innovative nature of this device it was chosen by *Industrial Research* magazine as one of the most significant 100 new products of 1971. It was later included in the top ten new products. Its first application will be in housing projects of the UDC. It is estimated that the cost of installing electrical switches will be reduced by $15 to $35 per switched fixture in new construction and provide even greater potential savings in rehabilitation/renovation.

In late 1971, the MSFC was funded to develop a flat conductor cable to carry power circuits for residences. This is another application of previously used aircraft and spacecraft technology. Problems to be resolved during development include design of associated hardware and mounting arrangements. All work will be closely coordinated with a committee of experts to be established by UDC.

Utilization of Failure Mode and Effects Analysis. Manufacturers of consumer goods have been concerned principally in the past with developing techniques for increasing production and minimizing costs to maximize profits. Little consideration was given to techniques such as setting operational requirements or quality control maintainability. As a result, an increasing number of items in the consumer market do not operate as specified, at times are a hazard to the user, and difficult, if not impossible, to repair.

The failure mode and effects analysis technique (consisting of statistical analysis), developed by the Marshall Space Flight Center (MSFC), if implemented, could alleviate many of these problems. Because of this potential a development program was funded in late 1971. The procedure for performing failure mode and effects analyses was developed by MSFC during the Saturn Program; it was one of many analytical techniques needed to evaluate design performance against established equipment. This technique allowed the design engineer to determine the effect that failure of his hardware would have on the Saturn vehicle crew safety and mission accomplishment. Provisions were made for redesign, redundancy, safety standby condition, and the like, whenever the failure effect became a factor affecting accomplishment of mission objectives and crew safety requirements.

With this program, a similar type methodology could be developed for performance evaluation of consumer goods such as dishwashers, refrigerators, and vacuum cleaners. In the housing area, this system could be used for evaluation of systems such as electrical, plumbing, heating, and air-conditioning. It is anticipated that implementation of this methodology would result in more reliable, more easily maintained, less hazardous equipment for the consumer.



Photograph of switching device shows the thinness of the flat wire.

Figure 46. Switchpack and Flat Wire

As an outgrowth of earlier discussions, in May 1971 the U.S. Geological Survey requested NASA's Mississippi Test Facility to propose a plan by which the applicability of NASA procedures for quality control and hazard analysis to offshore oil and gas operations might be determined. With the cooperation of Marshall Space Flight Center and the Office of Manned Space Flight a study was carried out and a report written. During the study period offshore oil and gas facilities and operations were studied first-hand. The report describes preliminary recommendations for action by the Federal Government and the oil industry to provide greater assurance that offshore energy resources can be produced with reasonable safety and protection from pollution of the marine and coastal environment.

Water Recovery and Solid Waste Processing for Domestic Applications. The problem of water and solid waste disposal is directly related to increasing urban expansion. A technology resulting from NASA work on space stations can be used to develop a home treatment system which would remove potential pollutants at the source, and provide for water recovery and reuse in the home. Because of the great potential for such a system, the NASA Manned Spacecraft Center was funded in late 1971 to develop a hardware module for residential use. It will utilize aerospace-oriented low-water uses appliances and waste-collection equipment designs, coupled with water recovery, sterilization, and recycle concepts.

The goals of the system are: (1) Reduction of the quantity of water used for each function, and (2) Reclamation and reuse of waste water. The program will consist of three phases leading to demonstration of the water/waste management technology in a pilot operation. Phase I will involve design analysis to select subsystems and to prepare a preliminary system design. The functions to be analyzed include clothes washing, bathroom wash water, dishwashing and food preparation, and the commode. Phase II will entail design and fabrication of a water-recovery/solid-waste handling module with associated collection/distribution equipment in a size to support a single-family dwelling. Phase III will be the installation and demonstration of the hardware module in a mobile home or residence. This project will be closely coordinated with the Environmental Protection Agency.

FIRE SAFETY

Fireman's Breathing Apparatus. The problem of the Fireman's Breathing Apparatus originated from the need of municipal fire departments for a reliably functioning breathing device to use during fires. While most fire departments furnish such breathing apparatus, smoke inhalation is a statistically significant cause of injury. The underlying reason probably is that most fire fighters neglect using breathing apparatus because it restricts mobility and vision. As a result, men work at fires without using breathing apparatus, hoping for the best. But injury records attest that their hopes are often not realized.

NASA initiated an effort in the spring of 1971 to develop an improved breathing apparatus. This was in cooperation with the National Bureau of Standards (NBS) Office of Fire Research and Safety, and Public Technology, Inc. (PTI). PTI polled its member cities on their breathing apparatus needs, then organized a User Design Panel. The User Design Panel includes fire chiefs, city managers and a representative of the NBS Office of Fire Research and Safety. PTI has compiled the requested needs of the various cities to result in one multipurpose device.

At the first Panel meeting, held at NASA's Manned Spacecraft Center in June 1971, principal problems in currently used breathing apparatus were identified. The main deficiencies were: insufficient duration, excess weight and size, protrusions, and lack of an adequate air depletion alarm. In response, NASA funded a program to apply its background and expertise in life-support systems, to develop an efficient breathing apparatus to remedy the problems.

First, the presently utilized compressed-gas demand systems were reviewed. After analysis of concepts, including chlorate candles and potassium superoxide, NASA determined that the compressed gas system

could be improved significantly by developing a lightweight (4000 PSIG) design pressure vessel. This would have a potential 30 percent reduction in system weight. Other improvements included making the system more compact and changing the shoulder mounting of the device to a more comfortable hip position. The PTI Panel agreed that such a development program was required.

A second User Design Panel meeting was held in October 1971 to review NASA developments on the pressure vessel and balance of the system. Periodic meetings between the PTI User Design Panel and NASA will be held during the project to assure full communication between the NASA scientists and engineers and the city managers and fire chiefs. Contracts will be let in early 1972 for the pressure vessel development program and the remainder of the system. After tests by NASA and city fire departments, the improved breathing apparatus will be available to commercial organizations for manufacture and distribution.

In a complementary program a lightweight breathing apparatus (Figure 47) developed at the Kennedy Space Center has been demonstrated at the Chicago Fire Academy. This easily donned, short duration breathing apparatus might be ideal for early reconnaissance of interior fires. As a result the Fire Academy requested two units for a testing and evaluation program.

Little information is available on the breathing requirements and environmental conditions during actual fires. For this reason, NASA supplied initial funding to the Harvard School of Public Health to obtain firefighter's minute volume data, and environmental oxygen and carbon monoxide concentrations. The National Bureau of Standards has supplied additional funds to continue this program. The data are being gathered in cooperation with the Boston Fire Department.

The firemen's breathing apparatus program is being pursued by NASA with a systems approach similar to that used in its design of advanced space portable life-support systems. The man and the breathing apparatus are considered as a total system, wherein the physiological and mechanical relationships are optimized. NASA has also studied many types of life-support systems that incorporate several different methods of supplying breathing gases for space applications. This procedure includes development of improved chlorate candles and cryogenic gas systems, as well as lightweight high-pressure gas systems. Hence, the involvement of NASA in the development of an improved firemen's breathing apparatus is a logical extension of current space technology.

A Low-Cost Reliable Fire-Warning System for Residential Structures. Early smoke detection is one of the top priority technological requirements of the Operation Breakthrough Program of the Housing and Urban Development Department (HUD). The requirement was underscored in HUD's Guide Criteria for Operation Breakthrough, which requires that smoke detection and alarm systems be installed in multilevel dwellings under the program's sponsorship.

Alternate technological approaches for a solution were reviewed which include infrared, ultrasonic, and ultraviolet detection methods. A new polymeric material, polyphenylacetylene, was specified which has electrical properties that change as it absorbs gases or particulates. The polymer acts as an effective contaminant detection device when used as a coating on a field effect transistor (FET). The FET can detect the polymer's changing electrical properties and actuate an alarm device. McDonnell-Douglas Corporation invented the detection device and developed it for use on the NASA Voyager mission. Meetings with the Federal Housing Administration (FHA), McDonnell-Douglas, the Massachusetts Institute of Technology and the National Bureau of Standards (NBS) have determined the parameters along which an early warning system would be evaluated.

As a result of this meeting, McDonnell-Douglas and MIT are preparing a proposal for funding early in 1972 to pursue development of the device for application to residential structures.

Breathing apparatus developed at Kennedy Space Center has superior human factor features incorporated it its design. Note pressure vessels mounted at the hips of the rescue team member.

Figure 47. Fireman's Breathing Apparatus

LAW ENFORCEMENT AND CRIMINALISTICS

Indented Writing Detection. One of the most important pieces of evidence confiscated during a gambling raid may be a writing pad which was used to record betting information. Even if the page bearing the writing is destroyed, the pages underneath often carry an indented impression of the writing. A device which will recover this indented writing would facilitate solving criminal cases.

Retrieval of indented writing depends on the backing beneath the second sheet, the quality of the papers, the shape of the writing instrument, and the writer's pressure. If the writing is clear and visible, techniques such as side-lighted shadow-casting, thermosetting plastics, or various photographic approaches may reproduce it. If it is indistinct or superimposed, most approaches are quite fruitless. An interesting fact–and one that destroys an old amateur detective technique–is that pencil "shading" is virtually never used in actual practice since it will destroy the information rather than aid in its recovery.

A fiber optics profilometer (Figure 48) developed for NASA's Marshall Space Flight Center by Metro-Physics Inc., showed promise of meeting the requirements. The profilometer was originally used to detect flaws on the surface of rocket tubes.

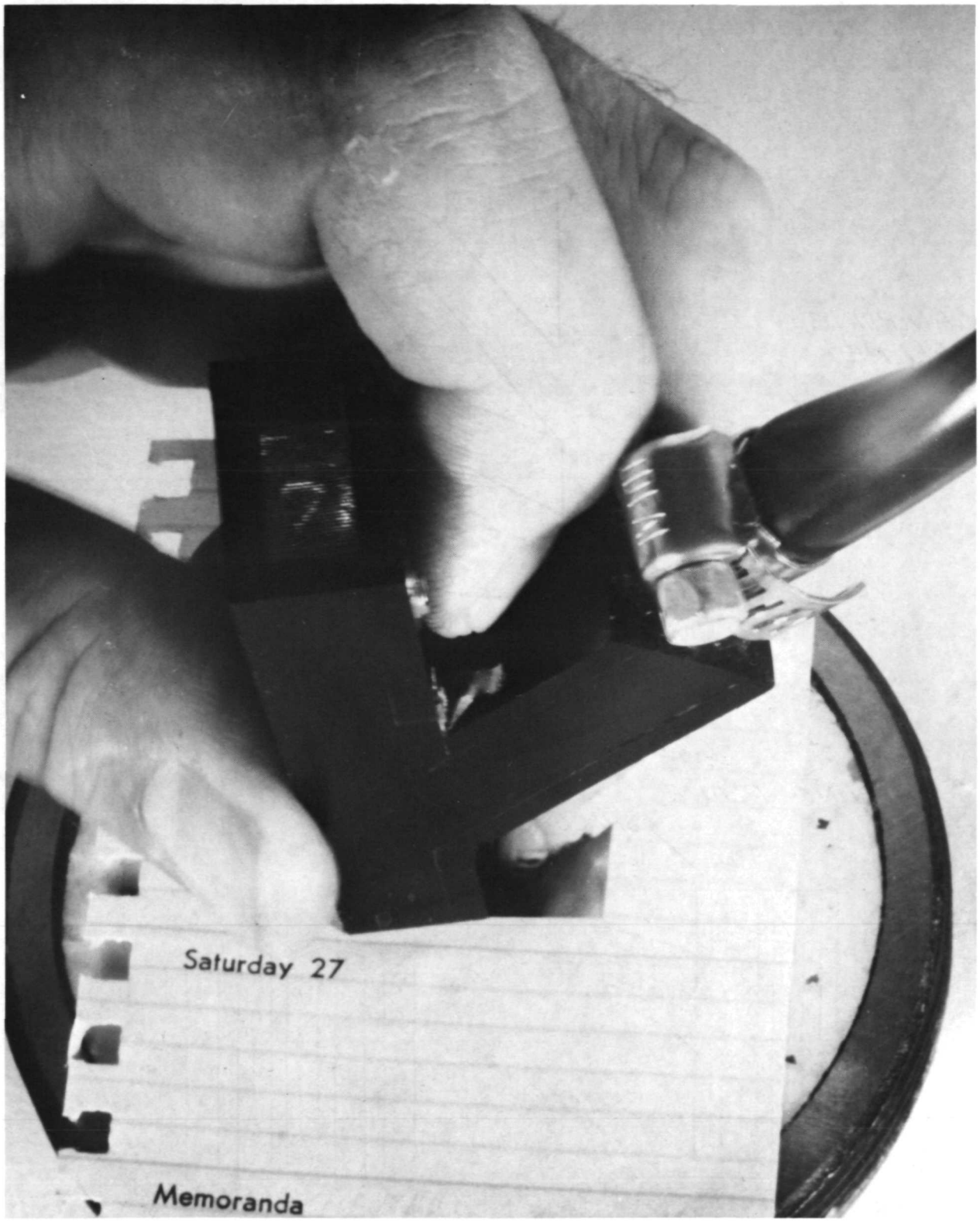
The probe is a simple reading device (Figure 49), consisting of a bifurcated fiber bundle encased in a housing of black lucite. After being encased, the end plane of the bifurcated bundle is ground flat and polished. The bundle itself is made of layers of fiber ribbons. Every other layer is brought up to a viewing plane (Figure 50) where spacers are placed between the layers. Thus, a bundle of viewing fibers is obtained which is oriented so that undistorted imaging is maintained. The remaining fibers that end at the sample plane are assembled into a bundle without regard for orientation and serve to illuminate the sample surface (transmitting fibers).

