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PROCEEDINGS

First Houston Technology Transfer Conference

September 24-25, 1974

PROCEEDINGS

OF

THE 1974 TECHNOLOGY TRANSFER CONFERENCE

SPONSORED BY

THE HOUSTON CHAMBER OF COMMERCE

IN COOPERATION WITH

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SEPTEMBER 24-25, 1974

The Technology Transfer Conference is presented by the Science and Technology Committee of the Houston Chamber of Commerce in conjunction with Johnson Space Center.

Science Committee Chairman - Loren B. Odell
Research Director
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Conference Chairman - Lyman M. Edwards
Division Systems Coordinator
Research and Engineering
Petroleum Services Division
Dresser Industries, Inc.

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WELCOME

Bernard Sakowitz

It is quite an honor to be able to speak at this, the first Technology Transfer Conference held in Houston and one of the first in the country. I welcome all of you ladies and gentlemen who are here today and thank the speakers and participants who make such a meeting possible. As Chairman of the Board of the Houston Chamber of Commerce it is my privilege to promote our city to many different groups with varied interests. I think no group better represents our city than the one gathered here today.

Houston is the petroleum capital of the country and very possibly the world. We are also well on our way to becoming a national and international energy center. We have one of the world's finest medical facilities in our Texas Medical Center. The oil industries have assembled in Houston the greatest concentration of earth scientists. Through the efforts of the petroleum companies and our major universities we are assuming a position of leadership in the ocean sciences and are acknowledged world-wide as the headquarters for our nation's space efforts. Houston is a world-renowned technology center.

The benefits of having such varied technologies concentrated in one spot producing interdisciplinary innovations are just now becoming known, although we can trace our development back to the national commitment to put a man on the moon by 1970.

In eleven days it will be seventeen years since the Soviet Union launched Sputnik I, the first man-made satellite, and provided the competitive stimulus which was to ultimately propel the U. S. into the space age--the leadership of the space age. Back in 1957, at that low point in our history, we were behind in space technology. But we quickly caught up!

In May, 1961, Alan Shephard's Mercury Redstone 3 put the first American into space--for a 15-minute trip. In February, 1962, John Glenn became the first American to orbit the earth. Finally, in 1969--and it hardly seems 5 years ago--Neil Armstrong proclaimed "one small step for man, one giant leap for mankind" from the surface of the moon.

The space program and its associated technology have come a long way. We are just now beginning to discover and apply all of the subsidiary benefits from it. Houston provides a perfect culture-medium for the propagation of commercially successful applications of this technology due to the unique interfacing of the life sciences and the earth sciences with the ocean sciences and space sciences concentrated here in unique combination.

Technology is defined as the application of science to industrial or commercial objectives. As businessmen we have the opportunity to draw from this tremendous reservoir of knowledge, to build on and combine these concepts to provide totally new products and services as well as to improve techniques for existing products and services.

However, the technology available here is not limited to just that from the space program. We have speakers representing other government agencies and private firms, physicians and professors who have ideas which can be transferred across disciplinary divisions and successfully applied to commercial endeavors. We can learn much from each of them. We can profit from an exchange of innovative ideas.

In between the sessions I hope you will use your time to examine the exhibits in the Scorpius Room--just north of us--and also those exhibits located in the lobby.

It is my privilege to welcome all of you officially to our conference. I am confident you will find it a profitable and rewarding investment of your time and interest.

OPENING REMARKS
Dr. Christopher C. Kraft

Good morning ladies and gentlemen.

It is indeed a pleasure to welcome you to this Technology Transfer Conference. I hope it will prove a worthwhile and productive manner of effecting technology information exchange.

The National Aeronautics and Space Act of 1958, which created NASA to conduct the nation's space exploration programs, specified that we should do so in such a way as to preserve "the role of the United States as a leader in aeronautical and space science and technology and in the applications thereof...". The Act further specifies that NASA provide for the widest practicable dissemination of information concerning NASA's activities and their results. It is in response to these directives from the Congress that we conduct the technology applications programs you will hear described during this conference.

The benefits of space technology are many. We have learned to take for granted television from China, Russia and Europe as part of the evening news. A facet of such developments not widely appreciated is that a single 1500 pound satellite has the same capability as a transatlantic cable weighing 11,500 tons and using 2,500 tons of copper. The savings in energy and material resources are as significant as they are obvious.

The observation of the Earth from space is the routine basis for our analysis of the weather.

Other observations of the Earth are giving us new insights into the Earth's structure and new perspectives on the use of land. Eventually, we may know enough to venture weather modification to relieve drought and prevent hurricane.

One of the most exciting experiments in the Skylab was the test of space processing techniques. The unique environment of weightlessness eliminates convective flow in heated materials and the removal of this disturbance allows the formation of metals, alloys and crystals of unprecedented purity and size. While this activity still needs a considerable amount of research to establish its true potential, the economic benefits could be very rewarding.

These, and other space activities, receive great public notice; equally important, but not so readily identified are the benefits derived from applying technology developed in the aeronautics and space program to commercial, industrial and medical processes in general use.

It is always difficult, and sometimes impossible, to trace how such technology flows from its initial development to widespread application, but the results of several studies emphasize the importance of information exchange. It is in discussions between knowledgeable people that the compatibility between capability and opportunity has been, and will continue to be, recognized.

The incentive for dialogue is significant. The government has an annual investment of more than 15 billions in research and development. The value to the Nation of this investment is greatly enhanced as it is more widely exploited. To make access to this body of information readily available, NASA and other agencies provide information dissemination systems which will be described in some detail during this Conference.

To provide economic incentive for the business risk in commercial applications of NASA inventions, terms for exclusive license may be negotiated. A conference describing the NASA Patent Licensing Program will be held in Salt Lake City this fall.

Let me finish these remarks on a somewhat different, but perhaps more important, note. The success of the Space Program owes much to the energy and initiative of the men and women who participated in the design and operation of the spaceflight systems. These same people see many challenges which excite them in the energy, environmental, and productivity needs which confront the Nation today. They believe we have something to contribute in these areas. We also recognize that we have much to learn about how to make space activities more widely useful.

We at the Johnson Space Center are fortunate to be part of a community that is based on high technology and aggressively interested in expanding the use of technology to improve industrial productivity and the quality of life. We intend to do our part, and I am grateful to Mr. Sakowitz and the Houston Chamber of Commerce for the opportunity to join with them in sponsoring this Conference.

TECHNOLOGY TRANSFER

FIRST SESSION

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TECHNOLOGY APPLICATION AT ROCKWELL INTERNATIONAL

C. J. Meechan

N75 17189

INTRODUCTION

There are probably few places in the world where the meaning of the term "technology transfer" is better understood than here in Houston. Houston is the birthplace of much of the technology used in the transfer process. NASA's technology utilization program has made, and continues to make, beneficial contributions to commerce and industry. Its impact on biomedical, material sciences, structures, electronics and related fields, is in evidence in products, processes and our ever-expanding national base of knowledge. You will hear more about the specifics as this conference unfolds.

Just as NASA's technology has contributed to the growth and economic well-being of the Country, so have Rockwell International's scientific and technological skills helped our Corporate development by generating needed products and services. Being a high-technology corporation, we are sensitive to external and internal directional trends. We appreciate the insight provided by meetings such as this. Our product and organizational planning are predicated on technical accomplishments to date and the extrapolation of our technological portfolio, for future endeavors.

In the next few minutes, I would like to trace the maturity of technology transfer and utilization at Rockwell International, starting with the transfer concept. The latter provided some of the stimulus for the 1967 merger of the aerospace and electronic talents of North American Aviation with the multi-industry commercially-oriented Rockwell Standard.

Our experience in applying technology across business segments and organizational lines falls into three categories as depicted in Fig. 1.

I will discuss the first mode in more detail shortly. An example of the second mode is the following:

TECHNOLOGY APPLICATIONS ORGANIZATIONAL MODES

- o Transfer from technologically developed to under-developed organizations within company
- o Transfer between technologically developed organizations to form four new operations within company
- o Formation of high technology spin-off beyond the corporate entity

FIGURE 1

A new, high-technology organization with devices and products for commercial markets (our Microelectronics Divisions) was formed from an equally high-technology division - Autonetics. The new divisions develop and produce metal oxide semiconductor devices for calculators, electronic slide rules, digital watches and similar articles, as well as the end items under our own brand names and those of large retailers.

The third form of organizational structure involves two spin-off companies. Advanced Rockwell developments in liquid and gas purification and in remote sensing systems stimulated the formation of Envirotech and Geosource Corporations. Here again, commercial markets benefited from aerospace technology.

Now I would like to go a little deeper into the first mode which entails experiences that seem to be quite interesting to others beginning to practice technology transfer.

Technology transfer, as we use the term, is the process in which aerospace and electronics experience is applied to beneficial ends in the commercial arena (See Fig. 2). First-generation products, processes and management or business systems emerged. This was accompanied by the physical transfer of well over 300 people, one-third of whom we can classify as foremost specialists in their fields, with pedigrees bearing names like Apollo, Saturn, Minuteman, Sabre-jet, and many more.

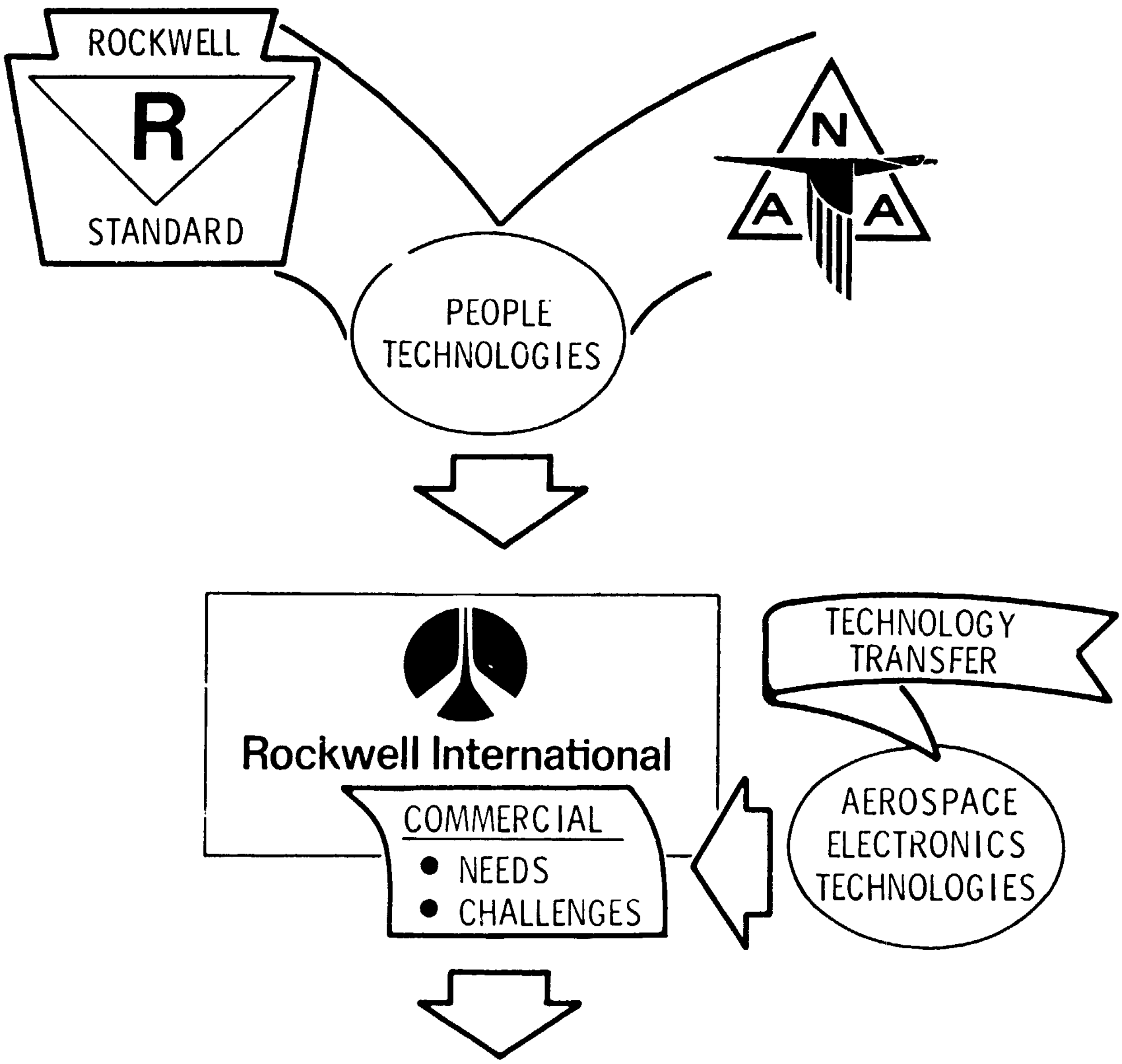
About half of the experts went into middle management positions - Chief Engineers, Controllers, Directors, and Department Managers. Another quarter maintained technical and specialist classifications. The remaining quarter were almost equally split between top management (Group and Division Presidents, Vice Presidents and General Managers) and first-level supervision. Thus, technology transfer has not only impacted our product lines but will have significant ramifications in our policy and decision-making processes. The benefiting divisions will become obvious when I describe certain programs.

Most of our commercial products are principally mechanically driven and, in some cases, derived through centuries of evolution such as textile and printing machinery. Competitive pressures in our markets today demand greater productivity, more flexibility and improved benefit-to-cost ratios - characteristics which mechanical designs cannot satisfy. Thus, one of the primary thrusts was in the direction of fast responding, easily programmed, inexpensive electronic and electro-mechanical devices, to replace the heavy, momentum-limiting, mechanical, machine members.

Metro-set is a typical Rockwell product of this nature. It employs a type memory and mini computer control of a cathode ray tube to photographically image 1,000 lines of newspaper copy per minute. The photographic output, in any of 100 type faces and in various sizes, is used as an input to the typesetting machine.

Another development, Skid-trol, represents a product which resulted from a Department of Transportation legislated market. The

PHASE I
TECHNOLOGY TRANSFER



FIRST-GENERATION PRODUCTS

- ELECTROSPIN
- ELECTROKNIT 48
- METRO-SET
- SKID-TROL

FIGURE 2

need stems from a desire to reduce accidents, property damage and liability claims resulting from jackknifed tractor-trailers during panic stops.

As with Metro-set, Skid-trol, is an example of a whole new technology (electronics) being introduced into a conventionally mechanical market. With Skid-trol, an advanced-device mini computer is used to perform parametric calculations of wheel deceleration during braking. The computer selects and solves any one of more than 500 equations of motion, 50 times per second. At the point of impending wheel lock up, the brakes are automatically released and reapplied, much like a driver pumping the pedal. The action is not only faster than a driver's reflexes, but results in straight stops, in shorter distances, than if the vehicle were under driver control. Self test features are included in the electronic circuits.

Through fiscal 1974 the Corporation has invested over $25 million in technology transfer. Our annual outlay has been between eight and ten percent of our R & D budget. Ninety-five percent of the investments to date have been adjudged to be fully productive, in that either marketable products were obtained or program objectives were met.

By use, the distribution of funds includes about 50 percent for development, 20 percent each for prototypes and production activities, and the remainder for feasibility, marketing or methods studies.

The people transfer (See Fig. 3) resulted in the second or technology utilization phase, which I referred to before--a form very much in evidence at this time. The people transfer has built up relatively independent capabilities, within the receiving divisions. The divisions gained new skills, so essential to the sale, distribution, operation, servicing, and maintenance of the products. Inherent in the newly acquired skills and technologies was a fresh look at traditional product lines and traditional ways of doing business - a look which is just starting to evolve second-generation products and efficiencies, as transferees undertake the design of broader product lines.