When a sheet of paper that does not have indented writing is placed on the sample plane (Figure 51) no light emanating from the transmitting fibers can reach the viewing fibers. But with indentations in the surface of the sheet, light from transmitting fibers at an indentation is reflected into the neighboring viewing fibers. Images of indentations are thus obtained in the viewing plane as bright spots against a dark background. They have proved to be good facsimiles of the original writing.

Although the agency that identified this problem was the Chicago Police Department (CPD), it was the Law Enforcement Assistance Administration (LEAA) of the Department of Justice that showed an interest in the problem and funded a prototype to test the feasibility of the idea. This early model showed that the idea appeared to be worthwhile, but the model was not sensitive enough. The device was demonstrated to CPD officials, who were impressed with the potential of the device. The device was then demonstrated to the LEAA and received favorable reception from technical personnel.

As a result of these demonstrations, NASA agreed to fund a cost-sharing effort with MetroPhysics to build a second prototype. To improve the sensitivity, this model will be built using fibers of smaller diameter, .002 inches, instead of .005 inches. This will increase significantly the resolution of the instrument, improving its ability to read indented writing. After this is completed, the addition of a mounting platform with random motion scanning will automate the process. A breadboard model will be completed and tested in early 1972.

Several significant features of the technology application process were demonstrated by this effort. Foremost is that many Problem Originators lack funds for development of potential solutions and adaption to a program. Equally important, however, is that Federal mission agencies such as LEAA are seriously interested in furthering innovations in areas which have been traditionally hostile to innovation.



Device permits the detection and recovery of indented writing by law enforcement agencies.

Figure 48. Fiber Optics Profilometer

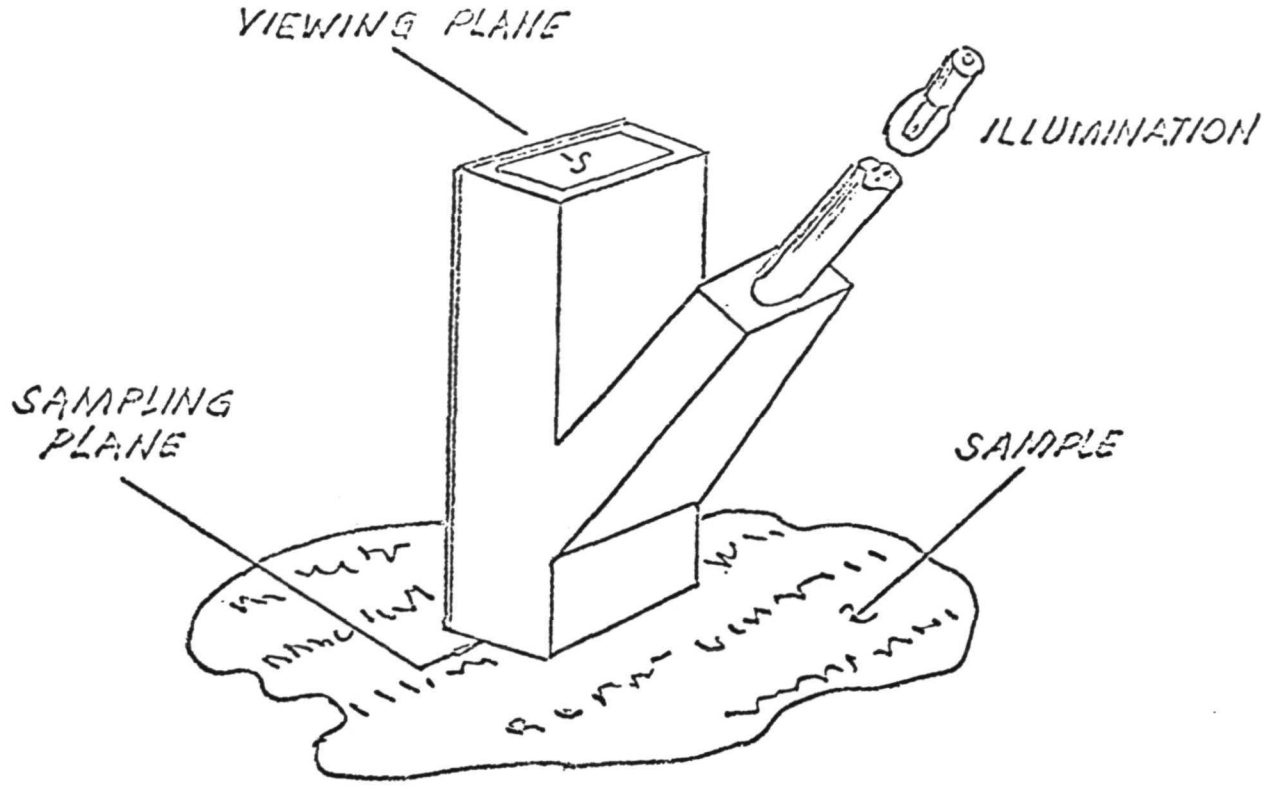


Figure 49. Fiber Optics Housing

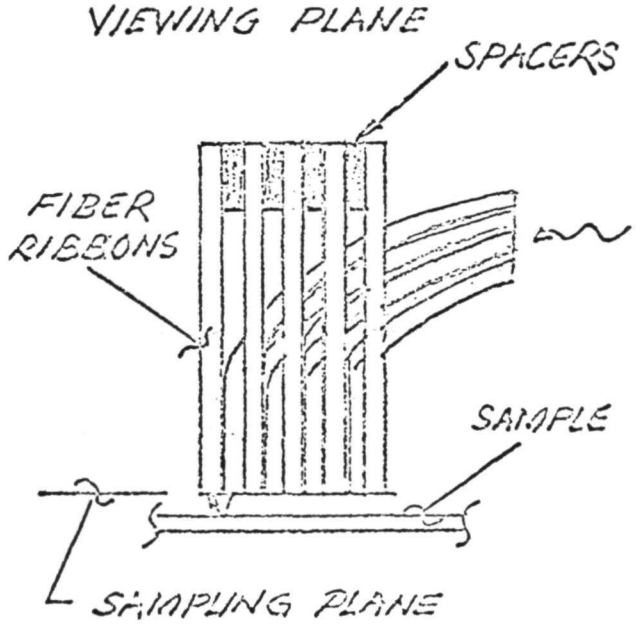


Figure 50. Cross-section of Housing

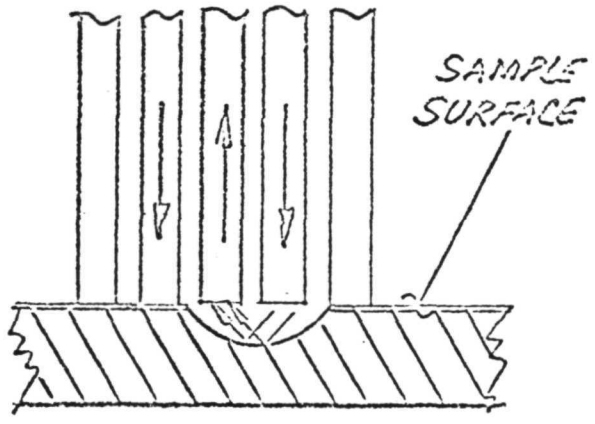


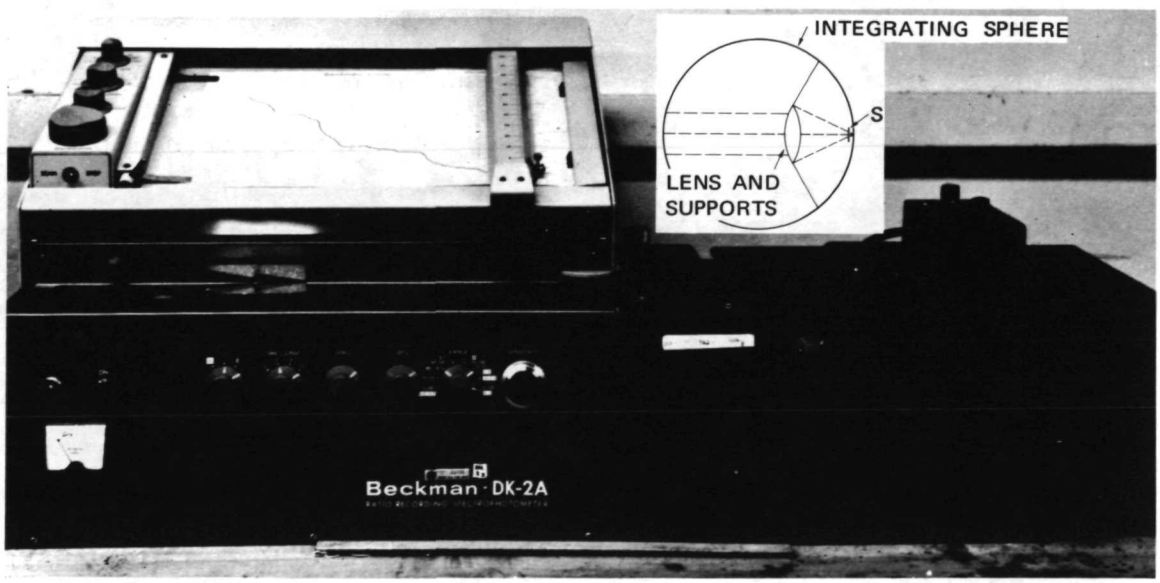
Figure 51. Incident and Reflected Light Paths at Sample Surface

Measuring Reflection Spectra of Very Small Samples. A problem of the California Criminal Identification and Investigation Bureau is common to all criminalistic laboratories: identification of an automobile from a small paint scraping left in a hit-and-run accident. It has been practice to make a visual comparison of the scraping with sets of manufacturers' standard paints by means of a binocular microscope. But comparison is frequently difficult and sometimes impossible. A more objective instrumental method of comparison would be helpful to provide evidence in quantifiable and reproducible form, and facilitate identification of the automobile.

A solution (Figure 52) was suggested and tested by a NASA scientist at Goddard Space Flight Center. It was then evaluated by forensic scientists. The method is to mount the paint sample in the integrating sphere which serves as the reflectance attachment of a visible ultraviolet spectrophotometer. Normally, a very small sample will give no measurable absorption in this position. However, the interior surface of the integrating sphere is a diffuse reflector. The number of times the ray hits the sample is increased by mounting a convex lens in the integrating sphere, so that its focus coincides with the sample. The effect is one of enlarging the *apparent* surface of the sample to approximately that of the lens surface. Any ray that hits the outer surface of the lens is focused onto the sample, from which there are reflections. Thus, the absorption signal is greatly increased and can be recorded in the usual manner. Any of several commercially available spectrophotometers may be used. The proposed system is inexpensive, easy to calibrate, and does not have any adverse effect on the spectrophotometer to which it is attached.

One set of samples from an actual California case was analyzed by Goddard Space Flight Center. The Sheriff's office thought that two paints were different, but there was no objective way to determine difference in colors. The modified spectrophotometer showed that the two paint samples were different red paints, which helped to exonerate an innocent person.

A description of the spectrophotometer system was published in the April 1971 issue of *Journal of Forensic Sciences*. This will help to provide crime laboratories with justification for the purchase of necessary equipment, and for the incorporation of this technology into daily operating procedures.



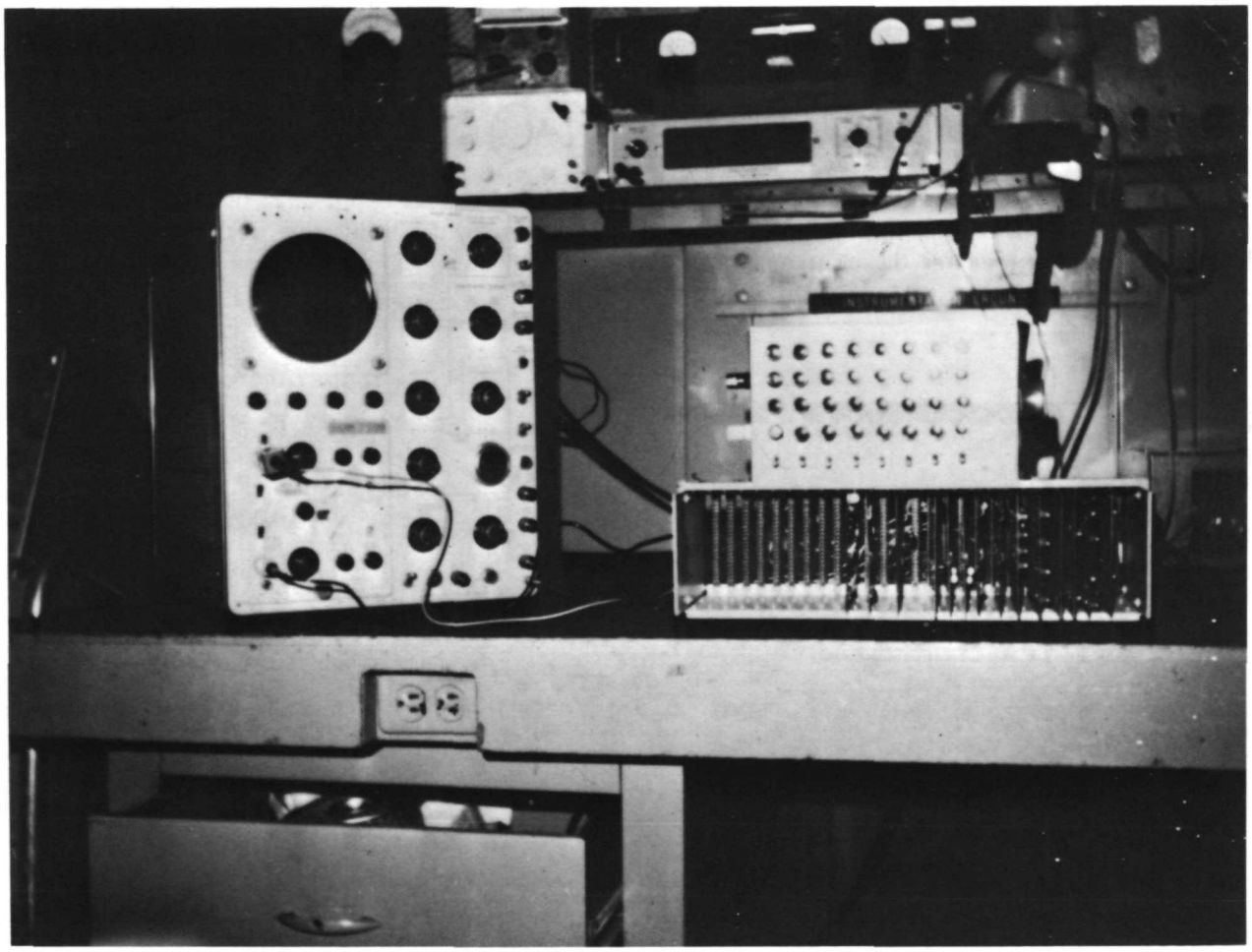
Ultraviolet spectrophotometer, with modified integrating sphere to serve as reflectance attachment, used for criminalistic evaluation of paint chips.

Figure 52. Paint Chip Analysis System

Communications Link: Automatic Trouble Shooting. Many state and local police departments employ data communications systems to connect a central computing facility with terminals at remote field stations. Interruptions in the flow of the data are sometimes caused by telephone network failures, however, and valuable time is lost while the sources of the trouble are manually traced. The main difficulty stems from the fact that there is no quick means of demonstrating to the telephone utility that the fault lies within the telephone network. Because downtime in the data system is costly, both in terms of lost computer time and criminal apprehension, the police are often forced to lease the highest quality, and most expensive telephone lines available.

A "hardline" monitor (Figure 53), developed at NASA's Kennedy Space Center, gives a continuous check on the quality of data communication cables in the Center's automatic checkout system for testing the components of a launch vehicle. This monitor is capable of continuously sampling 16 telephone lines and warning operators, when the quality of transmission has deteriorated beyond recognized tolerances, or when the line has catastrophically failed.

The monitor's circuitry can be adjusted for variable acceptance levels of incoming data to conform to the requirements of the receiving equipment. These critical parameters include amplitude, rise time, frequency response, and background noise. When the quality of the line approaches the preset limits, a warning command is given from the monitor. In operation, the monitor continually scans all the lines in a selected sequence. It analyzes data being transmitted over the line and interrogates those lines having no data. The interrogation involves stimulating a small transponder at the other end of the line to send a generated set of pulses for evaluation.



Monitor provides continuous check on data communications cables, and may be used by police departments to monitor hardline transmission quality (Breadboard unit is at the right-hand side of the picture).

Figure 53. Hardline Monitor

The technical details of the monitor were given to the Maryland State Police in October 1970, and the New York State Identification and Intelligence System (NYSIIS) in December 1970. The latter estimated that their use of a similar monitor would produce an annual saving of $50,000 by eliminating the need for leasing the highest quality telephone lines.

A meeting was held at the Kennedy Space Center to demonstrate the device to representatives from Maryland and New York. Both state agencies agreed that the monitor would meet their needs. A system design study of NYSIIS requirements was then made. The inventor agreed to commit his own funds to develop a prototype line monitor for this application. It is planned that the receiver portion of the hardline monitor will be located in Albany and the transmit monitor will be located at the Nassau County Police Department.

The prototype will be completed in the winter of 1972 and demonstrated soon afterwards.

Fingerprint Image Enhancement. Fingerprint records generated at police field stations in New York State are transmitted by facsimile equipment to a central facility, the New York State Identification and Intelligence System (NYSIIS), where they are received, cataloged and stored. About 60,000 prints each year are transmitted and processed in this way. An estimated 20 percent of the prints are not usable, due to smudges, prints that are too light, or distortion during transmission. It would be advantageous to law enforcement authorities if these poor quality prints could be restored to a readable state.

A possible solution for the fingerprint problem is in a computer processing method, developed by the Jet Propulsion Laboratory (JPL) for the purpose of enhancing the detail of photographs taken during space probes of the moon and other planets (Figure 54). The method has also proved applicable to other areas, such as the clarification of medical x-rays.

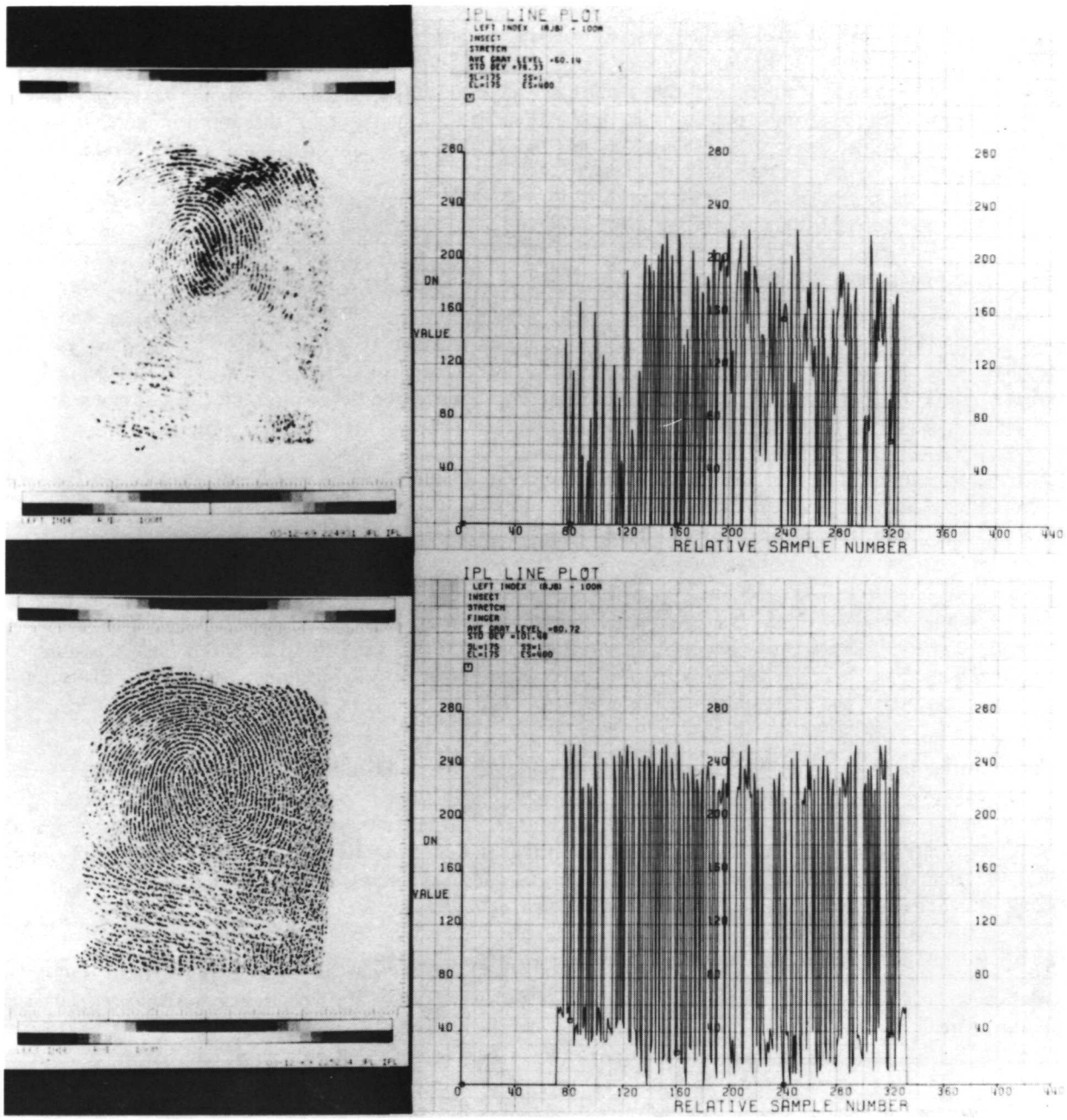
The potential solution has been presented to, and accepted by, the NYSIIS. The JPL is currently conducting a series of tests on smudged fingerprints provided by NYSIIS. The tests will be completed during the winter of 1972. If legibility of the fingerprints is successfully restored, the NYSIIS system will make efforts to adapt the method to their use.

Simple Analytical Methods for Drugs. A great part of the workload of forensic laboratories is drug analysis, of two types: determination of the daily identity of seized samples; and determination of drug levels in blood, urine, and other physiological specimens. The latter is more difficult since the drugs are present at a very low level. Although analytical instrumentation currently exists, there has been no combination of techniques and instruments which includes all of the necessary features to provide low-cost and portable instrumentation, for rapid, reliable, and routine determination of drugs.

The seriousness of the heroin problem, and the fact that heroin is broken down into morphine derivatives when injected into the body, prompted scientists at NASA's Ames Research Center to consider first the detection of that compound. Preliminary chromatographic column work has shown that it is feasible to detect morphine quickly and unequivocally. The outgrowth of this work, the Ames concept of a compact and inexpensive device, is described below. Development of a prototype was funded in late 1971. It is believed that a production instrument of this type could be produced in quantity, to sell for less than $500 each.