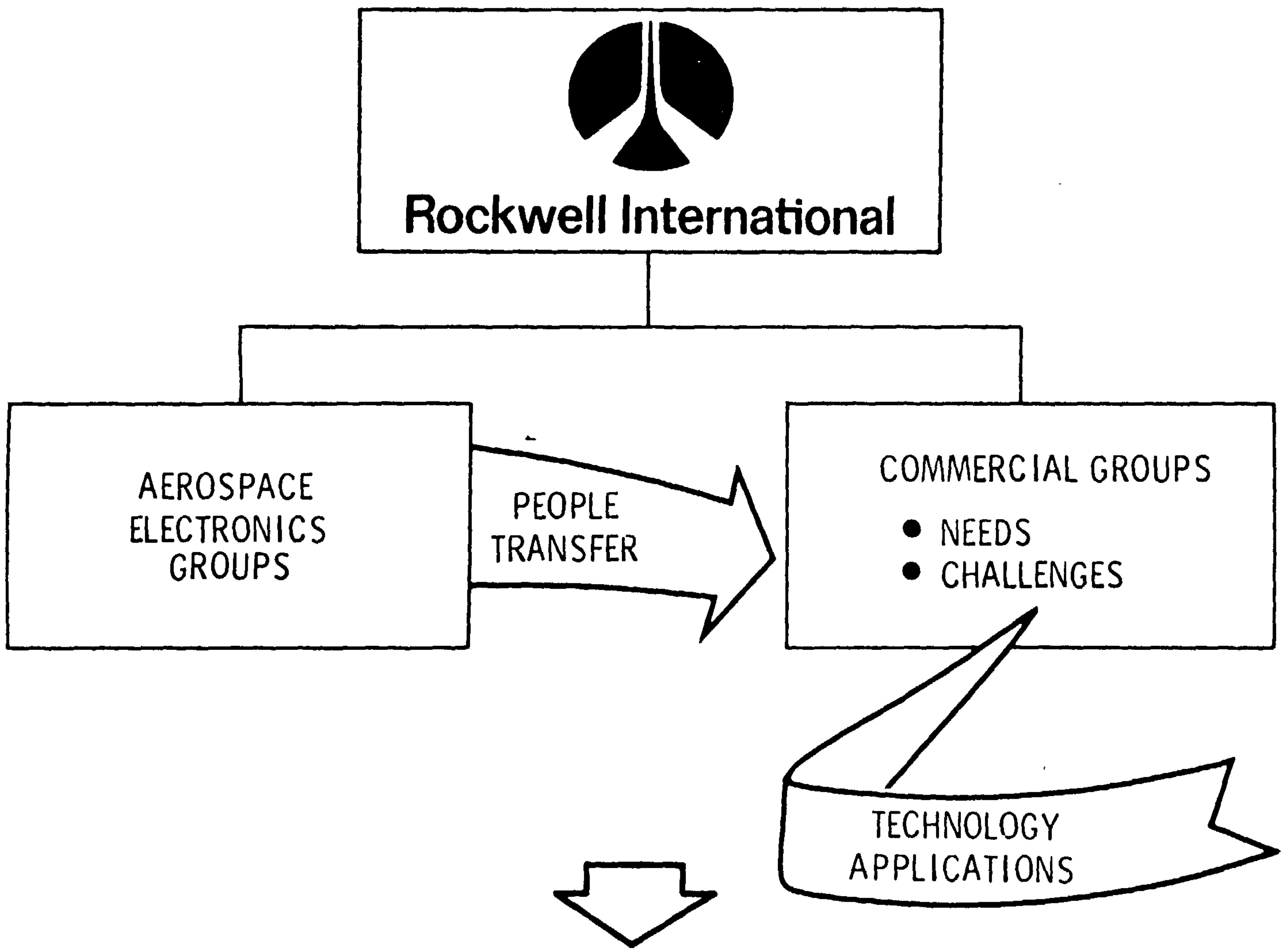
We continue the thrust toward commercial applications as an outlet for our advanced and future technologies. Current activities include:

1. The use of molten salts in the gasification of high sulphur coal.

2. The use of a modification in applying Saturn second stage insulation for low-cost liquified natural gas tankers, rail cars, storage tanks, and pipe lines.

3. Application of turbo-machinery knowledge to waterjet propulsion on jetfoil boats.

PHASE 2
TECHNOLOGY UTILIZATION



SECOND-GENERATION PRODUCTS
(Self-Developed)

- SOLID STATE CONTROLLER (Electroknit 48)
- METRO-READER
- CORESPINN

FIGURE 3

In summary, technology diffusion at Rockwell International has progressed from (1) the application of special skills to solve specific problems to (2) the transfer of the required people and skills to allow the commercial divisions to solve their own problems and develop or improve their own products. Our prime effort is concentrated on commercial industrial applications. Rockwell's major emphasis on advanced technology utilization is directed through three operational modes, namely, transfer from technologically developed to underdeveloped organizations within the company; transfer between technologically developed organizations to form new operations within the company; formation of high technology spin-off organizations beyond the corporate entity. Two key lessons we have learned are that successful technology transfer required people transfer and committed conversion budgets. Without both of these ingredients, beneficial transfer is doomed from the start, at least as we practice the subject. But heeding this caveat, technology transfer has been and we expect it to continue to be a major contributor to our improving product lines and organizational growth, and we highly recommend the practice.

TECHNOLOGY PIPELINE

Butch Voris

N75 17190

NASA recognized early that the rather informal and sometimes serendipitous process of natural diffusion had to be enhanced and accelerated through the development of an organized technology program; hence, the establishment of the Technology Utilization Program back in 1962.

After ten years of evolution, the Technology Utilization program now uses three basic and complementary technology-transfer mechanisms: Publication, Technical Assistance Dissemination, and Application Demonstrations.

My discussion today will be directed to the marketing of NASA technology and industrial applications.

PUBLICATIONS

Each of NASA's field installations has a Technology Utilization Officer. His assignment is to identify, document and evaluate new technology generated by NASA and its contractors. In addition, he is also charged with assuring that such technology is rapidly available to potential users in and out of the aerospace community. These Officers administer a special clause in NASA contracts with private firms. The clause requires contractors to report to NASA any new technology developed in the course of their work. And, such new technology--when it is deemed to have commercial potential--is announced to business and industry through various media.

THE TECH BRIEF

The NASA Tech Brief is probably the most widely known announcement medium. It is a technical description of an innovation, with straight-forward explanations of basic concepts and principles. The Tech Brief reader can obtain more detailed information from a NASA Technical Support Package (TSP). The TSP includes test data, drawings, specifications, and it is avilable by writing to the Technology Utilization Officer whose address is provided in the original Tech Brief. While obviously innovations often need to be modified for new applications, the record indicates high interest and considerable technology transfer stimulated by Tech Briefs and TSPs.

For example, NASA Tech Brief 70-10520, which describes a NASA Langley Research Center flowchart, provided an ordered test sequence allowing quick identification of metals and alloys and attracted major industry attention. The accompanying TSP attracted requests by more than 1,000 people. Using the NASA system, even complex alloys can be identified in 30 minutes or less by workers with very little training. The test requires only the application of standard chemical reagents to metal surfaces, spot-plate depressions, or on filter paper. Colors or specific reactions produced by the reagents allow identification, and only a minute amount of the metal is destroyed.

Many of the people who inquired for details have found applications for the system. And, the Institute of Scrap Iron and Steel has distributed copies of the NASA Tech Brief to its member companies.

Here are some examples of applications of the NASA spot-test technique:

- o The Houston Branch of the Rockwell Manufacturing Company, a producer of offshore oil rig equipment, uses the spot test as a standard procedure to process customer complaints on malfunctioning equipment. Such malfunctions often result from using incorrect alloys in a given component.

- o An industrial hygiene chemist with the New York State Department of Labor is using the spot test to help identify health hazards associated with metal fabrication. He is especially interested in alloys using beryllium and cadmium.

Another example of Tech Brief spurred technology transfer:

- o The Boeing Company, under contract to NASA Marshall Space Flight Center, invented a portable, electrically-powered ultrasonic hand tool for rapid scanning of spot-weld discontinuities in small and inaccessible places. The unit includes an ultrasonic search unit attached to a solenoid in a housing assembly that includes the scanning motor. The solenoid is fitted with a recording stylus in contact with pressure-sensitive paper to provide a readout of results. The front end of the scanner is placed on the area being examined. The spiral scanning motion of the ultrasonic search unit is recorded as a spiral pattern on the pressure-sensitive paper. Weld discontinuities appear as breaks in the spiral pattern.

The Moragne Machine and Manufacturing Corporation in Texas is using several copies of this hand tool, built on its premises, to inspect welds on equipment produced by Moragne for industrial uses. The Company's president has used the original NASA TSP and other TSPs in an extensive investigation of ultrasonics. Those investigations have produced inventions: a patented ultrasonic precipitator to clean the air in the Houston Astrodome, a carbon- and fire-brick plant; and a welding method in which the work piece is vibrated ultrasonically to produce a superior weld. The company president credits NASA technology-transfer for some $3.5 million worth of new sales.

Another major source of information to industry on NASA innovations that may lend themselves to adaptation is the Technology Utilization Compilation. These are collections of a number of related ideas into a single book, covering a general technical subject. These books are generously illustrated, and serve as workbooks on a practical level.

Some recent examples of Technology Utilization Compilation Volumes:

- o Biomedicine
- o Solid State Technology
- o Chemistry Technology
- o Electronic Control Circuits
- o Computer Programs, Mechanical and Structural Design Criteria

The scope of the Tech Brief and allied dissemination efforts is illustrated by the fact that nearly 6,000 Tech Briefs--and 84 Compilations, have been published since 1964.

And, during 1973 alone, more than 68,000 requests for detailed Technical Support Packages were received by NASA from American industry. Such a heartening response demonstrates the continued viability of this proven technology transfer mechanism.

DISSEMINATION AND INDUSTRIAL APPLICATIONS

Dissemination of technological information is crucial to orderly technology transfer, and the Technology Utilization Offices at the various NASA field centers play a major role in this function. Not only do they respond to inquiries stimulated by the publications programs and to inquiries of a more general nature, but they also conduct periodic conferences on specific technological subjects such as fire safety, ion plating, as well as the convening of technical conferences for specific user groups such as electric power producers.

Also, the Technology Utilization Program operates a network of Regional Dissemination Centers (RDC's) which provide access to aerospace technology for the industrial sector of the economy. Specially structured Biomedical and Technology Application Teams offer technical solutions to problems in the public sector. The overall concept is linkage--that is, the Technology Utilization Program is geared to the conviction that only through direct contact with potential users can transfer of aerospace technology be successful beyond the normal groups that have access to it. That means a continuing effort to work with potential users to define problems that might be amenable to aerospace-derived solutions and then to actively assist in problem solving efforts with the customers for such technology.

THE RDC's

NASA's Regional Dissemination Centers are a major element in this effort. They provide available technology in response to specifically stated technical problems and information needs of users ranging from small business to the largest companies. Firms subscribing to RDC services cover a broad spectrum of the U. S. business community. The

Centers also serve university faculties and students at the RDC locations, many national, state and local organization, and government units at all levels.

A telecommunication network connecting the Centers permits RDC customers in any part of the country to reach--through the Center most convenient to them--the full technical resources of all the centers, and to avail themselves of the full range of data available in the total network. These include technical contributions, research findings and related material assembled by NASA's Scientific and Technical Information Office, as well as comparable information from other sources on advanced research and development. The RDC's through their working relationships and people-to-people contact with NASA field centers, act as constant catalysts to bring industry closer to problems and needs closer to NASA's technical experiences and capabilities.

The Centers serve as professional technical-assistance consultants to clients in the major industrial regions in which they are located, providing two basic kinds of service: technical information gathered by retrospective search of the NASA data bank to uncover all information relavant to a given problem and current awareness' service that informs clients of innovations. The data includes abstracts, research reports, full-text printouts of technical articles, and other documents. Also, clients can receive technical assistance on specific problems from RDC staffs and from NASA research scientists and engineers.

The response to the RDC service is illustrated by the fact that last year the Centers provided service to more than 3,200 industrial clients, a 25% increase over 1972. The RDC's also aided a number of state and local governments by providing access to advanced aerospace technology.

REGIONAL DISSEMINATION CENTERS:

- Aerospace Research Applications Center (ARAC), Indiana University, Bloomington, Indiana 47401
- Knowledge Availability Systems Center (KASC), University of Pittsburgh, Pittsburgh, Pennsylvania 15260
- New England Research Application Center (NERAC), The University of Connecticut, Storrs, Connecticut 06268
- North Carolina Science and Technology Research Center (NC-STRC), Research Triangle Park, North Carolina 27709
- Technology Application Center (TAC), The University of New Mexico, Albuquerque, New Mexico 87106
- Western Research Application Center (WESRAC), University of Southern California, Los Angeles, California 90007

The NASA Technology Utilization Program leadership is convinced that many of the discoveries emerging from the nation's aerospace program have potential nonaerospace applications. And, the RDC's have already developed a strong record of participation in successful technology transfer along these very lines.

One recent example: A Regional Dissemination Center recently assisted a company that was looking for a way to remove bacterial organisms that were contaminating large vats used in the production of antibiotics. An RDC search of NASA data sources revealed chemical methods that had long been used to clean NASA space rocket fuel tanks. The aerospace solution made it possible for the company to solve its problem without diverting expensive technical manpower from their regular work.

Most often, companies call on RDC's for information on a specific problem. For example, Pyronetics, a company in California, was developing a portable, low-cost multi-purpose welding torch. But, the company faced the technical problem of a bulky high-pressure oxygen supply. Pyronetics asked for an RDC search of NASA data for information on chlorate candles. These candles are unique in that they generate oxygen while they burn. The Western Research Application Center at the University of Southern California provided information on chlorate-candle compostion, hazards, applications and manufacturing and shipping regulations. The data was crucial to the development of Pyronetic's final market product--which weighs only seven pounds. By the end of 1972, more than 20,000 units had been sold.

Another very typical example. Owens-Corning Fiberglas in Texas is supplying the insulation for the Alaskan pipeline. Unique thermal stresses and concern with environmental considerations required the company to analyze the mechanical-thermal stresses on the insulation, which was to be made of a jacketed rigid foam. An RDC data bank search identified a NASA report dating back to 1965 that offered the basis for the required analysis.

Another example of RDC contributions: The ILC Company in California produces pulse lamps and continuous-wave devices and communication equipment. This firm asked the Western Research Applications Center to prepare a state-of-the-art search on arc-lamp cathode technology. Using the data from the search, the firm introduced several innovations into their arc-lamp product line. ILC says that the RDC service saved them $25,000 and improved their competitive position.

COSMIC

The U. S. space program has spurred major advances in computer technology and NASA's Technology Utilization Program has provided access to these software benefits to the Nation's computer users. Thus, an important component in the technology transfer effort is NASA's Computer Software and Management Information Center (COSMIC), located at the University of Georgia. This Center collects, evaluates, and distributes computer tapes, cards, decks, program listings and

and machine-run instructions. COSMIC and all Regional Dissemination Centers sell "software" to potential users at prices based on cost of reproduction and distribution.

COSMIC serves as a central clearinghouse and dissemination outlet for computer programs and related data developed by NASA and its contractors, as well as those developed by the Department of Defense. The Center is now established as a locus of support for the industrial, educational and business communities. It has already disseminated nearly 20,000 items.

New items are constantly being added to the COSMIC program inventory and nearly 1,000 complete programs are now available.

One example of technology transfer in the computer program field is NASTRAN (NASA Structural Analysis Program). NASTRAN is a general prupose digital-computer program originally developed to analyze static and dynamic behavior of elastic structures. The program was originally and is still used by NASA and aerospace companies, to analyze aircraft fuselages, wings and tail assemblies, space vehicles (Viking and Skylab) and related launch facilities and turbine engines.

Because of its versatility, this computer program is now widely used by scores of firms including the Ford Motor Company (to assure quality of auto frames). More than 200 companies have purchased the NASTRAN program. Ford, one of the most well-known users, says it is saving $12 million a year with this computer program.

MARKETING

The programs discussed above are important and essential to establish a continuing relationship with industry. To supplement and reach the objective of "creating a national state of mind which accepts and supports NASA as being vital to the growth, security and well being of our nation" new initiatives in marketing were initiated in 1973 and are being accellerated now and will become more intensified in coming years. Two of these programs are:

INDUSTRIAL SEMINARS

A series of Industrial Seminars have been presented and met with a great deal of success, enlisting very favorable comment by attendees. The purpose of the Seminar is to introduce a select group of key industrial managers to NASA's Technology Utilization Program and the role of the RDCs in providing technology transfer services. The meetings have been held in selected midwestern cities with a large industrial or manufacturing base, such as Chicago, Detroit, Minneapolis, etc. Prospective atendees are generally presidents, technical vice presidents or managers of R&D of the major companies in the area. Each person selected is sent a personal invitation to the Seminar which is combined with lunch to make it convenient for a busy executive to attend. The invited group is restricted to 35 to

50 people to allow for a relaxed atmosphere and personal interaction between speakers and attendees. The Program usually consists of a short informal talk by a NASA official about NASA's Technology Utilization Program followed by a selected film and lunch. After lunch an RDC representative describes the various services and opportunities offered by the NASA program. Sufficient time is allowed for general questions and discussion. The meeting is then adjourned and attendees are encouraged to stay and engage in further discussions with the NASA or RDC representative at their option. The industrial Seminar has proven to be a very cost/effective mechanism to communicate directly with a highly select group of business executives, and has increased the visability of NASA and the Technology Utilization Program materially in the business community where Seminars have been held.

Seminars held in the past have been directed primarily to technical management audiences. We are planning to hold Seminars for more general audiences, such as, city and state officials, businessmen and leaders of organizations concerned with problems which concern the general public such as transportation, the environment, delivery of health services, etc.

PATENT LICENSING CONFERENCES

Four NASA Patent Licensing/Technology Utilization Conference have been held to date. The attendance has averaged 200 per Conference, with the audience comprised primarily of management representatives from companies of all sizes. Heavy NASA representation and personal interface are emphasized in order to get maximum exposure and induce genuine interest among the attendees.

The reactions to the Conferences have been very favorable, with a high degree of interest and surprise at the efforts NASA is making to provide its technology in an easily accessible manner to industry. Conferences have been held in Los Angeles, Boston, Jacksonville and Chicago; the next Conference is tentatively planned for Salt Lake City on November 19, 1974.

In conclusion let me say that my organization is market oriented and is planning additional programs to inform the public of NASA's national resource in technology available for immediate application. You can be assured that these plans will be developed to increase the return of the national investment in aerospace research and development by encouraging additional uses of the technology gained in those programs.

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COMPUTERS AND TERMINALS AS AN AID TO INTERNATIONAL TECHNOLOGY TRANSFER

William T. Sweeney

Obviously, this audience is composed of individuals not only generally interested in new technology, but also responsible for R&D, corporate development, and the control of related budgets. A popular, effective, and less expensive method of enhancing new business opportunity programs, involves technology transfer through international licensing. Today, more than ever, corporations recognize the potential of opportunities derived from sources outside of their own research and engineering efforts.

Such opportunities do exist and are available from sources not only in the United States, but from many countries throughout the world, and involve all technological fields. When a corporation is confronted with the problem of making available a new product or process to be introduced, it is best to find out if the related technology already exists -- why re-invent the wheel! However, this oversight is a common daily tragedy.

Examples of sources that do exist include:

A. Independent Research Laboratories
B. Governmental Agencies
C. Universities
D. Corporations

The Independent Research Laboratories are important sources of new and useful technology because they are in business for one reason, and one reason only, and that is to develop a product or process which can be licensed and/or sold for a profit to corporations. Past experience shows an outstanding record of success in preparing very salable technology.

The Governmental Agencies are also providing new technology to companies throughout the world. Here in the United States, examples of these agencies would be the United States Department of Agriculture (USDA), Department of Health, Education, and Welfare (HEW), United States Department of the Interior (Bureau of Mines), National Aeronautics and Space Administration (NASA), etc. And in other countries there are similar agencies, such as NRDC in the U.K., ANVAR in France, etc. Governmental agencies provide tremendous scientific brainpower support which enables potential licensees to not only acquire technology, but the continued necessary related ability.

The Universities throughout the world are engaged in research and many of them now are beginning to work more closely with industry than they have in the past. Universities find they can receive additional revenue through options and licensing agreements with major industry. They are now developing their technology to a further degree, so the end-use application is more suitable to industry throughout the world. Due to this, many Universities have experienced success in developing license relationships. There are several success stories relating to this type of arrangement, which can be furnished to support this statement.

The Corporations throughout the world are the major contributors to the bank of available licensable technology. The technology derived from corporate sources is usually at more advanced stages of development. Often a significant amount of economic and marketing data is available from these sources.

A good example of the quantity of new and licensable technology would be the 7,000 products or processes which are presently contained in the Dvorkovitz World Bank of Technology. In most cases it is not spin-off technology, but it is new and unique, offering attributes enabling product introduction with expediency.

How do companies become aware of the new developments which are available from outside sources? Many of them do this through their own efforts, and are being somewhat successful. However, due to cost and time involved not all companies have a chance to do it alone.

Thus, it is obvious that a third party provides an important catalyst in the technology search and transfer process. Many corporations, both domestic and foreign, use a third party to supplement their R&D and corporate development programs; however, this is not limited to the large corporations. Numerous corporations with two to five million dollars in annual sales are also engaged in such activities and relationships with third parties. In fact, many small companies regard third party activities as their R&D or Corporate Development Department. Before this or any approach can be effective, a company must be prepared to properly utilize such services, i.e.:

1. While an abundance of new and useful technology is available, a corporation must determine what would most easily fit into its existing organization, or convey the direction it intends to go in the future.

2. The corporation must also have the proper facilities and resources to evaluate new technology. Frequently, new technology is presented but no advantage can be taken, due to an insufficiency in the evaluation system. In many instances, another company without this weakness (generally a competitor to the former) takes the same technology to commercialization profitably.

Once this criterion has been met, the company can proceed in selecting the third-party system which will best suit its needs. Dr. Dvorkovitz & Associates has implemented a unique third-party system, which has proven profitable to many corporations throughout the world. We believe, and our clients agree, that this computerized system is probably the most effective and least expensive third-party approach available. This system has been established for over 14 years, and has been tested and proven. Over 400 agreements have taken place as a result of the activities of Dr. Dvorkovitz & Associates.

A network of representatives has been established throughout the world, who are personally contacting every conceivable source of technology on a daily basis. Companies are also contacted daily to determine their needs and interests, enabling us to organize effective profiles of potential licensees.

As the system grew, the amount of technology and number of company profiles increased to the point where it became necessary to install a computer. The technology and companies were programmed into the computer, and more effective "matching" occurred. As this continued, the data bank grew even more rapidly and more agreements started occurring. This continued growth has required expansion of the computer system.

The present installation represents the third such expansion, which has included the addition of computer terminals to the system. Terminals allow our representatives and clients to tap the data bank from any location where a standard telephone is available. Licensable technology from around the world is now available at a client's fingertip in a moment's notice.

Several large corporations, not only in the United States but in Japan, are using terminals to retrieve information from an International Bank of Technology concerning new business opportunities. A satellite computer bank has been established in Japan and in Israel. A worldwide communications network is being established so that deposits and withdrawals can be effected to the computerized World Bank of Technology in Ormond Beach, Florida, with a local telephone call from virtually any developed country in the world.

Some of our clients are being furnished with terminals -- others are using their own terminals, which they also use for "in-house" projects. Over 20 terminal manufacturers produce units that are compatible with our IBM 360 system.

A Dvorkovitz client may use his terminal for detailed word searching, displaying all items in a specific technological category (companies are provided with a breakdown of over 90 such categories) or to display any single item of interest.

Additionally, a Dvorkovitz representative has access to approximately 15 other functions through the computer terminal, i.e., to discover the current status of a formal offer; display all items offered to a specific company; display all companies to whom a specific item has been offered; to locate all pertinent data concerning a company's needs or interests, etc.

Companies taking advantage of the Dvorkovitz system will receive technology in the form of a technical abstract. This will furnish data regarding the source and description of the product or process. Also included will be main uses and advantages over existing products, degree of development, economic data, patent information and availability by country. The computer print-outs are designed to furnish enough data to allow the prospective licensee to evaluate in less than three minutes the suitability of the technology to his needs. If the company is interested, more detailed information in the form of dossiers, prototypes, and samples will follow from Dr. Dvorkovitz & Associates, or from the licensors. Acting as an intermediary, Dr. Dvorkovitz & Associates makes every effort to supply all of the data necessary for clients to make a decision.

There are numerous other third-party approaches available. However, the computer and terminal system is unique, providing companies with the ability to keep abreast and take advantage of new technology. Our only business is licensing, and all of our resources are solely devoted to accomplishing successful licenses.

As technology transfer becomes more popular and proves to be an economical method for companies of all sizes to take advantage of a tremendous amount of new and available technology from sources all over the world, the introduction of computers and terminals into the International Technology Transfer process is proving to be a successful method for companies to take part in this beneficial approach to new business opportunities.

MAXIMIZING PROFITS IN INTERNATIONAL TECHNOLOGY TRANSFER

Win Straube

N75 17192

I come here from a business where our main job is to make money ... for our clients and for ourselves. This may sound like nothing unusual. But considering past audience reactions I am not so sure about this any more. I do not come here as an ideologist, nor do I object to moralists or social critics who have different views on my subject. I wish to stick to my business.

I have discussed my today's subject with other groups before in the United States and around the globe. In doing so I have made a curious observation:

Here in the United States, public defender of the profit motive, I have been told that maximizing profits as my company does for its clients seems to be something bad and undesirable, a little bit too much, straight Yankee imperialism.

In South America I have been told that, after all, American technology is there. The money for developing it was expended, and therefore why should the South Americans pay for it again ? They want it for free.

In the Soviet Union and in other Communist countries my case studies have been received with enthusiasm. Whenever I show some of our examples of maximizing profits in those countries all I hear is "MORE, PLEASE, MORE".

I am not the speaker on the philosophical aspects of International Technology Transfer. Nor am I here to judge whose approach or theory is right, the North Americans', the South Americans', or the Russians'. But since my topic often arouses sharp political opinions, I thought I get the question of social value out of the way first. I am not going to deal with how much of plenty is too much, or of how much of nothing is too little.

Instead I want to deal strictly with the question of how to maximize profits in International Technology Transfer. I want to prove that higher than 5% royalty rates can be obtained - and why rates of up to 200% are being paid ... cheerfully.

I will present a case study to illustrate one method used to obtain higher than usual earnings for both, licensor and licensee.

I believe that a professional in the field of international business will consider it one of his main tasks not merely to accomplish technology transfer, but to make sure that both seller and buyer reap the highest financial rewards possible.

To do this it takes a lot of detail work. You may want to use a computer. However, maybe the most decisive ingredient for the right outcome of your work is to combine the maximum of available facts with imagination.

Please do not expect a simple recipe.

Whether or not to effect International Technology Transfer could be phrased another way: How to enter a foreign market ? Quite often individuals and companies jump to conclusions as to what they should do in certain markets. International Technology Transfer is merely one way of entering a market, and it may be the wrong way,... always assuming that we want to maximize profits. If you wish to give your technology away, go right ahead. There are plenty of takers. And if International Technology Transfer by itself is the aim, there is very little to it.

To enter a foreign market profitably, you have many choices. To find the one which is most suitable for your product or process it might be advisable to do your homework first.

For instance: Take an inventory of wh[illegible]u have : People, products, money and time. Don't immediate[illegible] on a specific approach, whether licensing, joint venture [illegible]ever. Let the facts of the case determine that. Plan for [illegible]unity instead. Develop an organized approach for planning [illegible]pportunity. Do research in the market you want to enter.

You will find advantages and disadvantages, but the following may be your choices in general:

Licensing
Overseas repackaging and assembly
Overseas manufacturing subsidiary
Joint venture
Direct sales

and, last yet most important,
a mixture of above.

Let me start here with licensing since this is where many efforts of International Technology Transfer begin.

Technology transfer in the form of licensing a product or process to others is by itself a form of maximizing profits on existing know-how. For instance, if all your production capacity is used up, or if you don't want to invest in markets you are not ready for or unable to cover properly by your own efforts, technology transfer through licensing does two things:

(1) It makes somebody else in those international markets work with you instead of against you, and it may keep others from trying to copy or overcome your technological advantage - at least temporarily. In other words: It helps you maintain your international competitive position.

and

(2) It gives you additional revenue for which you didn't have to expend material or production labor.

I will disregard the obvious rewards of technology transfer here, such as being competitive, deriving a normal licensing income, etc. I am dealing here strictly with the PLUS in profits which can be obtained. My concern is: How much MORE can we obtain.

Let me stop at this point to make a fundamental statement, for some people think that maximizing profits is equal to making a fast buck. Nothing could be further from the truth. Successful and profitable technology transfer is NEVER a one-way street. Like in any good long lasting relationship of buyer and seller, both must obtain adequate benefits. The minute a licensor is so hungry to try and get all the profits for himself, leaving the licensee with little more than work and a nominal advantage, the relationship is not going to last very long.

Therefore, sharp deals are out. A steal or negotiated give-away is worthless. Technology changes very fast nowadays. A one-time advantage is often overcome much sooner than anybody thought. Long term cooperation is more important than a short term financial gain. And only a clear understanding of who derives which benefits from what will ensure a healthy and lasting relationship.

The basis for MORE profits between parties offering and buying technology is solid ethical conduct and complete disclosure of intentions.

Coming to the HOW of maximizing profits from technology transfer, you are all familiar with the patent attorney or corporate licensing department, where when the question of technology transfer comes up, this issue is mainly a question of percentages and form. Standard contracts are used with blanks to be filled in.

> What is the percentage we charge on licenses of this type ?
>
> 5%
>
> Well, let's try for 8.

Or if he represents the other side:

> Let's try and get it for 3.
>
> Of course the agreement must be in our language and the jurisdiction in case of court action is to be that of our home town ...

I am not saying that these questions are not important and should be neglected. Of course not. But what I am trying to focus attention on is this: If you want to increase financial rewards in technology transfer transactions, you cannot look at the process piecemeal, as a patent project, a licensing project, a marketing project, etc., but you have to look at it as a whole. You have to be very sceptical with boiler plate agreements and you cannot use a stereotype approach to finding a market.

Research in depth is necessary. This is hard to do from your desk at home or by merely writing to consulates, chambers of commerce, or your branch office or sister company. You got to get up close, very close. Your problem is always very specific - not general. If you want to get more for your technology or derive more benefits by obtaining it, it is obvious that you will have to do a little more than the ordinary.

Let me show you by using an example what I am talking about. This case study is a true relationship as handled by my company, Pegasus International. It also is not a closed and shut case out of a dusty file, but one that is alive and producing healthy revenue every day.

I have brought with me a sample of the product which we were to sell or license for one of our American clients. Here it is. The device is very simple. It combines the compressed gas principle of the aerosol with an ordinary atomizer. There are three parts:

(1) the can holding the propellant gas closed off by a valve

(2) the glass or plastic reservoir container, which holds the material to be sprayed; and

(3) the bridge, which links the two together. Only the last, No. 3, is patented; a novel design of expansion chambers results in an increase of efficiency in the amount of gas being used to propel the material being sprayed - an increase of about 35%.

From a pricing point of view, the separate components cost (at one time):

(1) 65¢ for the propellant container

(2) 10¢ for the jar with cap, and

(3) 15¢ for the plastic bridge.