The detector consists of a simple, self-scanning spectrofluorometer for use with column chromatography in detection and identification of morphine in the urine. Chemical treatment of urine specimen converts morphine, which is weakly fluorescent, to a highly fluorescent fluorophore. The compound is then introduced to the chromatographic column, and the morphine moves as a band down the column under standardized column conditions.

The column is irradiated with monochromatic ultraviolet radiation, and if morphine is present, the morphine emits fluorescent radiation. In this optical arrangement, the fluorescent band thus serves as the



Computer processing method used to enhance the detail of photographs from space which is applicable to sharpening distorted facsimile-transmitted fingerprints.

Figure 54. Fingerprint Image Enhancement

entrance slit of a spectrofluorometer. The fluorescent radiation from the morphine band is reflected by a diagonal mirror and passes through a collimator lens to a fixed diffraction grating. From the grating the light passes back through the lens, past the mirror, and is focused on the split. Movement of the fluorescent band down the column produces the required spectral scan.

A photodiode detector receives the spectral radiation from the grating; its output is amplified and is read out on a simple strip-chart recorder. The only moving part in the optical system is the fluorescent band which travels down the column. As the band moves down the column, it passes a number of narrow opaque masks which obscure the band's radiation, thereby interrupting the signal. From the known distance between the masks and the chart speed of the recorder, the rate of movement of the band down the column can be accurately calculated.

Thus, this system at one time measures the fluorescence spectrum characteristic of morphine, the rate of movement of the band down the column (which is further confirmation of that compound), and the spectral amplitude which gives a quantitative measure of the amount of morphine present in the urine specimen. In the development of this drug detector to the functional prototype stage, there are three research areas of required work:

(a) Chemistry. Optimization of the chromatographic column. This will require variation of all column parameters to arrive at a standardized column giving maximum sensitivity and specificity for morphine detection. Possible use of disposable inexpensive columns will be considered.

(b) Optics. Optical design including spectrophotofluorometric measurements of the morphine band on the column to determine optimum absorption wavelengths, as well as morphine emission spectrum and selection of all optical components.

(c) Electronics. Design of stable operational amplifier system matched to detector output and driving an inexpensive chart recorder.

Simple Methods of Analysis for Metals and Metal Products. A problem common to criminalistics laboratories is the inability to quickly identify the metallic composition of objects to determine their source. For example, obliterated serial number plates, tool marks, and bomb fragments must be identified to determine the manufacturer. Spectrographic techniques are useful but are not available in many criminalistic laboratories.

Langley Research Center scientists developed a wet-chemical quality assurance technique to assure quality fabrication of hardware and maximum safety to NASA personnel. The technique is relatively nondestructive; it consumes or affects an amount of material equivalent to that removed by a means of a smooth file or cleaning with an abrasive. Standard chemicals are used and the technique takes less than 1 hour to complete.

The New York City Police Laboratory used this metal analysis technique in four cases involving firearms. Before attempts were made to etch out obliterated serial numbers, the wet-chemical approach was used to determine the metal alloy, in order to choose the most effective etching solution. An Alaska Crime Laboratory also found this technique helpful. They were asked to prepare reagents for a helicopter firm, who had been plagued by crashes, to differentiate between the various alloys they were using for helicopter blades.

A commercial company is now planning to manufacture and sell a metal identification kit based on this technology, for use in crime laboratories. Other potential markets will be sought, for development of the kits.

Portable Device for Recording Eye Motion. When approaching a highway sign, does the driver read it from bottom to top, or from righ to left? Do the colors or the letter sizes, or both, affect the effectiveness of the sign? Are flashing lights near a highway sign significantly distracting? Do the effects of fatigue, drugs, and pollution impair a driver's ability to follow signs and other directions along the highway? These problems are important to researchers in the Department of Transportation (DOT) in both highway sign safety and driver safety.

To study these variables under actual driving conditions, a driver should be provided with a head-mounted device to monitor eye motion which can be related to the visual scene. Devices currently used include a motion picture camera with a split view—one of the eye and one of the road ahead—that monitors eye motion. This is sufficient for gross eye movement. However, for information on the effects of fatigue, drugs, or pollution, study must be made of physiological variables such as pupil dilation, blink rate, and pupil position, and their relationships to the subject's mental alertness.

A table-mounted oculometer (Figure 55) had been developed for the NASA Electronics Research Center (ERC) by Honeywell. NASA was exploring the possibility of remotely monitoring the physiological responses of an astronaut to relieve him of the inconvenience of electrodes and wire attachment on long space flights. It was thought that it might be possible to measure not only physiological data through the eyes, but also mental alertness; to be able to observe when he was becoming fatigued or dizzy from the complexity of his tasks. The oculometer has an infrared source and a light detector which reveals the reflection from the cornea and retina of the subject's eye. This instrument permits highly accurate determination and recording of eye movement. It allows more accurate monitoring than the camera approach and permits results to be processed in real time by a computer. The oculometer is now undergoing further development by the DOT Transportation Systems Center. The improved device will have a small optical head and a much smaller electronic control package.

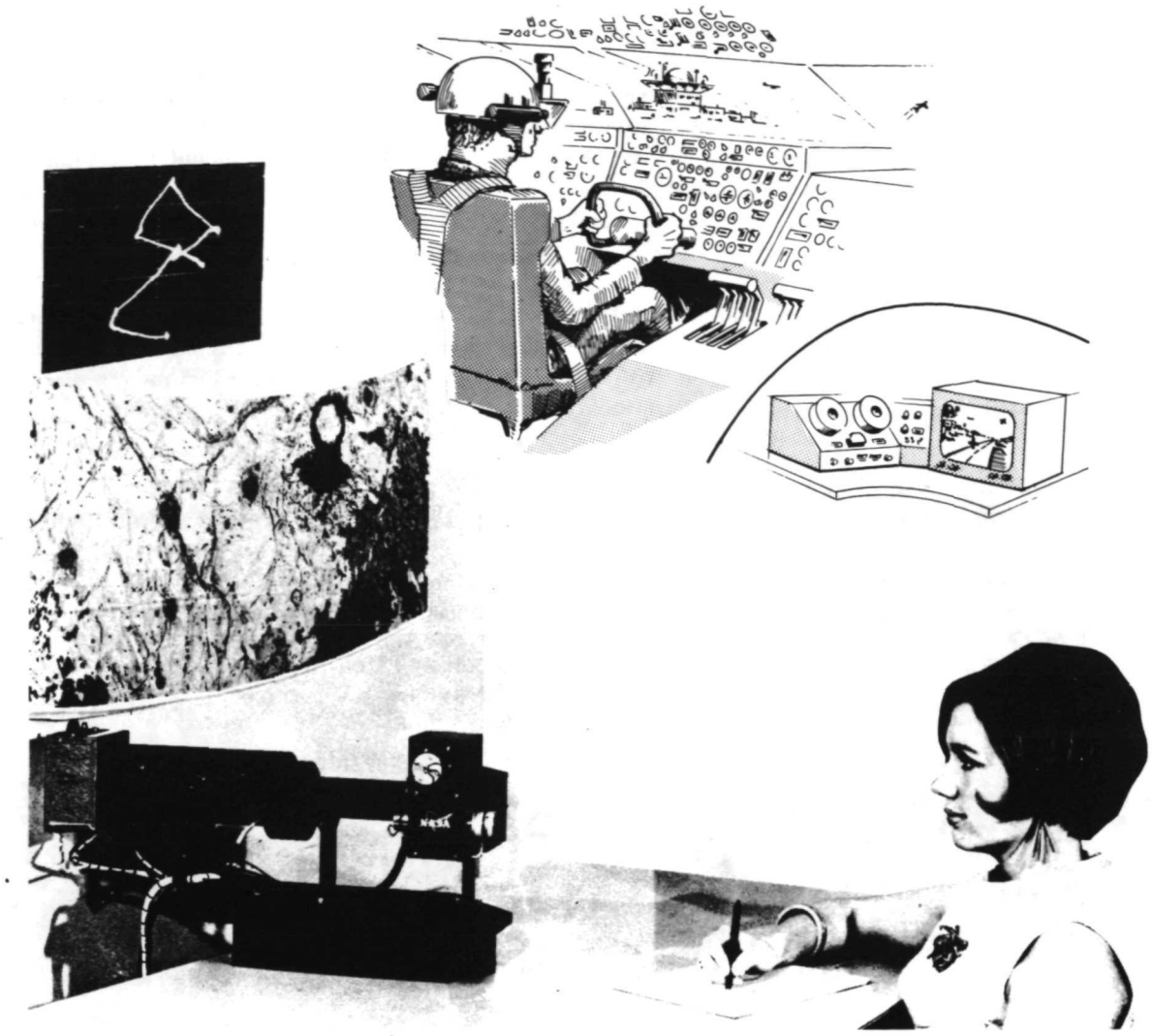
TRANSPORTATION

Concrete Repair Material. The necessity of keeping the dead weight on a suspension bridge to a minimum requires that lanes be paved with a thin layer (less than 1-inch thick) of an epoxy-coal tar mortar mixed with an aggregate. When a hole develops in this thin sheeting, a lane must be closed for repairs, which impedes traffic and creates a safety hazard. Such a situation makes it imperative that repair material be quick-drying and durable.

The current method requires spraying the damaged area with epoxy and then spreading it with an aggregate. Although the patch is ready for traffic in about 4 hours, provided weather conditions are favorable, the drying time is considerably greater in bad weather. Other disadvantages of epoxy are its cost ($12/gallon), toxicity to workers, and that it is not reusable.

The problem was identified by the Chief Engineer for the California Division of Bay Toll Crossings. A potential solution was found in a study which is reported in Tech Brief 66-10453, "Thermoplastic Rubber-like Material Produced at Low Cost." The thermoplastic material was originally developed during a search for a better fuel-binder for solid propellants. It is prepared by blending a copolymer of ethylene and vinyl acetate with asphalt and petroleum distillate. The Tech Brief indicates that the cooled blend has good tensile strength and resilience in the temperature range of -50° to 150°F. It is easily handled and applied, and there is no waste since the unused material can be remelted. The cost is about $4 a gallon.

Samples of the thermoplastic material made in the Stanford Research Institute Laboratory were tested in their parking lot. A sample has been given to the California Division of Highways for further laboratory testing on a bridge. Of considerable importance are its ability to adhere to aggregate and its flexural and fatigue strengths. One problem which will have to be overcome is the high temperature of 500°F required to liquify the thermoplastic material. Road repair crews already have a problem with burns from hot asphalt of ∿350°F.



Oculometer facilitates research into drivers' reactions to highway signs, as well as to fatigue, drugs and pollutants.

Figure 55. Portable Device for Recording Eye Motion

An important economical aspect of the problem solution is now being investigated: the thermoplastic material might be partly produced from old tires and used crankcase oil. Shredded or ground up tires might be used as a filler to extend the materials physical properties and crankcase oil might replace new oil. This might also solve the problem of waste materials that are difficult to dispose of, by recycling them.

Improved Friction Materials. The maintenance expense of Postal Service and other government vehicles could be significantly reduced by developing an economically feasible friction material with improved wear characteristics for brake linings. This problem is also of concern to the Association of American Railroads. It is hoped that a substitute for asbestos could be used in this friction material, thereby avoiding the potential problem of asbestos pollution.

The Ames Research Center research in brake linings for large aircraft is directly related to automotive application. Bench tests show that the new material may have an operational life of four to five times that of conventional brake linings. These results were received favorably by the Postal Service.

With Postal Service cooperation, NASA has established a program for development of improved brake materials. This program will include: (1) assessment of a wear-enhancing polymer (WEP) as an ingredient of automotive brake linings; (2) development of a brake lining formulation containing standard ingredients and the WEP; (3) investigation of the use of new materials for binders and substitutes for asbestos; and (4) development of a brake lining formulation having no asbestos. Steps (1) and (2) should be completed by June 1972. During step (2) several sets of brake shoes will be fabricated for Postal Service evaluation. The Postal Service expects the National Bureau of Standards to test a set; it will test them on their own vehicles.

The railroad problem is different in that linings for railcar wheels must withstand very high temperatures for long periods of time. Samples of railcar brake shoes have been sent to Ames by the Southern Pacific Transportation Company for comparison with the new NASA-developed material. Southern Pacific will work closely with the Association of American Railroads Research Committee on this problem.

Complex Coordinator Aids Traffic Safety and Air Pollution Research. The NASA Langley Research Center Complex Coordinator (Figure 56) was originally developed to test performance degradation in astronauts exposed to stressful environments. It has been used on two underwater experiments (Tektite I for two months, and the Ben Franklin in the Gulfstream Mission for 30 days). This device was suggested as a means of demonstrating to drivers the effects of drugs, particularly alcohol, on human motor behavior, and to test driver response to various air pollutants.

Tests driver perceptual and motor skills by requiring continuous arm and leg responses. It can demonstrate and measure the effect of drugs, particularly alcohol, on human motor behavior and test driver response to various air pollutants.

Figure 56. Complex Coordinator

The Complex Coordinator tests driver perceptual and motor skills by requiring continuous arm-and-leg responses from a test subject. It enables researchers to perform quantitative evaluation of the subject's performance prior to, during, and following normal and programmed abnormal conditions. The system consists of an operator-control console, recorder, the subject display panel and limb controls, and associated cabling. When a "problem" is presented by the programmer, it appears on the test subject's display panel as a series of lights. The subject must manipulate hand-and-foot controls to cause correct illumination of corresponding lights, thus indicating that the "problem" has been correctly answered.

Hand-and-foot movements are timed and counted, displayed on the operator's control console, and then permanently recorded. A serial reaction feature presents a new problem after the completion of each answer, and a self-paced feature assures that new problems are presented only upon completion of the previous one. Successful problem completion requires the correct positioning of all four hand-and-foot controls (complex coordination) of problem lights and performance of the correct action with the limb controls. The test is then completed, and a quantitative evaluation of perceptual and motor skills is made.

Initial psychomotor performance data using the Complex Coordinator was gathered by experimenters at Duke University, under contract to the Air Pollution Control Office. The "simulated drivers" tested were first subjected to varying concentrations of carbon monoxide, ranging from 50 to 100 parts per million, for 4-hour periods. The onset of degradation was then detected and recorded as a decrease in skill. Tests were repeated with other pollutants so that those causing performance degradation, and the concentration at which degradation occurs, could be determined and recorded. The feasibility of the device has thus been demonstrated for pollution studies.

The Complex Coordinator was provided to the California Driver Education Association for a demonstration of the effects of alcohol on human performance. The instructors tested the device before and after consuming cocktails, and considered it a good method for demonstrating the adverse effects of alcohol. Discussions are being held with appropriate law enforcement and highway safety organizations to identify resources for further development and use of this technology.

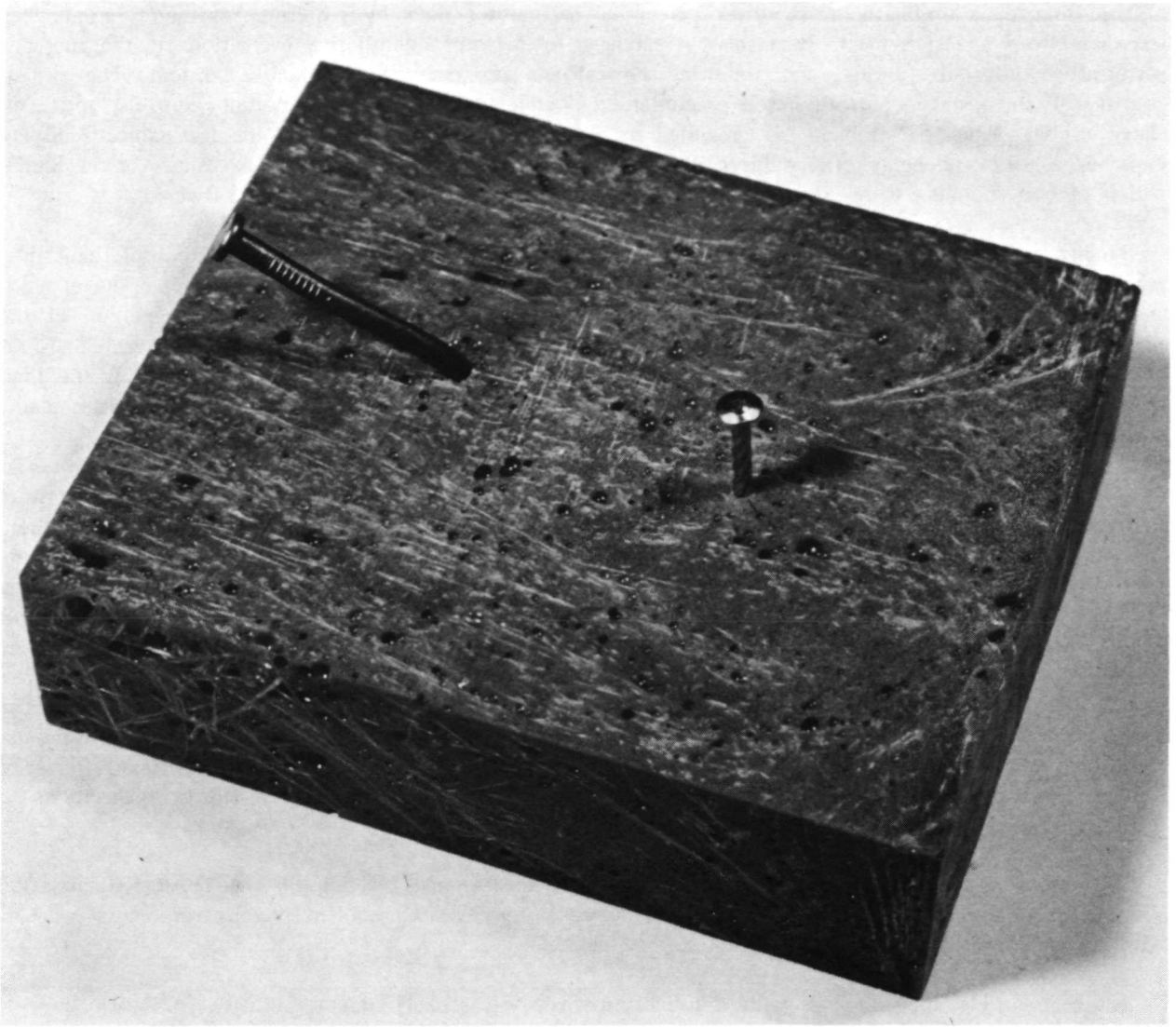
The Complex Coordinator was also demonstrated at the Annual Meeting of the Texas Rehabilitation Association. Interest was expressed in using the device as an exercising tool as therapy for mental patients with psychomotor disturbances, and as a screening device.

Another possible application is with the California Highway Patrol Training Activity to screen students prior to the time they actually get on a motorcycle. Additional uses in the training program might include testing motor skills related to driving, determining firing range proficiency, and illustrating the effects of alcohol.

Through the Small Business Administration dissemination of Tech Briefs, a minority business firm heard of the Complex Coordinator and has expressed strong interest in manufacturing and marketing the device. The Small Business Administration has agreed to provide funds for a market study and NASA will provide a portion of the necessary development funds.

Foam Building Materials for Use in Railroad Ties. Wood is by far the most widely used material for railroad ties, but it is in short supply, and therefore expensive. In addition, wood ties have a shorter life than most roadbeds. Sixteen million ties must be replaced each year and there is no adequate means for disposing of those worn beyond usage. According to the Association of American Railroads (AAR), a material with greater availability and durability is needed—perhaps one that can be repaired instead of being replaced.

The high-density plastic foams (Figure 57) developed at Ames Research Center for use in aircraft and spacecraft have been identified as a possible substitute for wood railroad ties. Material samples were shown to representatives of the AAR, and as a result of their interest, NASA has funded further development of materials for railroad ties.

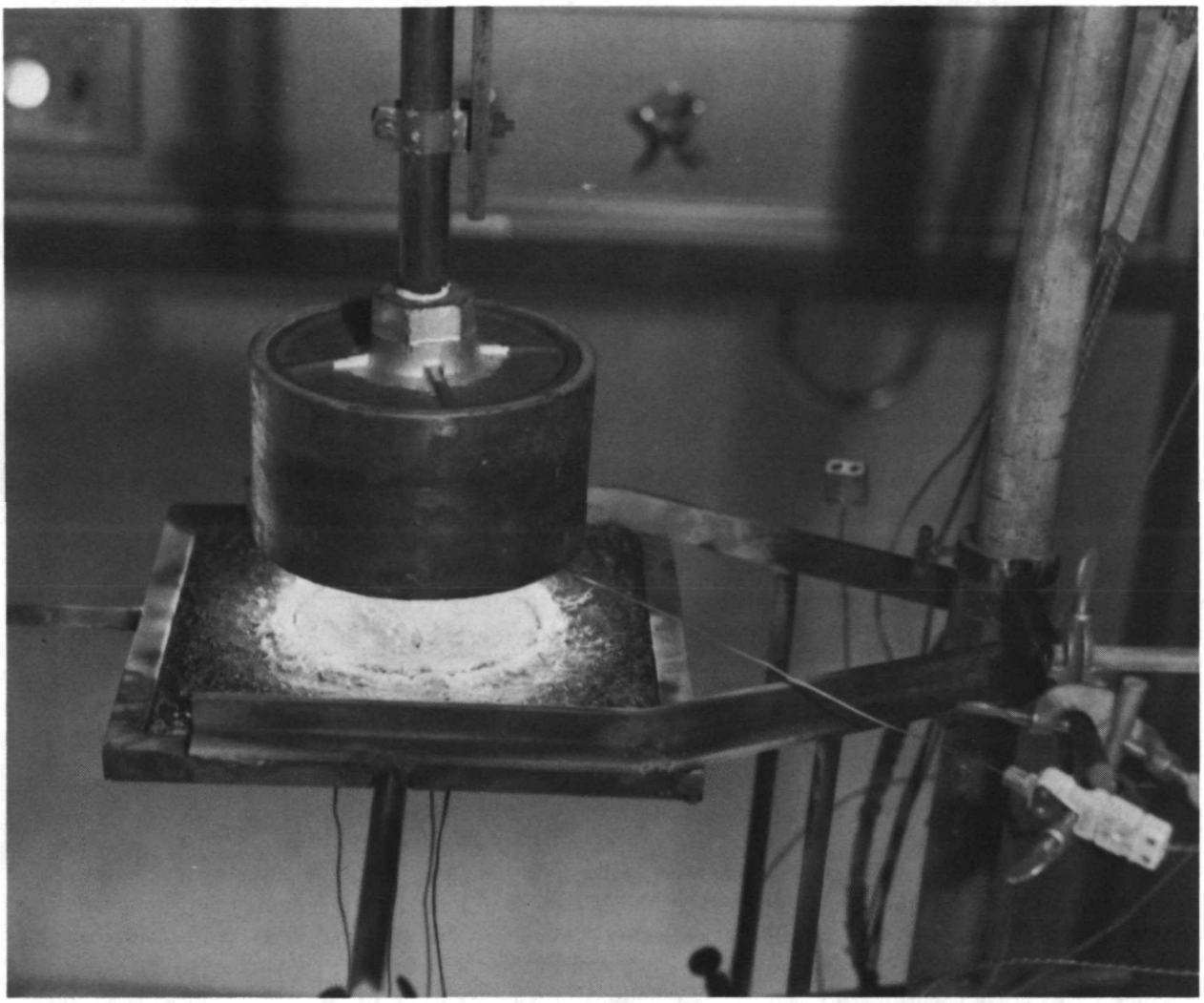


Fasteners imbedded in foam indicate some of its characteristics.

Figure 57. Foam Building Material for Use in Railroad Ties

Fire Protection of Rail Tank Cars. The Association of American Railroads (AAR) is carrying out an extensive tank care safety study. One aspect of the study requires finding materials to protect tank cars in postderailment fuel fires. A protective coating is needed to prevent the steel tank car shell from reaching a temperature of 800°F within a period of 1/2 hour to 4 hours. When there is a hazardous load, one that is flammable, the damage radius of the fire that usually follows derailment can spread appreciably by further rupturing tank cars, caused by severe heat loads.

The Chemical Research Projects Office at Ames Research Center has done extensive work in the development of materials for fire protection, essentially for use with aircraft and spacecraft. A fiber-loaded intumescent coating has been developed that has fire protection, strength, and weathering characteristics (Figure 58). It is superior in some respects to commercially available coatings and meets the requirements for tank care protection.



Tests being conducted on fiber-loaded intumescent coating that has fire protection, strength, and weathering characteristics.