In our initial thinking about this item for export sale, we had to consider that most customers might desire to produce the two non-patented components locally, and thereby avoid transport and import duty costs involved in purchase from the

United States. This would mean that export sales would very quickly be limited to the bridges only, which at 15¢ each - and considering that they are reusable - would mean a very small dollar volume in return for the considerable effort involved in introducing the product.

Since most license agreements provide for the manufacture, use and sale of the product being licensed, we felt that in this case we were not merely selling, but also conveying a right to USE the patented item, and that consequently, a royalty as part of the sales price would be appropriate. Our market studies showed that five refills plus five jars were used - and I emphasize again the word USED - with each single bridge before the bridge wore out or became clogged or lost. It seemed appropriate to assess a royalty figure that approximated 5% of the total value of the USE of the product. Totalling up one bridge at 15¢, plus 5 jars at 10¢ each, plus five refills at 65¢ each gave us a total figure of $3.90. Applying a 5% royalty thereto gave us a royalty figure of 19.5¢. This would be a royalty higher than the cost of the bridge itself. Therefore we compromised and added only 15¢ royalty to the price of the bridge, making its cost for export sale 30¢ each.

We were careful to point out in our negotiations with prospective licensees and customers that the royalty was calculated on the cost of not the bridge alone, but rather the cost of all the components used throughout the expected life of the bridge. At 15¢ royalty, this meant that the actual royalty percentage was 3.85%, which is generally considered an equitable percentage - although in fact this means a 100% royalty being paid on the item our client is supplying.

In the larger sense, thus, we established this pricing policy with the long term view that licensing the production of these units was inevitable, and we wanted to have our logic straight from the start to justify this figure.

License negotiations did in fact occur, with the result that a licensee was set up in one major industrial country with rights to sell there and in a few selected areas elsewhere. There was no objection to the 15¢ royalty rate, because of what we had done in the market first, which was to establish an export price based on the use of all components which was still competitive.

We now had a source outside the U.S. for the unpatented components of the unit, namely the refills and jars - as well, of course, of the bridges. With a growing international market for this device, we considered that one or more additional licensees might be required.

But before doing so we did another study, including to find out what it would cost to have the refills and jars made in the international market. It turned out that we could buy the refill fully packaged for 40¢ and the glass jars for 6¢ each. Rather than license someone else we went to our customers and told them that we would shortly be able to supply them with refills and glass jars at the prevailing U.S. factory price, but instead of their paying freight and import duty on products from the United States, the U.S. domestic price would now apply delivered duty-paid to their factory. They of course, were delighted, and immediately held forth about tripling and quadrupling sales in a few years.

We then, in association with our American principals, set up a separate company to develop this international market. With a nominal capitalization, this firm contracted with manufacturers to produce refills and jars and hold them in their warehouse until instructed to make deliveries in accordance with orders received by the joint venture company. Invoices were then rendered by that joint company to the buyers at the prices previously agreed upon. Eventually we arranged with the suppliers to accept orders directly and invoice directly to the buyers, remitting to us only the price differential.

The net result of all these individual steps was: Instead of receiving a "normal" or "ordinary" royalty of 5% on 15¢ or 3/4¢ per bridge, the American licensor is now receiving 15¢ royalty per bridge plus the markup on the refills and jars, which amount to a total of 25¢ for the former and 4¢ for the latter, making a total per set of 29¢. Going back to our original premise that five refills and five jars are used with one bridge, this total profit now amounts to $1.45 plus the 15¢ from the bridge royalty, or $1.60.

Therefore instead of 3/4¢ royalty income per piece through "ordinary" licensing our American clients are receiving $1.60 via Max P.

Mr. Max P as we call it is our short form for Maximum Profits.

In this case involving Max P represents a 200 fold increase in expected income through a combination of policies involving export sales, licensing, and joint or wholly owned subsidiary activities in the international market. All three activities cannot be divorced - one from the other - all these must be totally integrated. And, most importantly, a master plan has to be established BEFORE any commitments are made. Too many times isolated international activities are generated within a company with, in the end, a truly unworkable and frequently unprofitable conglomeration of separate and often conflicting operations being conducted.

So far with this example. I would like to add that techniques of this sort are not necessarily applicable to all types of technology transfer. I also would like to point out that all through this exercise, as you have seen, we did not merely bestow a benefit on our clients, but also on the licensees by expanding their opportunities and giving them more value for less money. Naturally, under different circumstances the details also will differ.

To summarize: Max P can be introduced into international technology transfer by observing the following:

(1) Ethical and open dealing between the parties.

(2) Maximum knowledge of all facts concerning the technology, the use of the technology, the market, competition, prices, and alternatives.

(3) Ability to coordinate exports, service, support activities, licensing and cross licensing.

(4) It needs knowledgeable people, the man or organization which puts these factors together and comes up with Max P.

Too many times when one thinks of technology transfer or licensing one considers only the obvious straight-forward agreement providing a royalty rate, minimums, and fees. And as well with joint ventures or wholly owned subsidiaries, one considers only that this requires a large scale investment in plant and facilities. There is a happy medium, where both risk and investment in plant and facilities can be minimized and yet profit maximized. There are many other variations of this type which are outside the framework of this presentation. This example is merely to give a glance at some of the avenues which are open to benefit MORE from technology transfer.

In many places outside the United States, American technological progress reaching around the world has been felt as a challenge. However, as you can see from my small presentation here, maximizing profits on international technology transfer transactions need not be an American privilege. And don't have any illusions, the world is full of imaginative, diligent people. International Technology Transfer is becoming more exciting and potentially more rewarding than ever before. But as the potential for profits increases, so do the risks. The same avenues and combinations of effort are available to everybody else, also to be practiced in the United States by Non-Americans - and are being practiced by the Germans, by the Japanese and many others not only in this country, but in Australia, in Africa and wherever you go. Technology transfer is an international and maybe a company necessity. Whether it is profitable or not depends on the technology itself, the market conditions, research and sales efforts. But HOW profitable depends on the people who know HOW TO ...

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THE ENVIRONMENTAL PROTECTION AGENCY INDUSTRIAL TECHNOLOGY TRANSFER PROGRAM

Kenneth H. Suter

In this paper I intend to present the need for and use of an active (technology) dissemination program by the Environmental Protection Agency, address the complexities associated with arriving at an acceptable solution to an environmental problem, and explain the mechanisms and associated products used by the Technology Transfer program to transfer the latest viable technological alternatives to the potential user.

The industrial Technology Transfer program was started approximately two years ago and was an outgrowth of an already very successful municipal Technology Transfer program. The municipal program got underway when it became apparent that although millions were being spent on research to develop efficient commerically available treatment systems (e.g. phosphorus removal, carbon adsorption, oxygen aeration, advanced upgrading techniques, etc.), these systems were not being widely considered for use in new Federally funded municipal plants. With large sums of money scheduled to be spent by the Federal government in the construction of waste treatment facilities, there existed the possibility of building control systems that would be obsolete before completion. Since the goal of this expenditure was to help clean up our rivers, this could have meant that areas requiring high efficiency systems to eliminate pollution problems would not have the controls available to accomplish this task.

Why weren't these systems being considered when they were commercially available? The answer is poor communication. The message must reach the user and be presented in such a manner that he will adequately study the technology alternatives as they relate to his specific problem. Another way of expressing this is that any good idea is worthless unless it reaches someone capable of implementing it and is presented in such a manner as to motivate a thorough examination of the idea. This need therefore required a new approach to information dissemination.

In order to define Technology Transfer as it applies to the Environmental Protection Agency we must first compare it with general information dissemination which is available throughout many of the United States Governmental agencies. Information dissemination, as it is generally applied, is the passive dissemination of information with minimal attention given to the design of the information output or the mechanisms by which it is to be disseminated to the users. In contrast, the Environmental Protection Agency's Technology Transfer program uses active dissemination of information, which is carefully designed for the specific users and transferred by mechanisms which are designed to impact the decision making process of these potential users. Both the passive and active information systems are needed in a information system. The need of locating and getting the developed information to a potential user and the need to motivate the potential user to examine the information, determines which system or combination of systems should be used. In a passive information system the potential user must use his own initiative to locate the topic of interest, and determine its applicability to his particular need. Both systems can be used effectively together when the need and application area are determined. As an example,in the environmental area hundreds of useful detailed research reports are published on new waste treatment techniques and made available through the United States Government Printing Office or the National Technical Information Service (NTIS) at a modest fee (passive information). These are useful if the potential user could locate the proper paper and be convinced that the research report truly included a treatment system that could be immediately installed and effectively operated. One of the mechanisms used by the Technology Transfer Industrial program to bridge this gap between the research report and the potential user is a Technology Capsule Report. These 12 page reports are designed to present a specific successful project in such a manner (i.e. describes the significance, operating efficiency, economics, areas of application) that the potential user will have enough information to decide whether to take the next step of ordering the detailed research report and/or contacting a consultant.

The program's primary function, therefore, is to bridge the gap between newly emerging technology and full-scale use through specifically designed transfer mechanisms which disseminate a sufficient amount of information for the appropriate user to evaluate the specific technology's applicability to his problem. Our target audiences have been consulting engineers; municiple, industrial and state design engineers; city managers; directors of public works; industrial managers; and others exerting influence over the design and construction of all pollution control and abatement facilities.

Before I discuss the presently available Industrial Technology Transfer information and the mechanisms used to transfer this information, I feel some time spent on understanding the many variables associated with arriving at an adequate solution would be warranted. A better understanding of these complex problems should help us, and industry, understand the real transfer needs, thus helping us to better identify the needed pollution control applications mitigating unwarranted transfer activities.

There are two important factors that should be considered before selecting pollution control equipment: 1) the environmental laws that could impact the pollution source, and 2) the many technical variables associated with maximizing your treatment efficiency to cost relationships.

First, it should be realized that their are now environmental laws (Federal, state, and local) that restrict the amount of pollutants which can be emitted to the atmosphere, or discharged to receiving streams, and specify in what manner waste material will be disposed. To minimize potential problem areas when evaluating what course of action to take in controlling discharges to meet these laws, all parameters should be studied. Three typical areas that could be addressed in such an evaluation include: (1) would change in manufacturing processes be the best solution when considering all the environmental impacts and costs for control equipment; (2) should more emphasis be given to segregation and recycle of process waste streams to reduce the quantity of waste material; and (3) will the control device seriously effect other areas of the environment.

It is realized that such ideal approaches to evaluating all pollution problems at once are not always possible due to the priorities of environmental concern, funds available, and time afforded to arrive at solutions. However, when studying one pollution problem of a process, at least define the other parameters and keep their interaction in mind. This will allow for a progressive coordinated effort toward minimizing the other pollution problems when it comes time for their evaluation and will allow for less chance of taking an improper step when the total environmental impact is assessed. As an example, realize that an air scrubber can generate water pollution and waste disposal problems. Therefore, know the extent of problems such as these when you make the selection of what type of control device to use.

The second important consideration after addressing all your potential pollution problem areas and the laws governing their control is to realize that waste treatment is not synonymous with pollution control. Waste treatment, collecting the contaminant from the waste stream, is only one part of pollution control. Waste treatment is the final step taken after all process control alternatives have been investigated. First try to maximize the materials recovery to minimize your waste treatment needs.

The best way to minimize the waste treatment cost is to minimize water and air flows. Treatment equipment will have a much lower cost per pound of pollutant removed if the pollutant is in a concentrated form. The more flow to the treatment equipment, the more expensive it is going to be to meet the discharge standard. The highly concentrated stream with low flow rate is normally more easily handled then the high flow at low concentrations.

In addition to minimizing flows, in the case of water, you should try recycling and reuse. Reuse of water requires that before discarding any water to a stream and taking in fresh water, check to see if that water is of sufficient quality to be used anywhere in the process. The ultimate case, of course, is the total recycle of water within your facility. This puts you out of the regulartory agency's realm. The company that treats its water and recycles it doesn't have to worry about stream standards. It only has to worry about treating their water to a point suitable for use in its own process. This is considered a nonpractical concept by many people, but there are plants approaching this now.

In air, to maximize the concentration of pollutants, the capture system (Hoods) are designed in such a manner as to minimize the amount of air required to capture the pollutants generated by the source. Substitution, such as taking sulfur out of the fuel prior to burning or changing to a less polluting process are also ways of minimizing the pollutants generated by the source.

Many industries in the past mixed waste streams containing very low concentrations of pollutants with streams containing very high concentrations. The principle to apply here is that of segregating wastes. Those wastes that require a high degree treatment should be isolated from those which require a low degree of treatment.

From the above discussion it should be apparent that the selection of a control device involves the close examination of many other variables. It should also be noted that for the Technology Transfer program to only address the control aspects without helping the users look into controlling these other variables would only perpetrate the economic problem magnified by the selection of an improper control device. The Technology Transfer program's main goal is to transfer the latest viable technology to the potential users. If this is done in a manner that also helps the source look at all alternatives of control, we will all be working in the most efficient manner to clean up the environment.

The last area of discussion is to let you know the information available through the Industrial Technology Transfer program and the mechanisms we use to attempt to effectively meet Industries needs. Due to the limited resources available for Technology Transfer these needs must be closely evaluated so that resources are applied to those mechanisms used and the information available through the mechanism:

INDUSTRIAL SEMINARS

The industrial seminars are developed to familiarize plant managers and their engineering and operation staffs with the availability and relative advantages of the alternative proven technologies for their industry. The target industries for these seminars are those industries characterized by large numbers of small manufacturers with limited accessibility to highly technical staff personnel. The topics included in the industrial seminars are:

Legislative Status
In-Process Pollution Abatement
Waste Treatment Technology
Strategies of Financing

The industrial categories presented thus far include:

Metal Finishing
Poultry Processing
Meat Packing
Dairy Products
Textile Products
Seafood Processing
Wastewater Monitoring

SEMINAR PUBLICATIONS

Seminar publications covering detailed information presented at the seminars are published and braodly distributed to the engineering and industrial communities. Publications to date include:

Metal Plating
Meat Packing
Poultry
Textile

POLLUTION CONTROL PROCESS MANUALS

Pollution control process manuals are being developed for the Power, Pulp and Paper, and Textile industries. Their manuals are intended for use by process design engineers, consultants and engineering companies. They will address the latest technologies relating to specific industries on in-plant changes, control equipment and measurement techniques developed by the Environmental Protection Agency or private industry.

TECHNICAL CAPSULE REPORTS

Technical Capsule Reports describing specific industrial pollution control demonstration projects. The objective of these publications is the quick, widespread, easy-to-understand presentation of the essential information developed in significant industrial pollution control full scale demonstration projects. The reports describe manufacturing process changes, waste treatment facilities, comparison of waste characteristics before and after process and waste treatment changes, and relevant cost information for the projects. The primary audience for these reports are the technical managers in industries where the demonstration projects have application. Publications to date include:

"Recycling Zinc in Viscose Rayon Plants"
"Color Removal from Kraft Pulping Effluent by Lime Addition"
"Pollution Abatement in a Copper Wire Mill"
"1st Interim Report on EPA Alkali SO_2 Scrubbing Test Facility"
"Dry Caustic Peeling of Peaches"
"Pollution Abatement in a Brewery"

Handbooks

Handbooks are issued to cover non-design technical subject areas in pollution control such as monitoring and laboratory procedure and operations. The objective of the handbooks is to maintain and insure the validity and consistency of air and water samples taken, analyzed, and reported. Publications to date include:

Monitoring Industrial Waste Water
Analytical Quality Control

Professional Organization Participation

The Technology Transfer Program from its inception has been involved with the professional organizations representing the users of environmental pollution control technologies. This relationship is: to familiarize large national professional gatherings with the program and their activities; to assist in supporting national introduction of major new publications; and to insure support of new technology evolving from EPA research and demonstration programs.

In addition to Technology Transfer personnel participating in many professional organization technical committees, the Program also participates in major conferences with exhibits and program material. These organizations include:

Water Pollution Control Federation
American Public Works Association
American Institute of Chemical Engineers
American Society of Civil Engineers
Consulting Engineers Council
Water and Wastewater Equipment Manufacturers Association
Air Pollution Control Association
American Society of Mechanical Engineers

NEWSLETTERS

Newsletters are issued quarterly and are intended to keep interested parties informed of program activities and promising EPA research and demonstration projects. The newsletter also is the mechanism for advertising and requesting Technology Transfer materials. There is a self-addressed order form at the back of the newsletter listing all of the available materials.

I hope that this paper has given you some idea of the Environmental Protection Agency's Technology Transfer Program and the many parameters that must be considered in the solution of an environmental problem.

Other areas of concern that are adding to the vari ables associated with having a successful process operation are energy utilization, increasing costs and difficulty of getting raw materials, and having available usable water resources. Process changes that solve problems in these areas could open up new opportunities to minimize the discharge of wastes into the environment. The need for a systems approach, keeping all the previously mentioned variables' inter-action in mind will challenge engineers to discover new process design techniques to maximize operating performance. This will increase the need to get the latest changes out to the potential users so that they can evaluate all alternatives before selecting which course of action to take. The challenge is before us to get the latest successful technological developments to the users in an effective manner. The Environmental Protection Agency's Technology Transfer Program is attempting to meet the challenge.

THE ROLE OF THE TECHNOLOGY APPLICATION CENTER IN THE TECHNOLOGY TRANSFER PROCESS

William A. Shinnick
Nancy M. Grogan

N75 17194

TAC is one of six NASA industrial application centers originally established to disseminate NASA technology to private industry on a regional basis. Located at the University of New Mexico, TAC has been in business nine years serving the region west of the Mississippi except for the West Coast states. Given the requirement by NASA to charge a fee for our services, TAC quickly became market oriented, and, in responding to the needs of the market place, has grown in several ways. First, we expanded our information dissemination capability to include all technology, not just NASA's and in the last two years we have developed a total information center capability including information services in the social, business, and economics areas. Secondly, TAC has broadened the user communities it serves which now, in addition to the industrial sector, also includes state and local governments, universitites, and even federal agencies. Third, TAC has added a number of technology transfer methods to the information dissemination approach initially used, and through this process has specialized in several areas of technology. Today TAC consists of a full-service Information Center and five programs, which are:

Our Industrial Program

The Energy Information Center

The Business and Industry Extension Program

The Remote Sensing Program

The Center for Environmental Research & Development

To address these programs briefly, let me begin with the Information Center which is the operational hub of TAC and as such provides support for all TAC programs. It also operates two other projects. One of these is a joint TAC/University of New Mexico Library program which provides a computerized literature search service to faculty members. An experimental program last year, this service has been so well received that it has been renewed for this year. It is largely due to the library program that TAC acquired the broad information bases and sources which go far beyond those in the physical and engineering sciences traditionally searched.

The Industrial Program serves the industrial community in TAC's region which includes Houston, and also numerous other users of technology including state and local governments. This is TAC's oldest program and the one in which the most significant changes have taken place over the years. Today our clients frequently ask for evaluation and consultation beyond the initial identification and citing of published information. TAC welcomes these occasions because they offer the opportunity to become more deeply involved in our basic mission, that of transferring technology, particularly NASA technology, into beneficial use.

The Energy Information Center program is a joint effort with University of New Mexico's School of Engineering, brought into being to provide energy information and research services to a wide audience. Its first comprehensive survey of energy technology--covering hydrogen as an energy source--was published in January of this year, and is being marketed nationally. Work is now almost completed on a similar survey of solar energy technology. In addition, the Energy Information Center has two proposals under consideration for funding by the new New Mexico Energy Research Program. The first of these proposals is intended to develop a profile of energy users and consumption in New Mexico, and to assess the potential for both interim and longer-range energy conservation methods which might be instituted. The second proposes to provide information search services to all participants in this research program, as well as providing energy information services to the Governor's Energy Task Force. Another project of considerable significance involves a number of state-of-the-art reviews on energy-related subjects being prepared for the NASA Lewis Research Center in Cleveland. Among the areas of interest to Lewis are:

Solar Heating and Cooling of Buildings

Wind Energy

Energy Storage Mechanisms

Turbine Technology

Deep Coal Technology

The Business and Industry Extension Program is a new program funded by an appropriation from the New Mexico State Legislature. Its general objective is to achieve a level of dissemination and application of technical and scientific knowledge that will aid in a general and orderly expansion of the New Mexico economy. Oriented toward small business, the Extension Program pursues this goal by encouraging use of already developed technology which appears promising for New Mexico use; by promoting use of new technology that will aid existing industry to become more efficient and competitive; and, by encouraging development of industrial activity appropriate to needs of the State.

Our Remote Sensing Program is involved in all phases of earth resources survey technology, with particular emphasis on the application of this technology by the state government community. A significant study for the NASA Office of Applications was made last summer of the potential of remote sensing to respond to the needs and problems of state government agencies in the areas of natural resource management and land-use planning. Another study dealt with the application of ERTS imagery to geologic mapping and exploration in New Mexico. And, recently, at the request of the Land Use Advisory Council of the New Mexico State Legislature, TAC conducted a joint program with New Mexico State University in which the structure of a computer-based land-use inventory and mapping system for New Mexico was explored and an initial inventory system design project proposed.

TAC is also a designated representative of NASA for the dissemination, nationally and internationally, of earth-oriented space photography from Gemini and Apollo flights, and from Skylab.

The final TAC program is the Center for Environmental Research and Development. This program has a broad interest in natural resource management, environmental design, and land-use planning, and has participated with the Remote Sensing Program in both the State-Needs Study and the Land-Use Advisory Council Study. This Center has considerable experience both in environmental impact studies for industry and in regional environmental programs such as those sponsored by the Eisenhower Foundation. Another major effort of the Center is a comprehensive survey of land-use planning information which is scheduled for national publication in the near future.

The Environmental Center is currently conducting for the New Mexico Land Use Advisory Council a survey of the land-use inventory data needs of the State and is also participating in a statewide water-use study and developing a rural land-use planning manual.

As mentioned earlier, TAC uses a number of technology transfer methods in its service to users. Since we deal with industry on a <u>strictly proprietary basis</u>, the benefits derived from the transfer activity are not always available for public disclosure. Nevertheless, I would like to describe for you some of the methods used to illustrate the scope of our program, particularly as it applies to the industrial organization.

First is information dissemination. TAC is a total information center now tapping over 40 computerized information sources covering the full range of physical and social sciences. In addition, these sources are supplemented as appropriate by manual searching at libraries and personal contacts with knowledgeable individuals. Information services are of two kinds: proprietary personalized searches for an individual or firm, and comprehensive literature reviews intended for publication and mass sale. At one level personalized searches provide answers to short questions like "Where can I find a supplier for copper coil wire west of the Mississippi?" or "How can I set up an Affirmative Action Employment Program for my firm?" At another level, we provide state-of-the-art searches on specific subjects to back up industrial research projects. Such searches answer questions like "What is the state of knowledge on the effects of alpha radiation on integrated circuit operation?" or "Where do we stand in the development of solar collector technology for heating and cooling of buildings?" Comprehensive literature reviews intended for publication and multiple sale usually cover a broader area of technology which has national interest or is of interest to a specific segment of our industrial clientele. Typical of these are "Hydrogen," a survey of the literature on hydrogen as an energy source and energy carrier, or possibly of more interest to the Houston area, a work we have done on "Well Drilling Fluids." In all of these areas TAC provides both a back search or retrospective search, and an updating or current awareness service, the latter on either a monthly or quarterly basis.

Although information dissemination is an effective means for dispensing knowledge, particularly through a personalized program like TAC's, it may not be the most effective way to directly transfer technology. We, like most people in technology transfer, have found it is through people that technology transfer occurs, and we use a number of approaches that are people oriented. First are short courses and seminars--these provide an open forum for face-to-face exchange between those who know the technology and those who want to learn about it. Our Heat Pipe Short Course is a good example of this. Now going into its seventh year, this annual event, together with the continuing information support provided participants, has led to a number of direct transfers including a device for tapping waste heat from house flues and a device to keep engine oil cool. Another effort of this type--oriented toward the public sector--was a symposium on the utilization of waste glass. Sponsored jointly with the Glass Containers Manufacturer Institute this symposium included the economics as well as the technology of a variety of secondary uses for waste glass.

An additional people-oriented-transfer-approach is TAC's ability to link up industrial firms directly with NASA research centers and their technologists. A recent example involved the Alaskan Pipeline which Butch Voris mentioned. The Alyeska Pipeline Service Company plans to use heat pipes to stabilize the permafrost along certain sections of the pipeline, and was interested in having outside experts review their design evaluation program for the heat pipes. The Goddard Space Flight Center of NASA, which for years had been qualifying heat pipes for use in satellites, was willing to provide this independent review. However, since this involved significant time on the part of the Goddard people it had to be done on a cost reimbursement basis, and TAC provided the conduit through which the interaction between industry and a NASA Center took place--I consider this to be an effective transfer mechanism and would like to see its use expanded.

Still another example of TAC bringing people together involved a small manufacturing firm which was experiencing severe problems in laying up fiberglass, a process which involves a high degree of operator skill and experience, and on which limited published information was available. In this case TAC was able to find a skilled person in another local and noncompeting firm who was lent to the firm with the problem until a resolution was achieved.

A final transfer approach is to actually demonstrate the application of a technology by doing. As I mentioned earlier, the Information Center of TAC is demonstrating the application of NASA's information retrieval technology to the State Library of New Mexico. This project involves using a Hewlett Packard 9830 calculator as a mini-computer for automating the New Mexico State Library along the pioneering concepts that NASA developed for its own internal information and retrieval needs. I mention this here because it looks like the mini-computer approach, coupled with NASA information retrieval concept, could be a cost effective way of automating industrial libraries.

TAC also is engaged in a number of application demonstration projects relating to remote sensing, and this approach is fast proving to be an effective means of achieving technology transfer.

To summarize in a very few words, TAC, over nine years, has tried to help others find beneficial uses for new technology through both information and people oriented approaches, and I hope that the examples recounted here have been of interest to you. However, I don't want to close by telling you that we've got some technology and you ought to be using it...you will hear a lot about specific technologies at this conference. I would hope to leave you with the thought that when you do have a need to know something beyond your internal limits, you will check with us. TAC might just be able to save you time, money, and an ulcer or two through one of the technology transfer processes I've been discussing.

L U N C H E O N

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N75 17195

TRANSFER OF SPACE TECHNOLOGY TO INDUSTRY

Jeffrey T. Hamilton

Technology transfer is not a new phenomena. Many of you, who have been responsible for delivering new or improved products to the market based on innovations generated from outside your firm, have engaged in technology transfer as we view it. In fact, in a recent review of the Government's efforts in technology transfer a National Academy of Engineering panel described it as "the process of collection, documentation, and successful dissemination of scientific and technical information to a receiver through a number of mechanisms, both formal and informal, passive and active". I might add that in our experience a dedicated user is also required if any technology is to transfer.

In our relatively free consumer-driven economy, existing research knowledge gets translated into useful products or processes if it can cut costs or improve profitability. This is a test that must always be made and a perspective that government technology transfer efforts should maintain if they hope to be effective. I suspect that most of the 300,000 manufacturers with no R&D capability, as well as11,000 companies with some formal R&D engage in technology transfer to remain innovative and competitive. This transfer activity takes place in very traditional ways. For example, your design engineers read an article concerning an innovation in one of the trade journals that becomes incorporated into your product line through corporate product improvement activity and technology is transferred. I would be pleased if the innovation happens to be one of the over 5,000 that we have published in NASA's Technology Utilization Program. When your plant manager requires assistance with a production problem and adapts a recommended solution from the published technical literature by a technical consultant, technology is also transferred. I hope that the plant manager utilized the services of our Six Regional Industrial Applications Centers to find the specific reference. Mr. William Shinnick, the Director of the Technology Application Center (TAC), operated by the University of New Mexico is available here today, if you want assistance.

The reason I am here is that the Space Act of 1958 directed that NASA share its research in the widest practicable manner and NASA established a Technology Utilization Program to encourage the secondary use of technology generated in the Nation's aeronautics and space program. I am sure that many of you representing high technology companies appreciate that the government stimulates, sponsors, and acquires rather significant amounts of research and development of a broad-based nature. Most of this activity has centered in the Department of Defense, the Atomic Energy Commission, and NASA although in recent years many other agencies have engaged in R&D programs to improve the effectivity of their mission responsibilities in the environment, housing, transportation, and law enforcement. All these civil agencies have recognized that research and development is requisite for productivity improvements in these critical public areas. Interestingly enough, most of these civilian mission agencies have recently established technology transfer activities to enhance and stimulate the use of these R&D programs within the industrial community and the public sector.

We made an attempt to measure the impact and value of R&D in the national economy through a study entitled the Economy Impact of Stimulated Technological Activity at Midwest Research Institute. It addressed the role of technological growth in national economic growth, and the factors and role that the space program played to the degree that they could be established. Its findings were on the average--each dollar spent on R&D returns slightly over seven dollars in technologically induced economic gains over an 18-year period following the expenditure. Assuming that NASA's R&D expenditures had the same pay-off as the average, we found that the $25 billion, in 1958 dollars spent on civilian space R&D during the 1959-1969 period has returned $52 billion through 1970 and will continue to produce pay-off through 1987, at which time the total pay-off will have been $181 billion. The discounted rate of return for this investment will have been 33 percent.

To put this into a perspective that is more easily understandable, I will cite a few examples.

In order to meet the mission objectives of Apollo, Skylab and Viking, materials, equipment, and men were challenged to new and often unknown environments at unprecedented performance levels with added requirements for absolute life safety, lowest weight, highest reliability and affordable cost. These requirements have caused a great stream of technical advances in materials, new research in stress analysis and structural design techniques all of which have broad utility outside the aerospace community. For example, the NASA Structural Analysis Program (NASTRAN) is a general purpose, digital computer program designed to analyze static and dynamic behavior of elastic structures and to display a summary of the computed structural behavior with standard computer plotters. The program was, and still is, used by NASA and aerospace companies to design and analyze aircraft fuselages, wings, and tail assemblies, space vehicles (Viking and Skylab) and their related launch facilities and turbine engines. The wide range of analytic capability built into NASTRAN includes: static structural response to concentrated and distributed loads; thermal expansion and enforced deformation; dynamic structural response to transient loads; steady-state harmonic loads and random excitation; as well as dynamic and elastic stability analysis. The program can handle structural problems of virtually unlimited size. Between 1965 and 1970, Goddard Space Flight Center developed the program through a combination of in-house and contracted research for approximately $3,000,000. The program was released to public users in November 1970 through our Computer Software Management and Information Center (COSMIC) at the University of Georgia, under contract to NASA.

Westinghouse Electric Corporation in Pittsburgh, Pennsylvania has used NASTRAN since 1970 to perform calculations which were not economically feasible with previous computer program capabilities. Applications include: elastic analysis of natural frequencies for steam turbine blades; transient response and thermal analysis of turbomachinery housings; and analysis of structures such as floating nuclear power plants. For most NASTRAN users, the primary benefit has been a substantial reduction in real operating costs and, therefore, a great increase in productivity. Ford Motor Company, for example, is saving millions annually by using NASTRAN for quality assurance analysis of automotive frames.

In meeting the rigorous energy requirements to put men on the moon, hydrogen, one of the world's most powerful, plentiful, and difficult fuels, was widely used. This experience portends well for the future if, and when, the predicted hydrogen economy emerges. In the meantime it may have real application in pollution free dispersed power generators such as fuel cells. For example.