Figure 58. Tank Car Fire Protection

Samples of this intumescent coating were evaluated by the AAR/Railroad Progress Institute (RPI) Tank Car Safety Group, along with more than 40 other samples. The Ames material was one of seven meeting the time-temperature specifications, and the only coating meeting the specifications for ease of application, weatherability, and structural integrity. Its only shortcoming, a major one, is its high cost. Ames scientists are now investigating ways to reduce the cost without sacrificing the excellent performance characteristics. A contract will be let in early 1972 to formulate candidate materials and evaluate them.

Measurement of Stress in Long Welded Rails and in Railcar Wheels. Thermal stresses that build up in long and continuous modern railroad tracks can cause buckling and breaking of the rail. This occurs when the uniform distribution of these heat-induced stresses is disturbed by improper alignment of ties, ballast, or rail anchors. Thus, an effective, rapidly applied method of nondestructively detecting high pre-yield stresses is needed, to be used by rail inspection crews in the maintenance of rail section. Another problem is that there are derailments because of the catastrophic failure of railcar wheels. Such failures are caused by stresses resulting from known vertical and lateral loads superimposed on unknown residual stresses in the wheel. A method is needed for inspecting railcar wheels in the field, to determine whether residual stresses are above a critical level.

Ultrasonic techniques of measuring stress are currently being developed at Marshall Space Flight Center for the nondestructive testing of spacecraft structures, which appear to have great potential applicability to rail purposes. These ultrasonic velocity techniques are effective for measuring stress in specimens made of well-characterized material, having uniform, reasonably flat, smooth surfaces.

A program was funded in late 1971 to:

1. Determine the ultrasonic velocity vs. stress relationships for the particular types of steel used in making wheels and rails.

2. Investigate the effects of temperature variations on the accuracy of stress measurements.

3. Evaluate measurement problems related to rail geometry.

4. Make actual stress measurements on wheel and rail segments under controlled laboratory conditions.

5. Demonstrate the practicality of the technology by making stress measurements on long rail segments under realistic field conditions.

If these techniques are proved feasible, the Federal Railroad Administration is prepared to support additional work as necessary for application in the rail field. A portable testing unit, based on work performed under a NASA contract, is being prepared for introduction in the commercial market early in 1972.

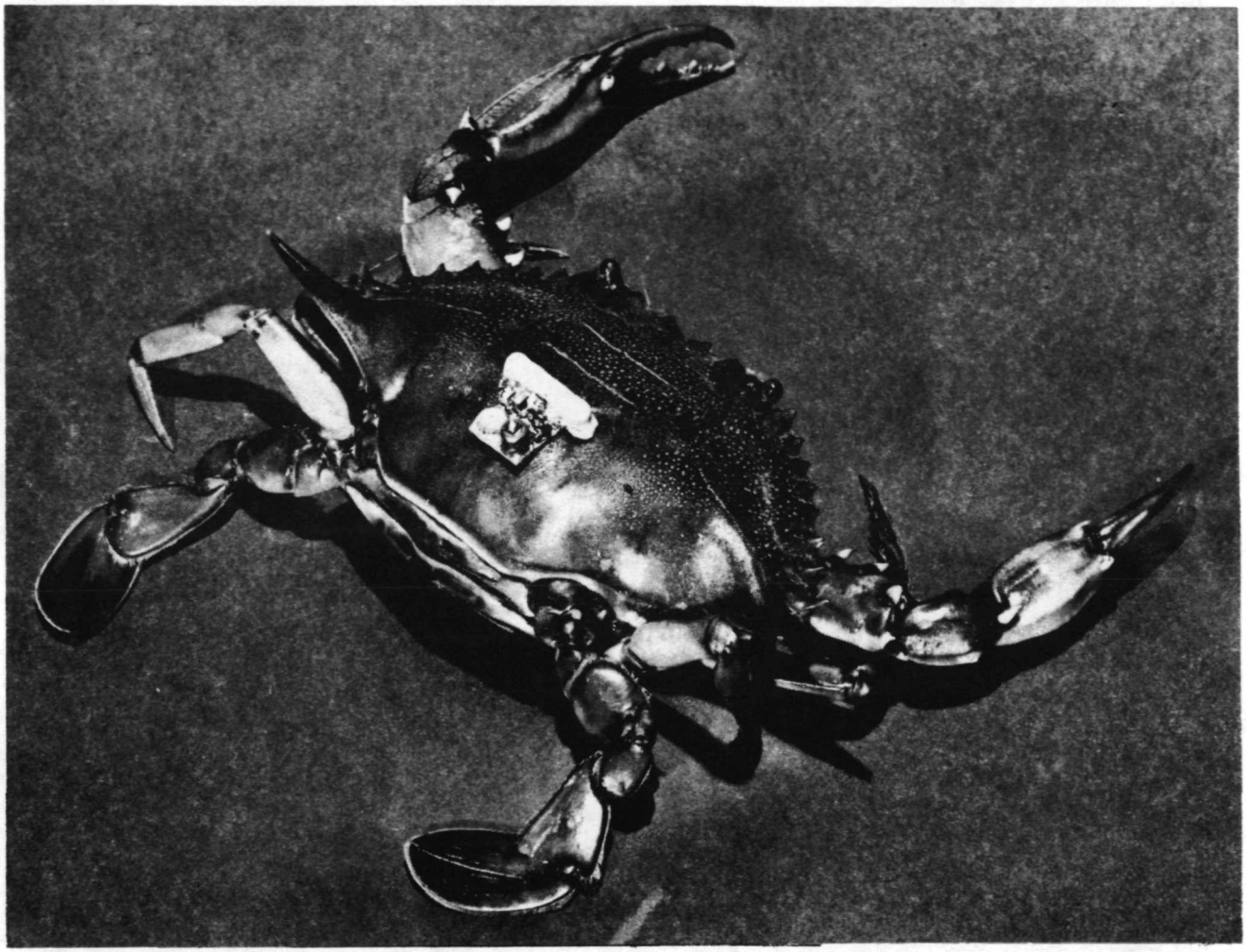
MARINE SCIENCE AND ENGINEERING

Measurement of the Osmo-Regulation of Blue Crabs. The blue crab is an important commercial source of food, so that it is important to understand the effects that individual pollutants and combinations of pollutants could have on the quality and quantity of blue crabs produced each year. One means of obtaining this understanding is to monitor the adjustment of the internal environment of the crab as a function of external changes. This can be accomplished to a reasonable extent by monitoring the conductivity of the circulating nutritive fluid (hemolymph) of the crab.

The present approach to making these measurements is to sacrifice the crab in order to obtain enough fluid to use standard laboratory techniques for making conductivity measurements. Since a crab is good for only one measurement, the test must be statistically designed, and requires a large sample in order to place reasonable limits of confidence in the results. Several difficulties have, until now, prevented the researcher from instrumenting the crab for continuous monitoring. One difficulty is the crab's aggressiveness, which precludes using a wire for signal transmission. Also, conventional telemetry systems will not transmit through salt water.

A system designed by researchers at the NASA Langley Research Center will eliminate the need for large numbers of test crabs and will permit obtaining more than one measurement per crab. The system consists of a microminiaturized conductivity probe, power supply, signal conditioning electronics, and a telemetry transmitter. The probe is inserted into the body cavity through a hole in the shell, which is then sealed. Rubber bands hold the transmitter on the crab's back (Figure 59).

The entire package weighs 2-3 ounces and is 1 square inch in size. An important feature is the transmission ability of the system through several feet of salt water. The transmitter sets up a very low frequency induction field that has very little attenuation through salt water. A receiving antenna and associated electronics are located nearby (out of water) to receive, process, and display the telemetered data as conductivity readings.



Transmitter permits monitoring conductivity of crab's circulating nutritive fluid for research on effects of pollutants.

Figure 59. Crab with Biotelemetry Transmitter Attached

During a test of the device, a crab's hemolymph salinity and heartbeat were monitored over a 3-hour period while the salinity of the water was varied from that of sea water to that of distilled water. The Problem Originator is with the Bureau of Commercial Fisheries. With his prior knowledge of the blue crab's osmo-regulating ability, he is confident that the system is generating valid data.

Application of this system has been successful in enabling the Problem Originator to derive a greater quantity of realistic physiological data over a shorter period of time than was possible previously, and by using a smaller sample size than in the past. The results of this research are applicable to development of meaningful regulation for allowable pollution levels in estuarine waters.

Miniature Mass Spectrometer for Oceanography Research. An understanding of the production of algae and marine animals to serve as lower links in the food chain is essential to better management and exploitation of marine resources. A key to this knowledge is the examination of metabolism in the primary elements of the marine food web. To this end, scientists at the University of Miami's School of Marine and Atmospheric Science have used mass spectrometry in laboratory studies of photosynthesis of tropical species of microalgae, as well as cultures brought back from the Antarctic. The former is a highly

sophisticated and sensitive analytical technique previously used primarily in chemical and geological research. With it, University of Miami scientists have demonstrated that algae in the sea respire far more rapidly in light than in darkness: this discovery would have been impossible with more conventional methods of studying metabolism. The discovery is extremely important, because all respiratory activity must be subtracted from photosynthesis to obtain net estimates of the production of potential food reserves.

This was made possible with the use of a NASA miniature mass spectrometer (Figure 60) which, with relatively minor changes to the ion pump and electrometers, satisfied the needs of the project. It was originally designed by NASA and personnel at Edwards AFB for use aboard high-performance aircraft.

In March 1971, this instrument was loaned to the University of Miami by NASA and taken into a manned habitat on the ocean floor. The habitat, a Perry Hydro-Lab, was operated at a depth of 50 feet off the coast of the Grand Bahamas. This was the first time that a mass spectrometer had been successfully placed in a manned habitat on the bottom of the ocean. It is planned to take the instrument into a habitat again, to use it in the study of photosynthesis.

Normally, biological samples that are collected at various depths and hauled aboard ship are subject to drastic changes in pressure, temperature, light, and dissolved gas concentration. With this analytical instrument in a habitat, all of these effects are minimized and the data obtained are more realistic than those obtained in other ways.

AIR AND WATER POLLUTION

Current Velocity Meter. An improved instrument to measure small water current velocities, in reservoir research and management, is needed by the Federal Water Quality Office and similar organizations. The problem has broad implications in the mathematical modeling of lakes, tracking pollutants for legal actions, and predicting river levels for shippers.

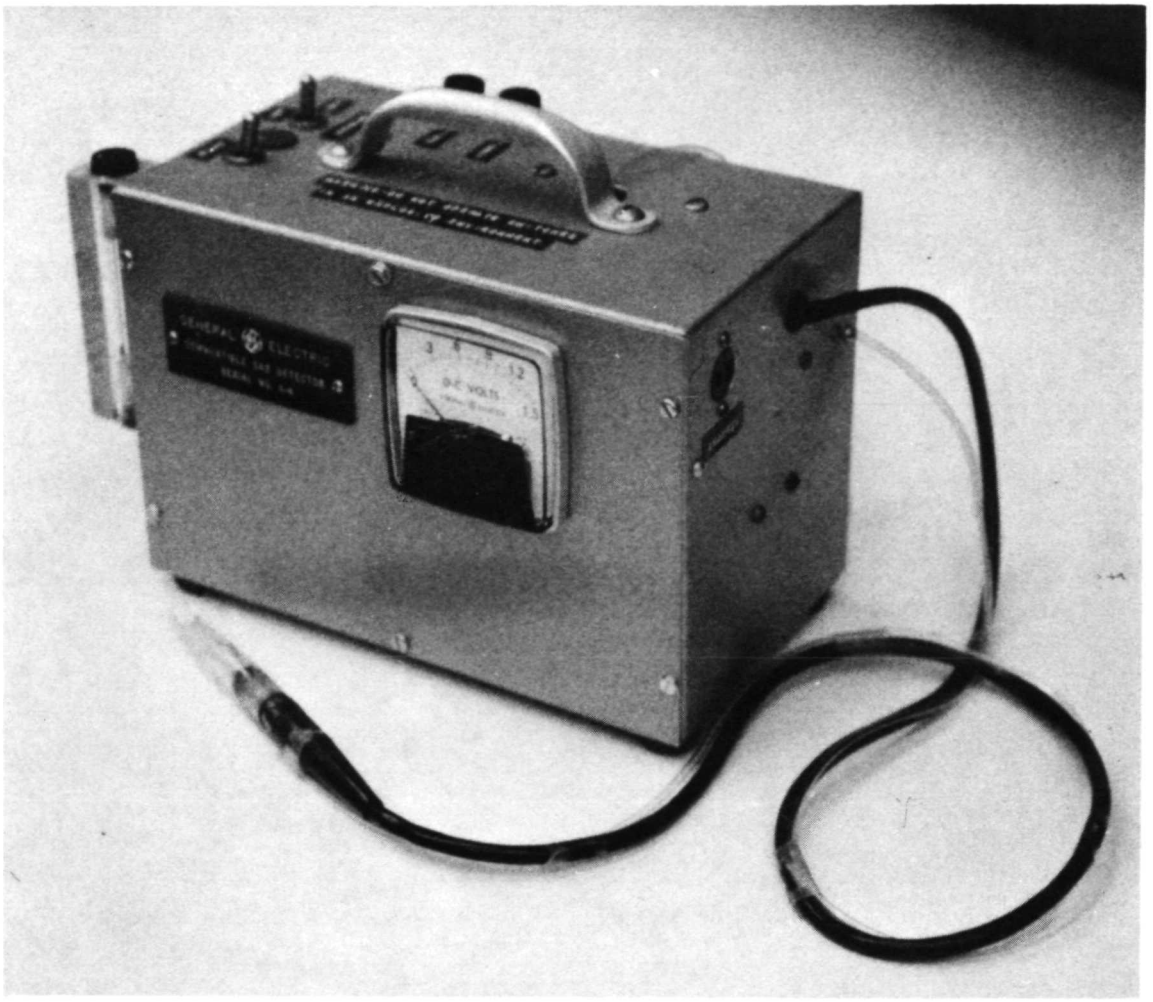
A water current meter, developed by NASA's Langley Research Center for wind tunnel monitoring, may provide a solution. It was developed to satisfy the need for a relatively simple, inexpensive means to measure generally steady flows characterizing certain near-shore waters. The design is compatible with automatic data acquisition and reduction equipment, so that several meters can be deployed and monitored simultaneously. The meter employs a strain-gauge technique to measure the force exerted on a submerged drag sphere over a flow velocity around the meter. For the fabrication of this device, discussions are being held with organizations interested in its use.

Development of Advanced Pollutant Sensor for Total Hydrocarbons. An inexpensive, advanced sensor capable of measuring total hydrocarbons in ambient air, auto exhaust, and stack effluents is needed by the Environmental Protection Agency for its field monitoring program. The instrument would be of great value since it would facilitate field monitoring as a substitute for the costly process of sample collection and subsequent laboratory analysis. At the present time, instrumentation using a flame ionization detector and gas chromatographic techniques are being used in the environments mentioned above. However, a lack of knowledge about flame chemistry and inadequacies of sample introduction have impaired progress in this area. In addition, this equipment is expensive, presents a potential safety hazard, and requires the services of an operator who is a skilled technician.

A device which would simplify and substantially reduce the cost of monitoring equipment for hydrocarbons is an indium-oxide, thin-film, combustible gas detector developed for NASA by the General Electric Research Laboratory (Figure 61). The indium-sesquioxide thin-film undergoes a change in electrical resistance when exposed to various concentrations of a combustible gas. The detector is maintained at 200° to 400°C, has a response time of about 1 second, and is currently designed to measure concentrations above 500 ppm. The device was designed to detect hydrogen, but it has been demonstrated that

Researcher using mass spectrometer in Perry Hydro-Lab at a depth of 50 feet of sea water off the coast of Grand Bahamas.

Figure 60. Miniature Mass Spectrometer for Oceanography Research



Advanced sensor for measurement of total hydrocarbons in ambitent air, auto exhaust and stack effluents.

Figure 61. Indium Oxide Thin-Film Combustible Gas Detector

it will respond to hydrocarbons and methane. The Bureau of Mines is strongly interested in improved detectors of methane for its mine safety programs. Successful application of the indium-sesquioxide thin-film sensor to the measurement of methane in mines, and methane and total hydrocarbons in ambient air, auto exhaust, and stack effluents would be a major breakthrough in hydrocarbon monitoring.

A meeting was held at NASA's Marshall Space Flight Center with representatives from the Environmental Protection Agency and the Bureau of Mines to determine the applicability of the device to air pollution and mine safety problems. Requirements for these applications were defined.

NASA's Marshall Space Flight Center has agreed to conduct in-house tests of the sensor utilizing application engineering funds from the NASA headquarters Technology Utilization Office. They will conduct a program to determine if a sensor can be constructed to meet the specifications of the Environmental Protection Agency and the Bureau of Mines. In order to be useful as an air pollution monitor, an instrument of this type would require the development of a circuit to monitor electrical resistance as a function of pollutant concentration. In addition, the operating temperature of the film as a function of a given pollutant must be delineated. The adequacy of the present gas-pumping system, optimum flowrate and the operating characteristics of the thin-film technique need to be evaluated. The Marshall test program will be completed in the spring of 1972.

Fluidic Flow Sensor for Use in Sewer Lines. A key urban problem is the collection and treatment of sewage. Proper distribution of sewage flow is necessary to avoid backup and its possible sanitation hazard, and to avoid overloading the sewage treatment plants. Information on actual sewage volumes is required to intelligently plan urban development and growth.

These problems can be helped by monitoring sewage flow at suitable points in the collection network, inputting the information into a central control facility, and providing (manually or automatically) redistribution, storage or treatment of the sewage. A first step towards this kind of system is being taken by the Dallas Water Utilities, who are conducting a program to monitor sewage flow with the immediate objective of identifying infiltration.

Accurate and reliable flow meters are essential to the safe and efficient operation of such systems. Because of the nature of sewage, conventional flow meters have limited accuracy and applicability.

To solve this problem the concept of a fluidic air sensor developed by Bowles Fluidics Corporation for the Electronics Research Center has been extended to measuring water flow. Among the features that make this unit especially suited for measuring sewage flow rates are: (1) the part of the unit submerged in the flow has no moving parts; (2) it is self-cleaning; (3) the sensor is rugged; and (4) it provides no obstruction to the flow. A technical description of a proposed sewage flow meter was sent to the director of the Dallas Water Utilities. The Dallas Water Utilities expressed interest in the device and agreed to serve as a test site if a suitable instrument can be developed. A meeting was subsequently arranged at which representatives of the Dallas Water Utilities, Bowles Fluidics, and IITRI resolved technical problems in the adaptation of the flow meter. Bowles Fluidics then prepared a proposal to design, build, and deliver an engineering model of the device to Dallas for their tests at low cost. NASA provided the necessary funds and Bowles is now building a device for testing by the Dallas Water Utilities.

Instrumental Techniques for Analysis of Formaldehyde in Ambient Air and Automobile Exhaust. Formaldehyde is an eye irritant and has a part in the photochemical reactions in the atmosphere. The exposure hazard of this gas is increasing, since a primary source is automobile exhaust and the catalytic processes which have been developed to decrease nitrogen oxide and hydrocarbon emission may actually increase formaldehyde emission. The role of formaldehyde in smog formation is being studied, but it is not sufficiently understood to set emission limits, and research is hampered by lack of satisfactory measurement techniques. The Environmental Protection Agency (EPA) has the responsibility of specifying a measurement method for formaldehyde by the end of 1972. Presently, manual or automated wet-chemical techniques are used to monitor formaldehyde in ambient air and automobile exhaust. These methods are cumbersome, time-consuming, and subject to interferences.

At EPA's request, NASA agreed to search for aerospace technology which might be relevant to the problem. A scientist at the NASA Langley Research Center responded to the circulated problem statement, his experience having been with the application of microwave spectroscopy to the measurement of formaldehyde and/or other pollutants in space stations. The work currently underway at Langley is directly applicable to the measurement of formaldehyde, nitrogen dioxide, and other pollutants in automobile exhaust and ambient air.

It was agreed that the Langley microwave spectrometry work would serve as the basis for a jointly funded EPA/NASA project for the development of miniaturized gas analyzers. Though Langley had already demonstrated the necessary capabilities using its laboratory spectrometers, it is now necessary to develop a smaller, single-frequency device to make the size and price suitable for general use in air pollution monitoring. The EPA/NASA agreement providing for each agency to fund approximately half the cost of the project was concluded in late 1971.

Liquid Metal MHD Technology for Utility Power Generation. The use of liquid metal magnetohydrodynamics (MHD) technology to improve utility power generation shows promise. It should help to alleviate problems brought about by rapidly growing power requirements and the resulting increased concern about environmental pollution. MHD is a relatively new technology which is not yet fully developed, but the degree of development it has reached merits investigation of its application to utility power generation. The liquid metal MHD concept utilizes a heat source to produce a high-velocity, electrically conductive fluid stream which interacts with a magnetic field to produce electric power. With the potential to improve power plant efficiency, MHD can be applied either as the prime system or as a topping cycle for central station power generation.

The Jet Propulsion Laboratory (JPL), through NASA sponsorship, has become a leading authority in the United States on liquid metal MHD. This is the result of a 10-year program and $5 million of NASA funding for space power development. For the potential nonaerospace application of MHD technology, JPL will be funded in early 1972 for a 6-month study to assess the potential utilization of liquid metal MHD to improve utilities' power generation. Applications for liquid metal MHD will be defined, liquid metal MHD will be compared with competing systems for each alternative application, and applications will be selected for which liquid metal MHD appears to be superior. Representatives of utility companies, utility power associations, component manufacturers as well as experts in the power field will make up a committee to provide realistic inputs to the JPL study and to review its progress. This joint participation should facilitate transfer of the technology to the power community.

Sand Height Gage. A problem common to studies of coastal erosion and sedimentation is the measurement of sand buildup. This is now performed with graduated rods which presents difficulties particularly when divers are required for underwater tests. An approach suggested by a Langley Research Center engineer incorporates transducer technology initially used to measure wind tunnel pressures. An initial breadboard unit was successfully tested by Old Dominion University in rivers and the Atlantic Ocean. As a result of these tests, a second less complex unit was funded and will be ready for testing in the summer of 1972. Organizations interested in the sand height gage include the Army Corps of Engineers, the Virginia Institute of Marine Sciences, and the Coastal Engineering Research Center.

MINE SAFETY

Detection for Automatic Quenching of Coal Mine Explosions. The Bureau of Mines has been working on a method for quenching an explosion at its point of origin before it can propagate throughout a mine. Ignition of methane-air mixtures is the cause of most mine explosions. For prevention, the approach taken requires a detector which is sensitive to the ultraviolet (UV) radiation emitted from the combustion of methane. The detector must respond within a few milliseconds of the time of ignition, and trigger the dispersion of a chemical-quenching agent to halt explosion propagation. A serious drawback to the detector system previously used is that it responds to false signals such as those from cap lamps, harmless sparks, and other extraneous sources.