In 1962, Pratt and Whitney Aircraft was awarded a contract from NASA's Johnson Space Center to develop and manufacture fuel cells for the Apollo spacecraft, thus extending the company's fuel cell capability for five years. Because the Apollo fuel cells used pure oxygen and hydrogen, the basic technology had to be adapted to operate on standard gas and liquid fuels with air. Nearly two-thirds of the support for this application has been provided by a group of thirty gas companies through a program called TARGET (Team to Advance Research for Gas Energy Transformation). Presently, 12.5-kilowatt fuel cell modules produced in the program have operated nearly 200,000 hours at thirty-five sites around the world. Within the past year a consortium of nine electric power utility companies signed contracts with Pratt and Whitney for fifty-six 26-megawatt machines valued at $300 million to supplement present power grids. These orders are provisioned on the completion of a successful research and development program expected to cost $42 million--two-thirds of which will be paid by the nine power companies.

Also, the experience and background in capturing the sun's energy to power spacecraft utilities for extended period of time, including the 2600 kwh of Skylab, should be useful for our emerging new responsibilities in solar heating and cooling.

We have found that technology transfers naturally where applications and markets are perceived and entrapreneurial activity, on the part of individuals and firms takes place. This is often referred to as diffusion and it takes many forms.

The Space Program, with its high reliability and often high sterility level requirements provided a major "first market" for advanced contamination control equipment design to NASA specificiations.

What is perhaps the greatest tribute to both NASA and the contamination control industry is the fact that the industry itself--by developing entirely new markets--no longer depends on aerospace as its main source of revenue. Sales of laminar flow equipment were increasing at an annual rate of 34 percent between 1964 and 1970, while the percentage of sales to nonaerospace industries rose from almost nothing ten years ago to approximately 90 percent in 1970.

Another effective transfer mechanism is through professional societies, industrial design codes and general published information. For example, NASA's concern for minimizing the weight of flight systems has also led to the extensive use of high-strength materials, and the performance of these materials is sensitive to the presence of flaws. To define this sensitivity, researchers at the Lewis Research Center developed the "plane strain fracture toughness test," and engineers for the first time could quantitatively determine the weakening influence of cracks in selected structural materials. Early dissemination of information on the plane strain fracture toughness test were primarily accomplished through the ASTM E-24 and Special Technical Publications.

As an indication of how this technology has transferred, I suspect that those of you who order steel from U. S. Steel are requiring the plane strain fracture toughness tests.

However, because the Space Act challenged NASA to disseminate its research and development widely, NASA recognized early that the rather informal and sometimes serendipitous process of natural diffusion could be enhanced and accelerated through the development of an organized program, and establishment of its Technology Utilization Program in 1962. Its real value lies in its attempt to give access to technology emanating from the Nation's R&D investment in aeronautics and space to those firms who do not have access in the more traditional ways cited above.

The NASA Tech Brief is probably the most widely known technical innovation announcement medium. It is a technical description of an innovation, with straight-forward explanations of basic concepts and principles. The Tech Brief reader can obtain more detailed information from a Technical Support Package. The TSP includes test data, drawings, specifications, and it is available by writing to the Technology Utilization Officer whose address is provided in the original Tech Brief. While obviously innovations often need to be modified for new applications, the record indicates high interest and considerable technology transfer stimulated by Tech Briefs and TSPs.

NASA's Industrial Applications Centers are another major element in the program to transfer technology. They provide available technology in response to specifically stated technical problems and information needs of users ranging from small business to the largest companies. They are operated for NASA by the Universities of Connecticut, Pittsburgh, New Mexico, Southern California, Indiana, and the North Carolina Science and Technology Research Center. Many of your firms are subscribers to RDC services and I would be happy to have more of them.

These Centers through their working relationships and people-to-people contact with NASA field centers, like the Johnson Space Center, act as constant catalysts to bring industry problems and needs closer to NASA's technical experience and capabilities.

As an example of the Industrial Applications Center program providing technical information and assistance to industrial firms, I would like to cite the experience of the firms working to meet the unexpected technical challenges of the design and construction of the Alaskan Pipeline.

TAC, the Center at the University of New Mexico, furnished heat pipe technical information and more importantly, access to the experienced heat pipe technologist at the Goddard Space Flight Center to the Alyeyesha pipe line service company, a former technical member of this community. Alyeysha is planning to use heat pipes as a thermal protection system to protect the pipe line from potential dangers, thermally induced structured stresses and should minimize the environmental impact to the tundra.

The last mechanism used to transfer aerospace technology is the adoption and demonstration of specific technical advances to significant public needs. A necessary requirement of these application projects is their early commercialization to insure lasting and widespread use.

These projects vary in size and scope depending upon the nature and significance of the public need, the level of involvement of a mission agency, or the degree of industrial participation.

An example of one of our applications I am most pleased with is the Rechargeable Cardiac Pacemaker. When the natural heartbeat fails or becomes irregular because of heart disease, an articicial pacemaker which delivers small, regular electric shocks can be life-saving. In the United States, approximately 30,000 pacemakers are implanted each year; another 30,000 units are implanted each year in the rest of the world.

The average life expectancy for pacemakers up to now has been about twenty-two months, after which time their mercury cell power supply is depleted. A surgical operation is then required to remove the pacemaker and implant a new device.

Scientists and doctors at the Johns Hopkins University Applied Physics Laboratory have developed, under the partial sponsorship of NASA, a new heart pacemaker which is rechargeable and much smaller than conventional units. The new equipment uses electrical and electronic components first designed by NASA for use in spacecraft.

Another advantage of the newly developed device is that it is immune to electrical interference sources, such as microwave ovens, car ignitions, and radars, that sometimes stop conventional pacemakers from operating. The improved pacemaker which has been implanted into over 500 patients is now available from an industrial firm Pacesetter Systems, Inc. of Sylmar, California under a licensing agreement through Johns Hopkins and the government participation in the technical transfer.

We also try to transfer technology to other government agencies when they request assistance. As many of you know, the United States Geological Survey (USGS) is charged with regulating the offshore oil industry which is operating more than 1,800 drilling and production platforms on the Outer Continental Shelf (OCS). In 1971, USGS requested that NASA study equipment and procedures used in the offshore oil and gas industry. The NASA study team of reliability and quality assurance specialists from the Marshall Space Flight Center analyzed the feasibility of applying advanced systems engineering techniques to increase the reliability of safety and anti-pollution equipment on offshore drilling and production platforms. The study report described appropriate quality control, failure mode effects analysis, and hazard analysis techniques based on previous space program applications. The report included a number of recommendations for improving safety and avoiding accidental pollution during offshore operations.

Industry and government reaction to the report has been very positive, and it is the basis for a dramatic change in offshore oil and gas production. A joint effort between the Survey and the American Petroleum Institute (API) was initiated in 1972 to develop procedures for implementing the NASA recommendations in specific applications.

We have also successfully adapted the technical know-how and experience in astronaut life support systems for the improvement of firefighters breathing system. At the request of 80 city administrators and with the continued user requirements of representatives of the fire community a very successful technical development has recently been completed. Using high pressure air at 4000 psi and aerospace composite pressure vessels of corrosion resistant aluminum with fiberglass over-rap the stored gas capacity and operating duration have been increased by 40 percent with no appreciative volume increase and a 20 percent decrease in weight. Useability and reliability have been enhanced by the application of aerospace human factors and quality assurance design standards. The system is to undergo verification tests in the New York, Los Angeles, and Houston Fire Departments beginning next month and should be commercially available to all fire departments next year assuming a successful test program. As an added bonus, the pressure vessel should also be available to scuba divers. The significance of this activity is that a very real barrier - the movement of an advanced technology to a very diffused marketplace known for its lack of innovation will have taken place in three years - the economic significance may well be the increased produtivity of firefighters.

Finally, one of the most significant applications of technology is undergoing continued development at our Jet Propulsion Laboratory. This effort is intended to demonstrate the feasibility of a low pollution improved efficiency spark ignition internal combustion engine. The principal of this concept involves the injection of relatively small quantities of hydrogen generated from on-board gasoline into the primary fuel/air system to improve the efficiency of the internal combustion engine. To date, the pollution particuarly NO_x emissions have been significantly reduced although the ultimate objective of meeting or exceeding the 1977 Federal emission standards has not yet been attained. However, the fuel consumption was cut by 25 percent. Future efforts are focused on better understanding of the fundamental process involved in adapting this concept to practical use with automobiles working with the Environmental Protection Agency, the Federal Energy Office, and the automotive industry.

In conclusion, I think that these case studies demonstrate that successful transfer of government technology is a two-way street involving both the industrial community and the government agencies. Without the active participation of both parties the government would retain its technology much to the detriment of the economy, and improvements in the quality of public services for which technology offers so much promise would not take place.

We need to have the American Industrial community which you represent aware of what we are trying to accomplish because without your active interest and participation technology will not transfer in a lasting sense. We also need your feedback to insure that we are accomplishing something meaningful and to determine ways to do it better.

SECOND SESSION

ENERGY

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N75 17196

ROCKET ENGINE HEAT TRANSFER AND MATERIAL TECHNOLOGY FOR COMMERCIAL APPLICATIONS

John Hiltabiddle and John Campbell

ABSTRACT

Liquid-fueled rocket engine combustion, heat transfer, and material technology have been utilized in the design and development of compact combustion and heat exchange equipment intended for application in the commercial field. An initial application of the concepts to the design of a compact steam generator to be utilized by electrical utilities for the production of peaking power is described.

INTRODUCTION

Rocketdyne is a division of Rockwell International Corporation, a multi-industry company with sales in excess of $2.3 billion for 1972. The parent corporation is involved in aerospace, automotive, electronics, utility and consumer products, and industrial activities, with current emphasis on expanding international marketing operations (Fig. 1).

Rocketdyne's beginning dates back to the end of World War II in 1945, when North American Aviation, Inc., a predecessor of Rockwell International, assigned a five-man team to study the feasibility of developing guided missiles for the United States. The study group was designated the Technical Research Laboratory. How best to propel such missiles was one of its major assignments. The present division's Engineering and Manufacturing facilities are located in Canoga Park, California (Fig. 2). Approximately 10 miles from the Canoga Plant in a remote hillsite lies the Santa Susana Field Laboratory and major test facilities.

As a division, Rocketdyne is concerned primarily with the design and manufacture of both liquid- and solid-propellant propulsion systems and associated components (Fig. 3). Its scope of activities has broadened to incorporate commercial waterjet propulsion systems as well as pollution control.

Most current in the list of Rocketdyne efforts is the Space Shuttle Main Engine. Powering the Space Shuttle Orbiter vehicle, this reusable engine is designed for up to 100 missions, with normal service

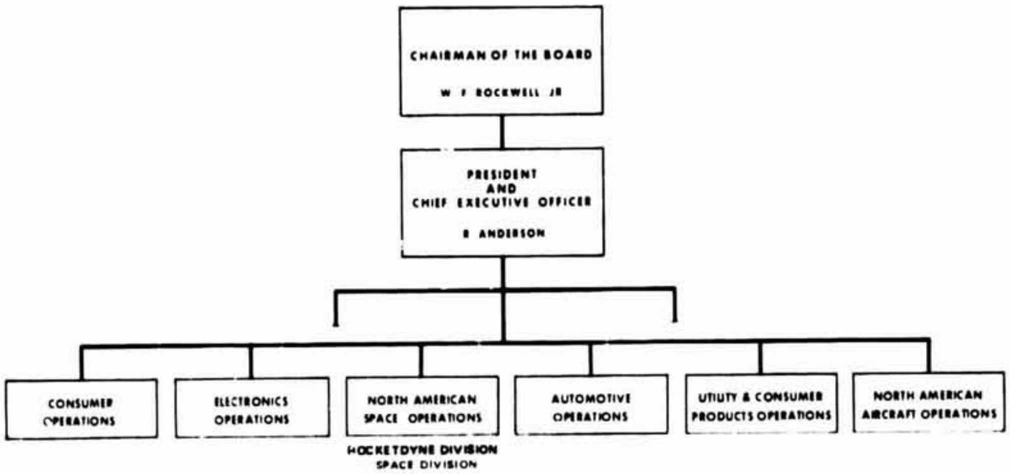


Figure 1. Rockwell International Organization

Figure 2. Canoga Facility

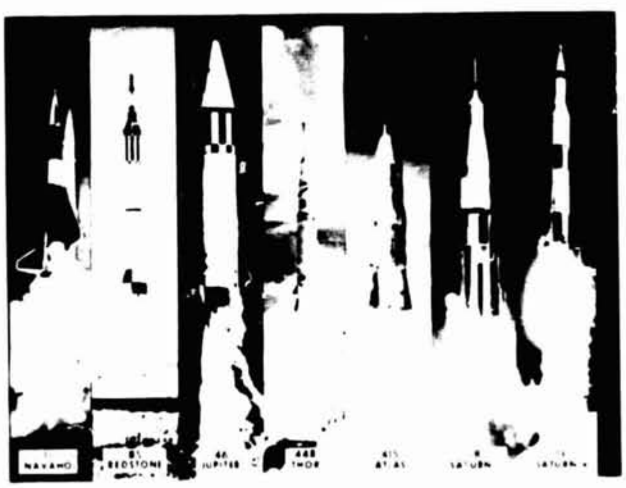


Figure 3. Rocketdyne Engine Launches (1036)

performed between flights much the same as routine airline maintenance techniques. Use of the high-performance, oxygen/hydrogen-fueled Space Shuttle will economize space travel to an extent not realized under previous programs (Fig. 4 and 5).

Rocketdyne and many other aerospace companies, plus the Government agencies who have been involved with the Space programs over the past 2 decades, are now putting their developed talents and capabilities to work for the commercial benefit of the nation. The subject of this review is one task Rocketdyne has undertaken with the help and support of a large commercial customer.

LIQUID ROCKET ENGINE TECHNOLOGY

The technology of rocket engines burning liquid fuels and oxidizers has been developed over the past 40 years. The initial developments were largely European, and culminated in the successful German development of the V-2 rocket engine in the second World War. Large-scale American development was undertaken after the war and is continuing to this day. We are all familiar with the moon landings and other space feats made possible by the development of an extensive and sophisticated rocket engine technology.

Liquid rocket technology has made great strides in many areas, including turbopumps, controls, lightweight structures, intensive combustion, and heat transfer. This paper deals primarily with the application of liquid rocket engine combustion chamber technology to the commercial area.

The liquid rocket engine thrust chamber is a fundamentally simple device whose operating principles are illustrated in Fig. 6. The liquid fuel and oxidizer are introduced into a combustion chamber where they are burned at elevated pressure. The combustion gases, being at higher pressure than the ambient pressure, are exhausted through a nozzle which raises their velocity, and by the reaction principle imparts an opposite force to the chamber. A figure of merit for rocket engine performance is the specific impulse, which is the pounds of thrust derived from each pound per second of combined fuel and oxidizer that is combusted. Figure 6 also indicates the relationships among the variables, and the effects one strives for to maximize performance. The effect of continually improving rocket engine and space vehicle performance objectives has been toward higher combustion chamber operating pressures and the utilization of fuels and oxidizers that produce the highest combustion temperature and combustion products with the lowest molecular weight. This trend is illustrated in Fig. 7. Thrust chamber design technology has thus had to cope with increasing heat transfer rates, cryogenic fuels as well as cryogenic oxidizers, extraordinarily intensive combustion and, at the same time, provide lightweight structures to contain high pressure and temperatures.

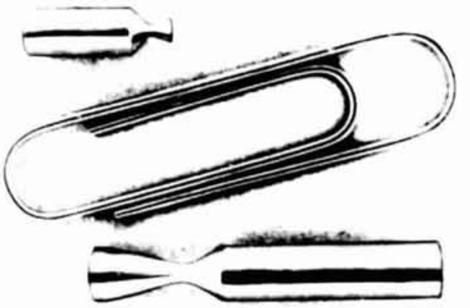
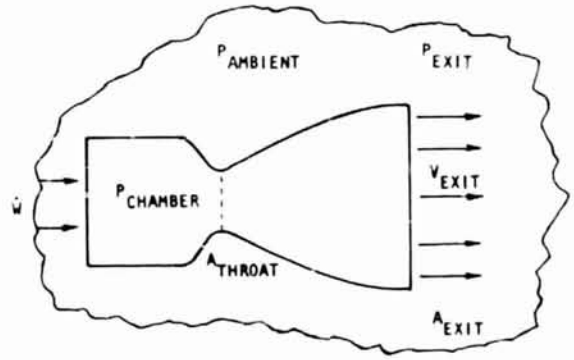


Figure 4. Rocketdyne's Smallest Rocket Engine

Figure 5. Rocketdyne's Newest Rocket Engine for Use in the Space Shuttle Mission



P - PRESSURES
A - AREAS
$\dot{W}$ - PROPELLANT FLOW RATE
g - ACCELERATION OF GRAVITY

$$THRUST = \frac{\dot{W}}{g} V_e + P_e A_e - P_a A_e$$

FIGURES OF MERIT { SPECIFIC IMPULSE = LBS THRUST/LB/SEC OF PROPELLANT FLOW
SPECIFIC WEIGHT = LBS THRUST/LBS ENGINE WEIGHT

TRENDS FOR IMPROVING PERFORMANCE OF SPACE ROCKETS {
HIGH COMBUSTION TEMPERATURE - FOR HIGH V_e
LOW MOLECULAR WEIGHT GAS PRODUCTS - FOR HIGH V_e
HIGH EXPANSION RATIO - FOR LOW P_e/P_c, GIVING HIGH V_e
HIGH CHAMBER PRESSURE - SMALLER SIZE AND LOWER WEIGHT

Figure 6. Rocket Thrust Chamber Principles

It is an interesting facet of large liquid rocket engine thrust chamber developments that current design has nearly always deemed it desirable to provide regenerative cooling of the chamber nozzle and combustion zone. The containment shell of a regeneratively cooled thrust chamber has either the liquid oxidizer or liquid fuel routed through its hollow walls prior to injection and combustion. The result of this practice has been the development of a technology capable of producing reliable equipment that operates at combustion and heat transfer rates several magnitudes above those found in more conventional industrial applications. Several illustrations of the intensity of combustion and heat transfer in liquid rocket engines, as compared with more conventional equipment, are given in Table 1.

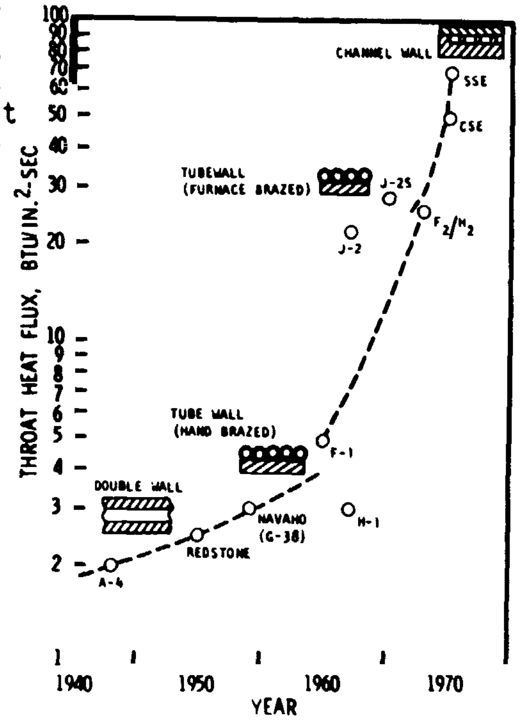


Figure 7. Throat Heat Flux Chronology

Table 1. J-2 Rocket Thrust Chamber Compared With Commercial Equipment

	J-2 ROCKET THRUST CHAMBER	500 MW STEAM BOILER	10,000 HP DIESEL ENGINE	50 MW GAS TURBINE
FUEL FEED, LB/SEC	280,000; H_2	360,000; COAL	3500; OIL	30,000; OIL
HEAT LIBERATION, $BTU/FT^3/HR$	5×10^9	20×10^3	3×10^6	20×10^6
MAXIMUM HEAT FLUX, BTU/FT^2-HR	9×10^6	100,000	NA	NA
AVERAGE HEAT FLUX, BTU/FT^2-HR	700,000	15,000	NA	NA
TOTAL SURFACE, FT^2	120	260,000	NA	NA

COMMERCIAL APPLICATION

We will describe the approach an aerospace rocket engine design and manufacturing organization used in transferring liquid-fueled engine combustion processes, heat transfer, and material technology to a commercial application.

Upon reviewing the 2 decades of rocket engine development, the management at Rocketdyne believed that the capability to design and develop a high-density energy system did indeed exist. The adaptation of the regeneratively cooled combustion chamber and the use of high-temperature combustion processes led Rocketdyne to the use of an indirect cycle for the generation of steam (Fig. 8).

Next came the identification of the end use for the Rocketdyne Compact Steam Generator. What type of vehicle was best suited to utilize this compact energy source?

We started with the wheel and track systems: passenger and freight trains; mine locomotion; where space is at a premium; and road transportation, such as packaging a steam engine into a bus (Fig. 9 and 10). Bill Lear beat us to the punch here, but considering all his problems, that was probably a blessing in disguise for Rocketdyne! Steam powerplants for marine use were investigated. Steam for chemical process plants, and steam generation to drive a turbine-generator set for producing electrical power also were investigated. From all the analyses that were developed, one fact kept coming home in the form of a black cloud! That was the cost of the oxygen and the logistics of getting the oxygen to the steam generator.

One use, however, stood out where the cost and logistics of using oxygen would prove to be economically worthwhile. This is in the generation of steam to drive a steam turbine-generator set and to produce electrical power for a utility during its periods of peak power requirements. Peak power generation is that electrical capacity that an electric utility must be capable of supplying at various times during the day when customer demand is at its greatest (Fig. 11). An electric utility's generating capacity is roughly divided into "base load," "intermediate" or cycling load," and "peaking load" (Fig. 12). Current peaking systems used by the utilities are their older fossil fuel systems that are the most expensive to operate and new gas turbine-generator systems which have a relatively high fuel cost. The Rocketdyne capabilit o develop a compact steam generator would allow a utility to ins , for a very low capital cost, equipment that when mated with an existing steam turbine-generator, will produce electricity at a minimum overall generation cost.

Preliminary designs indicated the Compact Steam Generator would permit the use of a single-pass, parallel-flow, hot-gas and water-steam system. The total steam generation device would be no longer than 21 feet. Use of the liquid fuel and liquid oxidizer would permit operation of the combustion chamber at a pressure substantially above atmospheric without having to use an expensive and power-hungry air compressor. The pressurized combustion would permit attaining higner mass velocities and, consequently, higher heat fluxes than exist with normal atmospheric pressure combustion. The absence of nitrogen in the oxidizer would minimize the production of nitrogen oxides in the exhaust flue gases. The absence or minimization of sulphur in the fuel would keep wi'' in the acceptable limits the

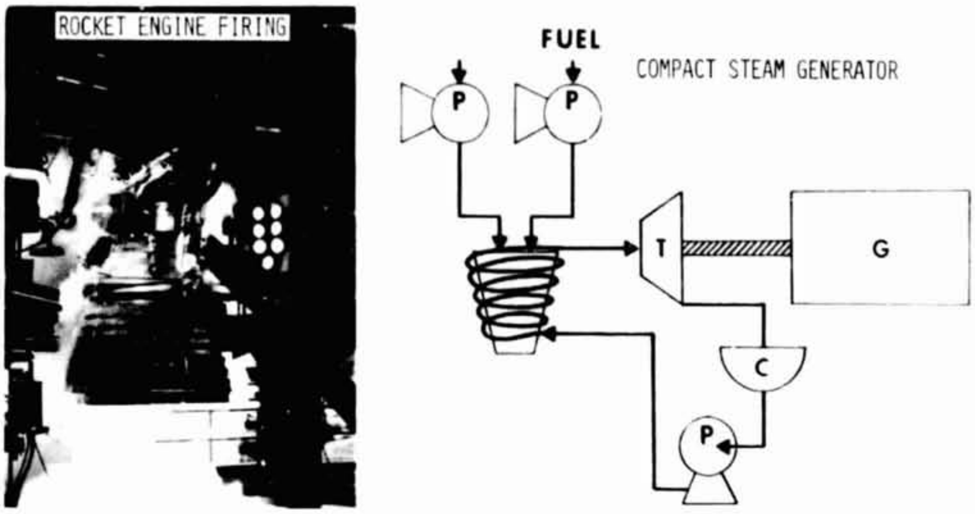


Figure 8. CSG Powerplant

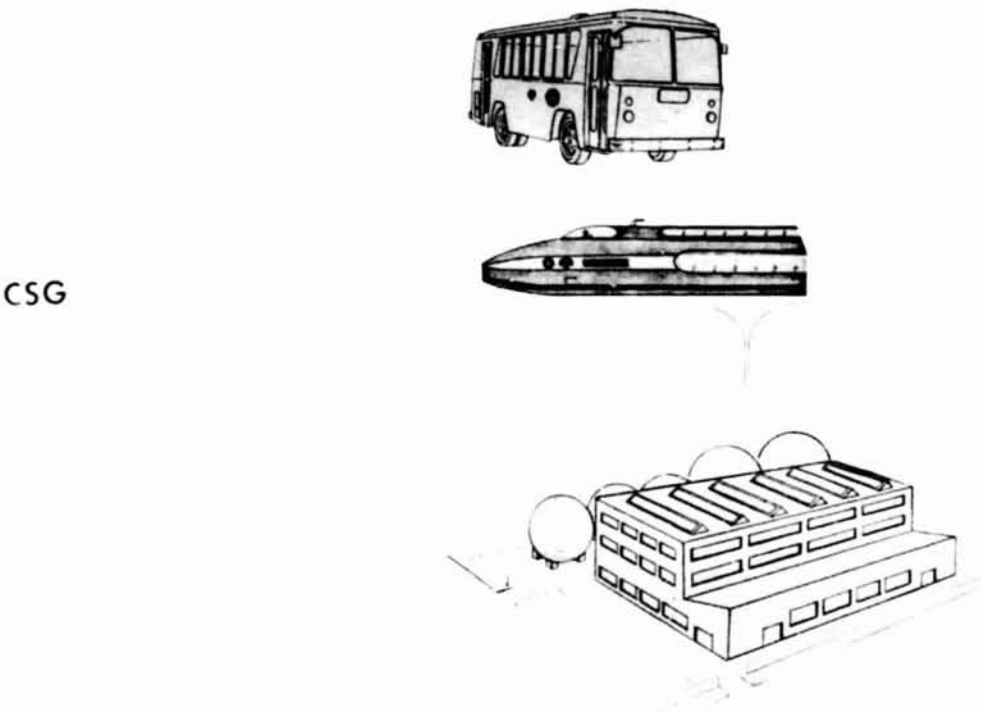


Figure 9. Applications for CSG

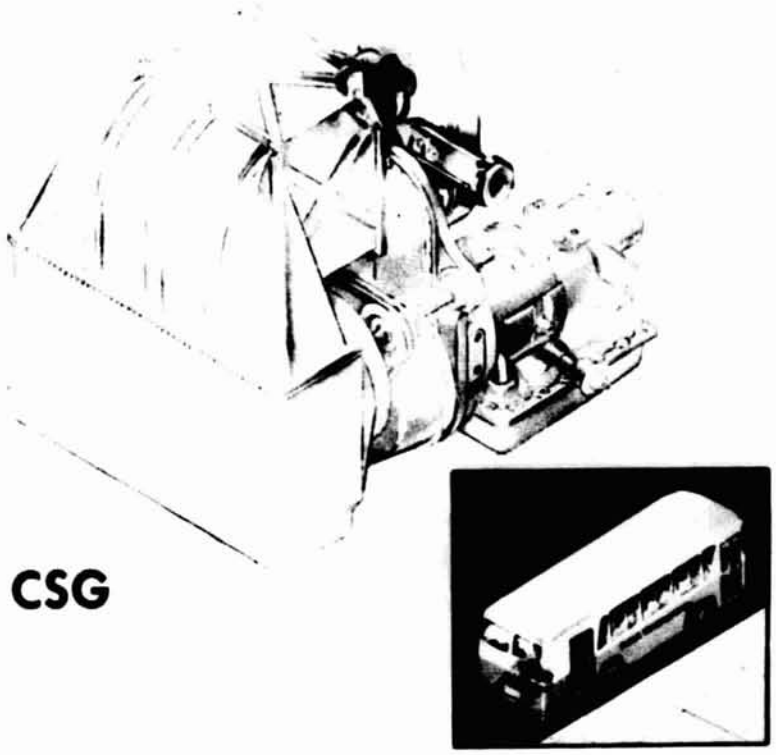


Figure 10. Applications for CSG

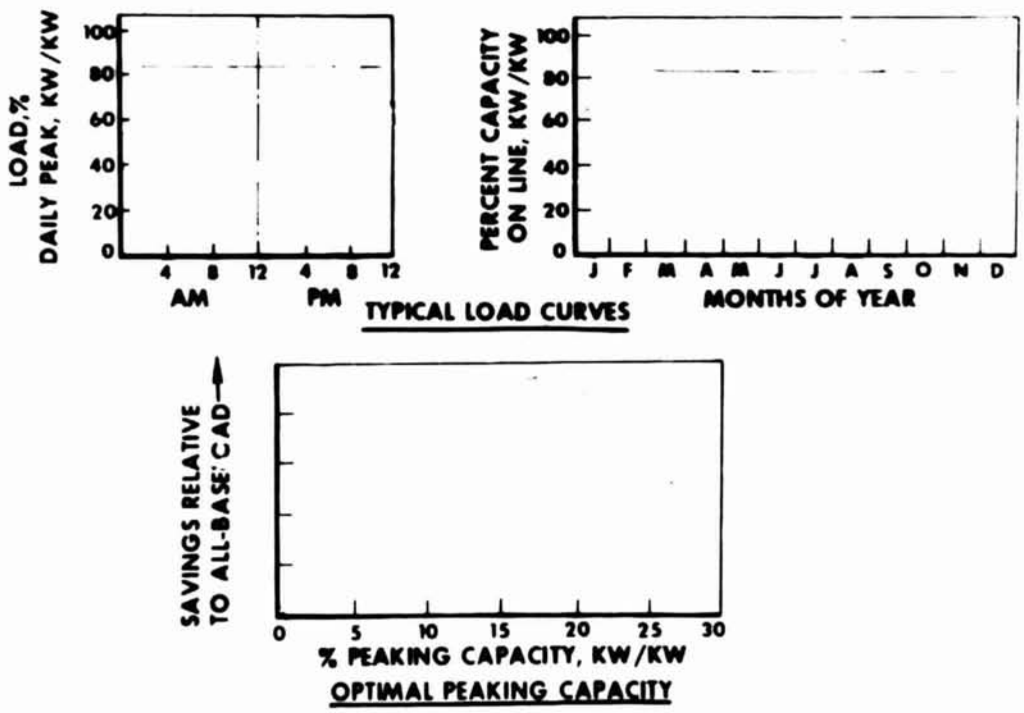


Figure 11. Peaking Power

production of sulphur oxides in the exhaust gases. Thus, the compact boiler would be a low-polluting device (Fig. 13). The pressurized combustion and the high flame temperatures would permit the attainment of high heat transfer rates, more on the order of those existing in a rocket engine thrust chamber than in conventional boilers, and thereby much reduce the required combustion volume and heat transfer surface area. The effect would be a very compact, portable, low-polluting steam generator.