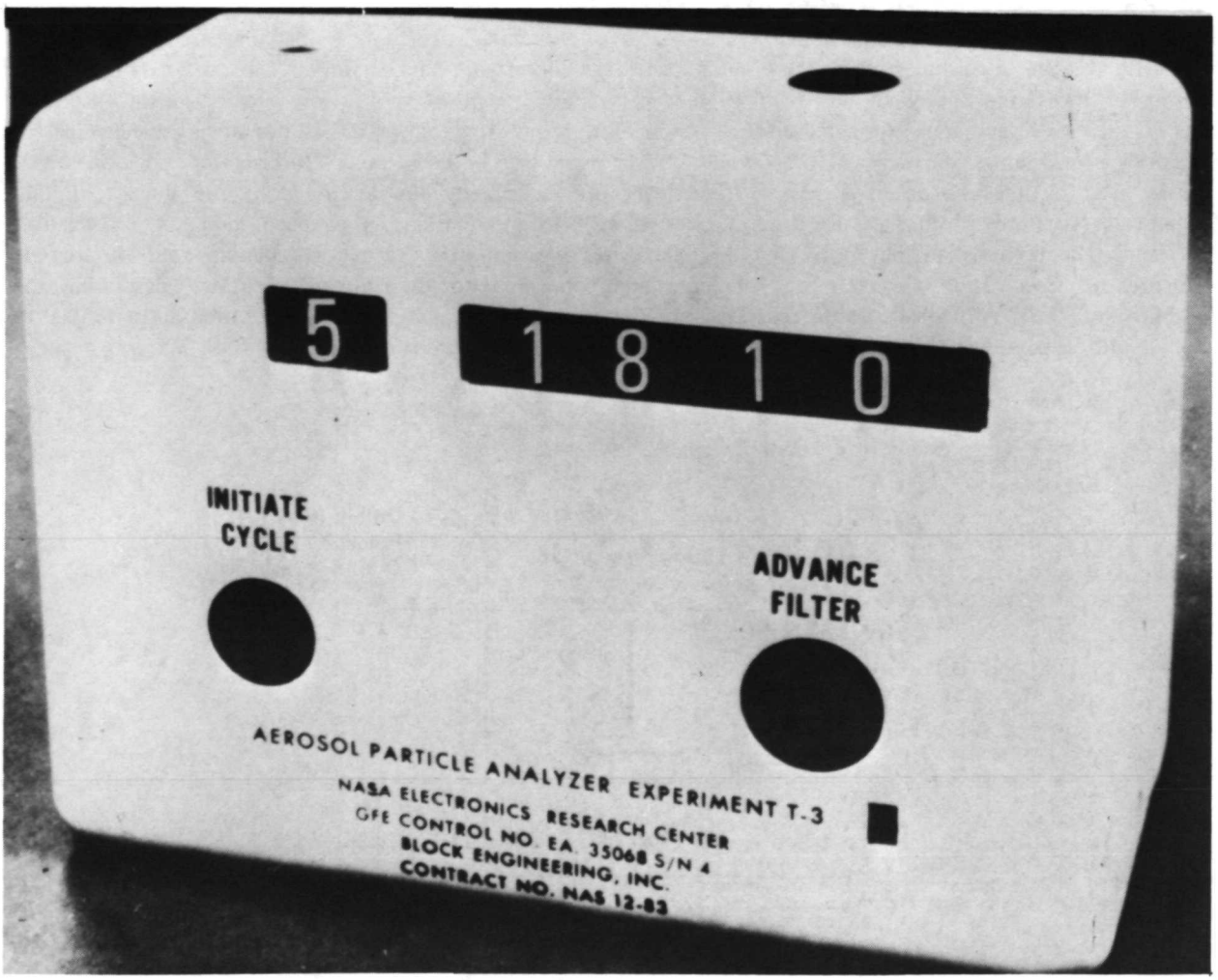
A scientist from NASA's Langley Research Center responded to the need with a suggestion that a two-channel detector could discriminate between the desired methane signal and extraneous signals. Each channel would be centered on a different portion of the UV spectrum, and the output would be a function of the ratio of the two signals.

Subsequently, experimental measurements were made at Langley using the above concept. The results showed promise and were delivered to the Bureau of Mines, who expressed an interest in the concept. One of their engineers stated that a mine explosion can raise amounts of coal dust in some instances sufficient to screen out available ultraviolet radiation and prevent it from reaching the optical sensors. He added that a dynamic pressure-sensor which could detect the advancing shock front of an explosion would prevent this from occurring. It was agreed that this sensor coupled with the ultraviolet detection system offer a promising redundant and fail-safe technique which appears to solve the explosion detector problem. The NASA Aerospace Data Bank is now being searched to locate a suitable pressure sensor.

Dust Monitoring in Coal Mines. Coal dust is an element that can contribute to mine explosions, as well as aid in propagating methane gas explosions over a wide area. Coal dust is also a major cause of "black lung" disease. Recent medical standards established for mine operations require reduction of the level of coal dust within the mine. To meet the standards, the reduction effort will require effective instruments with capacities that current instruments cannot fulfill. This situation established a Bureau of Mines' need for a sensor, or particle analyzer, to function as a dust monitor.

In a computer literature search for information related to the Bureau of Mines requirement, references to a particle analyzer developed for the NASA Electronics Research Center were located. The instrument (Figure 62), a portable multichannel aerosol particle analyzer, was developed for use in the Apollo Command Module. It is lightweight, compact, rugged enough to withstand takeoff and reentry of the space module, self-powered, and can operate over a wide temperature range. The instrument is also designed to count five particle size ranges between the limits of 0.5 and 10 microns. In the configuration for use in the space capsule, the instrument was in the one-of-a-kind category and expensive.

Bureau of Mines officials and scientists were given a demonstration of the instrument. Initial reactions were mixed, resulting from the fact that the instrument, as designed for NASA use, could not yield gravimetric readings, nor could it distinguish rock dust from coal dust.



Particle analyzer may permit particulate monitoring to ensure enforcement of new coal mine regulations.

Figure 62. Dust Monitor for Coal Mines

The early demonstrations of the instrument, however, resulted in bringing the need for coal dust monitoring to the attention of NASA scientists, which provided impetus toward development of the particular technology. A special project was initiated, coordinated by NASA's Office of Advanced Research & Technology (OART).

In cooperation with the Harvard School of Public Health, the OART tested the correlation of the NASA ERC particle monitor with standard mine-sampling techniques for coal dust; also investigated were the possibilities of instrument cost reduction and explosion proofing. The OART study personnel cooperated with Stanford Research Institute scientists conducting a study of dust monitoring methods for the Bureau of Mines.

The Bureau of Mines plans to compare the NASA device with a piezoelectric type monitor also being developed for the Bureau. This evaluation is schedule for early 1973.

Fluidic Flow Sensor for Use in Coal Mine Passages. An adequate flow of air through coal mine passages is a matter of utmost importance for safety and good working conditions. Fresh air for breathing and airflow to prevent accumulations of highly explosive methane gas are imperative. Since uniform airflow throughout a mine is virtually impossible, detailed knowledge of the airflow is extremely important.

A device to measure coal mine air movement was indicated as a basic need by the Bureau of Mines. Ordinarily, airflow measuring instruments are not sensitive enough to detect the low-velocity airflow in mines. A NASA Electronics Research Center scientist suggested that a fluidic air sensor (Figure 63), capable of measuring speeds of less than 10 feet per minute, might solve the low-velocity airflow problem. This is the same technique suggested for the sewer flow monitoring. Since it has no moving mechanical or electrical components, the sensor is especially suitable for use in coal mines. Information on this sensor was received by the Bureau of Mines with interest. The instrument was developed by the Bowles Fluidics Corporation for the Electronics Research Center (ERC), to be used as an airspeed indicator on vertical/shortfield takeoff and landing (V/STOL) aircraft. After further study, a report, *Measurement of Airflow Velocities in Coal Mine Passages,* was prepared and submitted to the Bureau of Mines, describing the capability of the NASA instrument for adaptation in mines. Bowles has submitted a proposal to NASA to build a prototype sensor for field evaluation. This proposal is now under review.

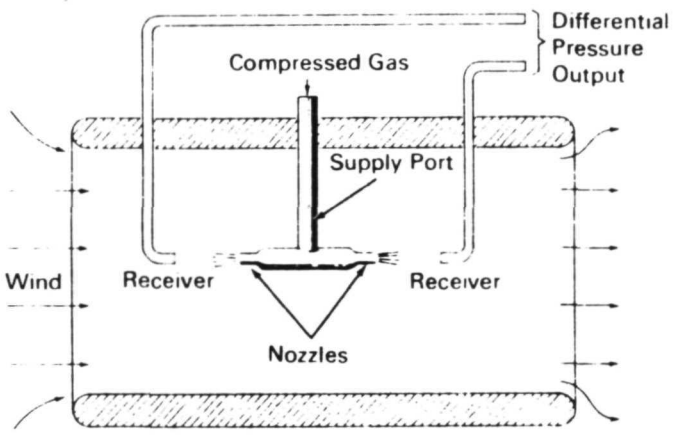
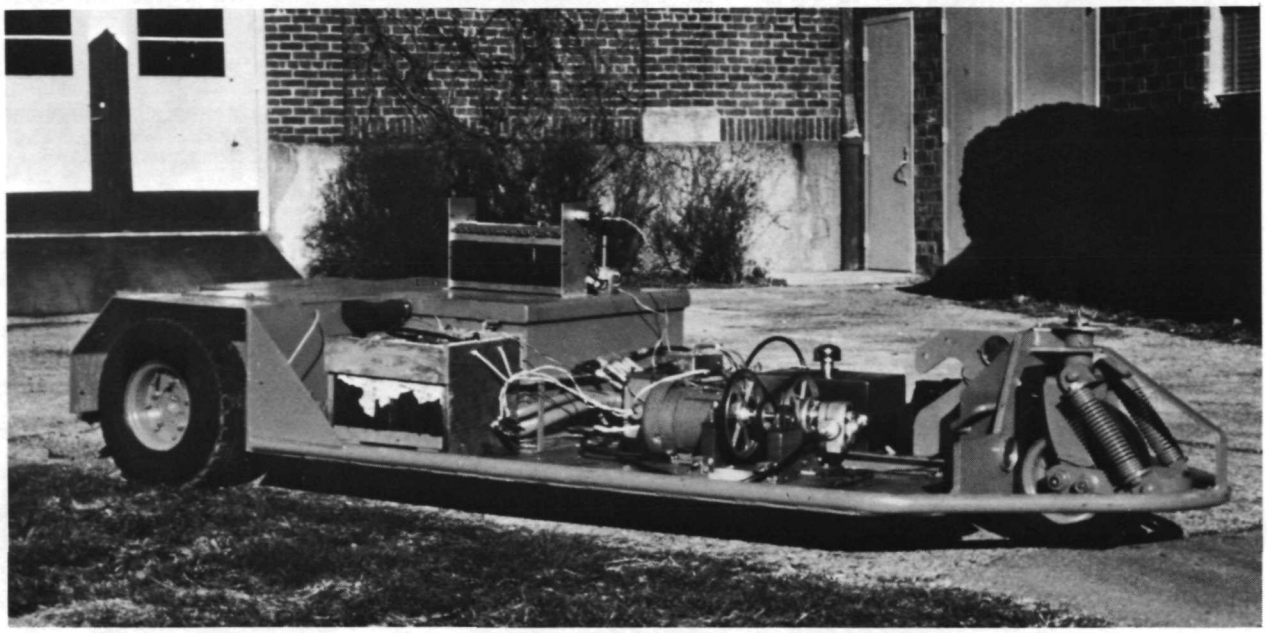


Figure 63. Fluidic Flow Wind Sensor



NASA-developed technology for the lunar rover vehicle might be used for its guidance system.

Figure 64. Rescue Vehicle for Use in Coal Mines

Rescue Vehicle for Use in Coal Mines. The Bureau of Mines is interested in developing special vehicles for use in mines after a disaster. A professor at the University of Kentucky has been funded by the Bureau of Mines to develop an unmanned remotely controlled unit (see Figure 64). There are several areas where NASA technology might be used. In particular the guidance system technology utilized in the NASA "lunar rover" vehicle appears applicable. Other areas where NASA technology might be used include a miniature, mine-safe television camera and fire resistant thermal insulations to protect the various systems of the vehicle in a mine disaster environment. Discussions are also planned during the winter of 1972 between the Bureau of Mines and Marshall Space Flight Center regarding the development of a manned rescue vehicle.

LOOKING AHEAD: RECENT NEW STARTS IN TECHNOLOGY APPLICATIONS

During fiscal year 1972, significant new starts were initiated in the effort to apply aerospace technology to important public sector problems. Two new approaches were taken. Requests for proposals were issued to the aerospace community to solicit project ideas for solving important public sector problems using space-related technology. Also, the agency solicited candidate applications projects from within NASA itself. The purpose of these new approaches was to provide new opportunities for those most familiar with aerospace technology to initiate project proposals complementing the problem oriented activities which have been generated by the Application Teams. The response to both efforts has been excellent and has made it possible to double the number of meaningful technology-applications projects.

The requests for proposals asked for ideas in the specific areas of air pollution, water pollution/solid waste management and clinical medicine. One or more of the most promising and innovative of the 225 projects proposed in each of these areas will be selected in early 1972 for award of contracts.

The request for application projects from within NASA attracted nearly 100 proposals. These candidate projects are coordinated with appropriate mission oriented agencies to ensure relevance and nonduplication. Examples include the evaluation of biomedical projects by the National Academy of Engineering Committee on the Interplay of Engineering with Biology and Medicine, with representation from the Department of Health, Education, and Welfare, the evaluation of air and water pollution projects by a special committee within the Environmental Protection Agency and the evaluation of law enforcement problems by the Law Enforcement Assistance Administration.

Some of these projects have been funded and are included in the Current Technology Applications Examples section of this report. Others are still under evaluation at this time.

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BIOMEDICAL EXAMPLES

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*Those applications which have not appeared in previous reports are marked by an asterisk.

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