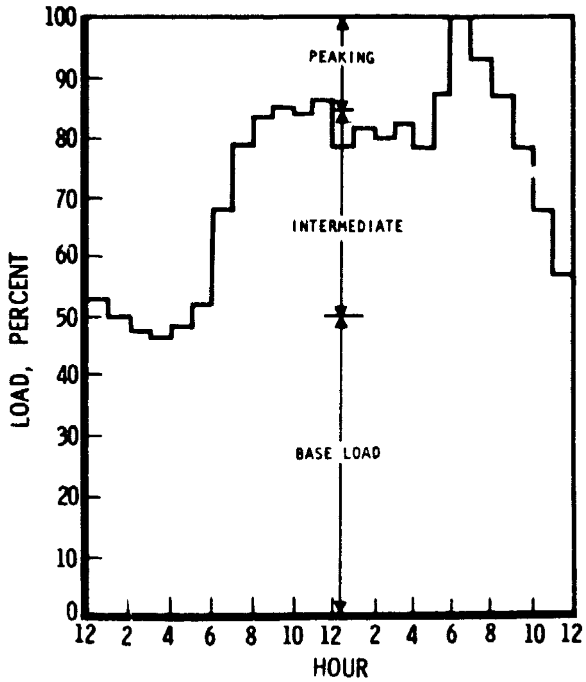


Figure 12. Daily Load Chart for a Typical Plant (Power Engineering May 1967)

PEAK POWER GENERATION

Allow me to develop the picture a little further as a "boiler replacement system." This story is built around the fact that electric-generating facilities are built up of a number of different devices which have differing life spans. Steam boilers have, on an average, a life span of from 30 to 35 years before they become uneconomical to operate and are retired (Fig. 14). The steam turbine-generator set usually has a life span somewhat longer, perhaps into the 40- to 45-year period. At present, when a utility retires its steam-generating equipment, it appears to be more economical to retire the entire system rather than try to go in and reboiler their steam generating facility. Studies indicate that using steam turbine-generators of a retired system, coupled with a low-capital-cost steam generator would be an economical way to produce peak power. This would be true especially if the steam generator would have the capability, because of the small physical dimensions, to be moved from one facility to another as the steam turbine-generators became available due to boiler retirements.

The electric utility industry is very capital intensive; in fact, it is perhaps the most capital intensive business that we know of. Large baseload systems, either nuclear or fossil fuel, require enormous amounts of capital. Thus, to achieve the economics of the system, these major baseloads are run continuously. Intermediate and cycling load systems are somewhat lower in their capital requirements. However, these systems are usually the older installed fossile-fueled systems that are either in their mid- or later-life spans and reflect higher operating costs (Table 2). Peak power generating systems are used for a very short period of time

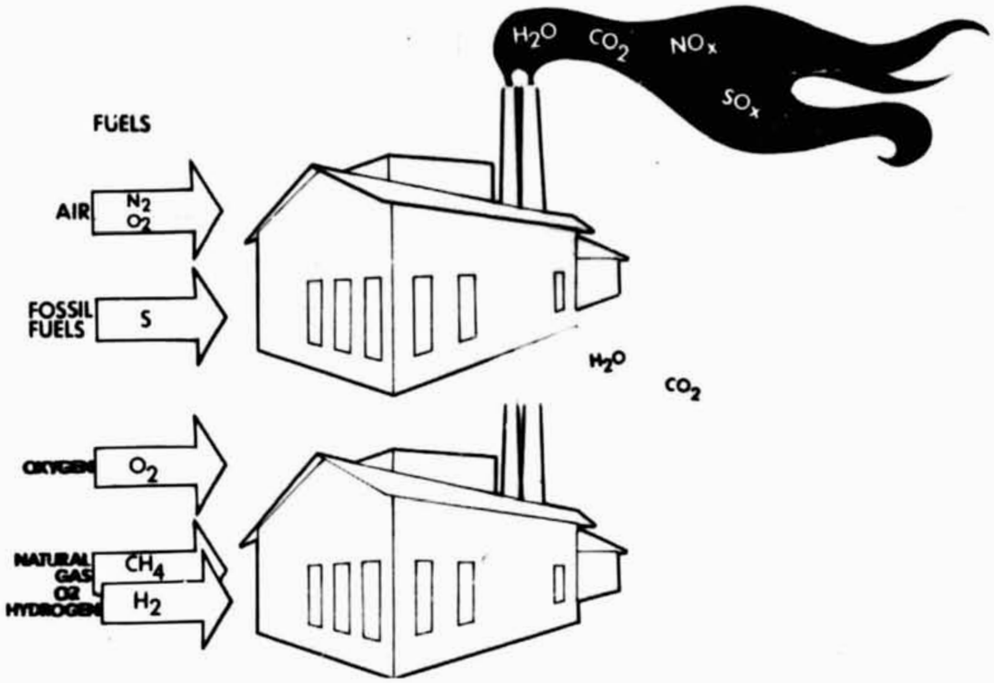


Figure 13. Environmental Effects

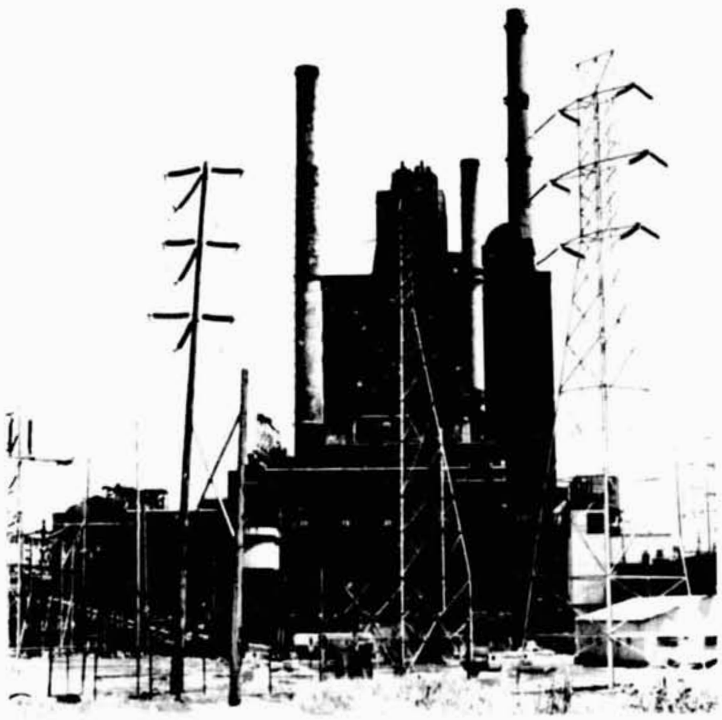


Figure 14. Commonwealth Edison Joliet Station

Table 2. Power Generation Forms

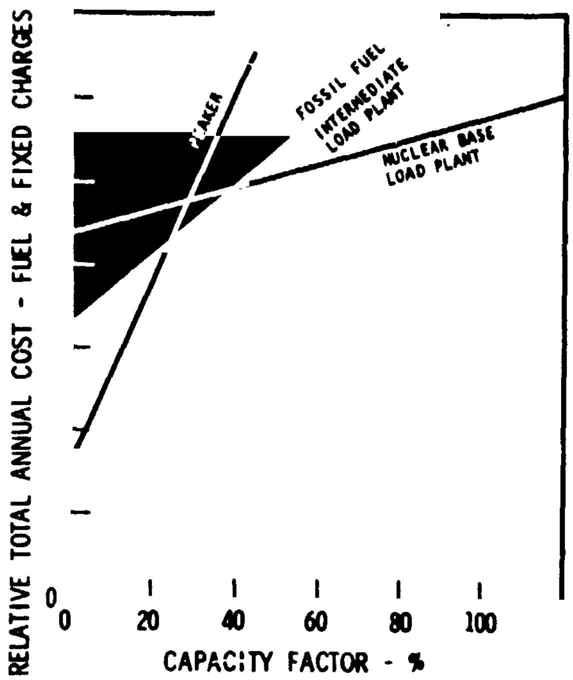
LOAD APPLICATION	PRINCIPAL TYPES	TYPICAL PLANT CAPACITY FACTOR	INITIAL COST	OPERATING COST
BASE (~40%)	NUCLEAR NEW FOSSIL (HIGH COST)	0.7	HIGH	LOW
CYCLING (~30%)	OLDER (~20 YEARS) FOSSIL NEW FOSSIL (LOW COST) COMBINED CYCLE	0.5	LOW-MED	MED-HIGH
SEMI-PEAKING (~15%)	OLD (~20 YEARS) FOSSIL COMBINED CYCLE PUMPED STORAGE	0.2	LOW-MED	MED-HIGH
PEAK SHAVING	GAS TURBINE DIESEL - VERY OLD (~30 YEARS) FOSSIL	0.1	LOW	HIGH

during the year, something less than a 15-percent capacity factor; these are relatively low capital cost units but do have high fuel costs. Current peak power generators may be diesel engine, open-cycle gas turbine and, as I stated, the older fossil fuel systems that have been replaced by newer baseload systems and also are nearing retirement. Utilities use these systems as the demand requires. In the past, systems brought on line during the day were determined entirely by their generation costs (Fig. 15). Today, however, the utilities are strapped from environmental restrictions as well as rising fuel and operating costs. Consequently, peak power generators may be called for entirely by the impact they may have on the environment in the form of air or thermal pollution. In each and every installed system, regardless of whether they are in operation, a major portion of the system cost continues as a fixed cost. Now, if the electric utility can combine a low-cost steam generator with the existing equipment that is paid for, and generate their peak electrical power, there will exist a tremendous economic incentive (Fig. 16).

It is here that Rocketdyne proposes the use of the Compact Steam Generator in a peaking system, replacing retired steam generation equipment boilers, permitting a minimum of interface, reducing environmental problems, and using existing equipment that a utility has installed and paid for (Fig. 17 and 18). Of course, there are requirements to meet: utility specifications such as the boiler code, serviceability, control, and reliability. Rocketdyne has built all of these into its Variflux Compact Steam Generator.

DESIGN-DEVELOPMENT

The concept of the Compact Steam Generator was discussed with representatives of a leading utility, and they were able to identify several possible applications on their existing system. They found the concept sufficiently attractive to enter into a cooperative arrangement whereby an experimental unit will be designed, developed,



TYPICAL VALUES	CAPITAL COST $/KW	HEAT RATE BTU/KWHR	FUEL COST $/MMBTU
PEAKING UNIT	140	14000	$1.25
FOSSIL FUEL INTERMEDIATE	300	9200	$ .50
NUCLEAR BASE LOAD	500	10000	$ .15

Figure 15. Economic Comparison

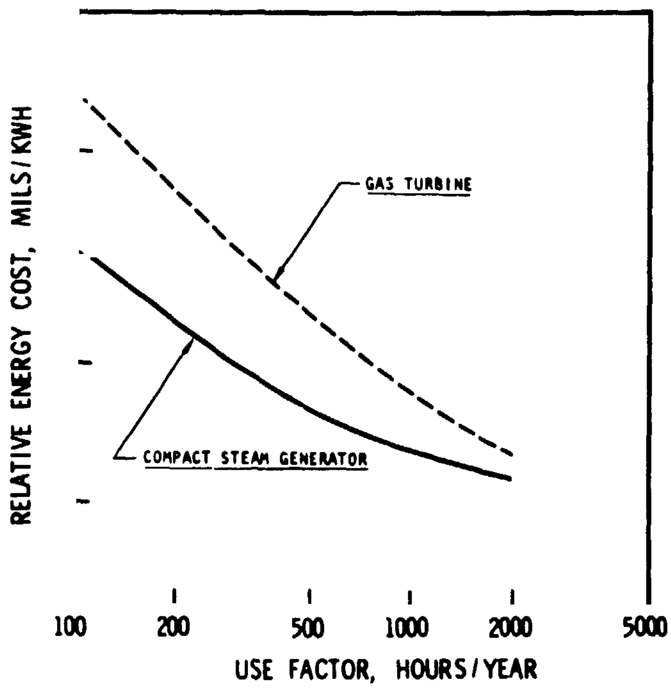


Figure 16. Peak Power Cost Comparison

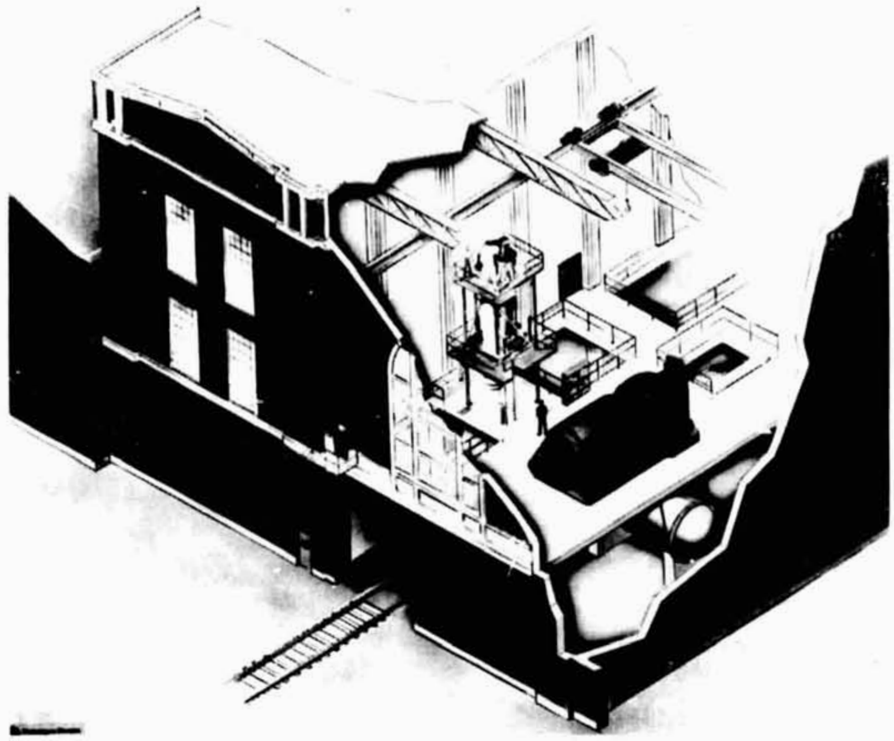


Figure 17. CSG Installation at Joliet Station

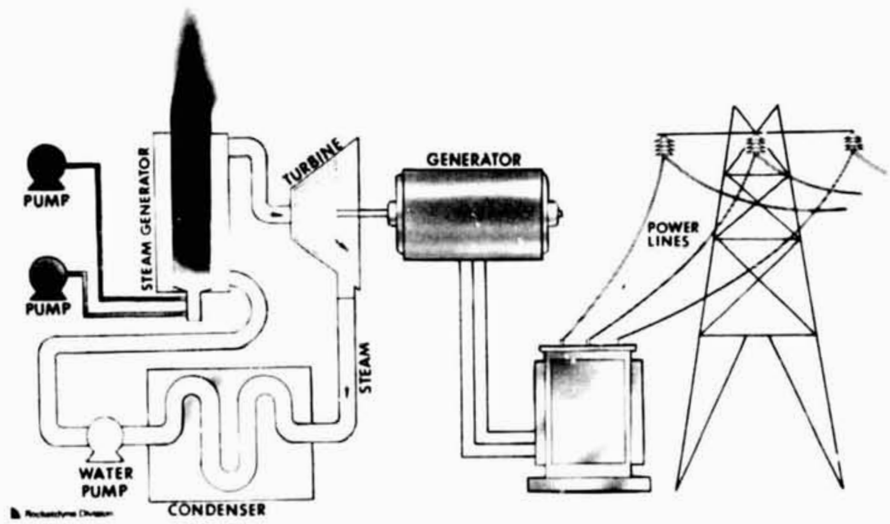


Figure 18. CSG System Schematic

and fabricated by Rocketdyne, and then operated by the utility in conjunction with one of their small existing turbogenerators at an existing station (Fig. 19). This relatively small and low-pressure experimental unit is expected to furnish a proof of the principles. Monetary arrangements are such as to provide a sharing of the cost of design, development, fabrication, and operation. The next unit, a true production prototype, will be nominally sized and will provide for modular buildup for higher-capacity requirements (Fig. 20). This will allow the utility a flexibility in generating to only that capacity they require during a given time period.

The fundamental design concept selected for the Compact Steam Generator is illustrated in Fig. 21. The attributes of the concept support the goal of intensive, nonpolluting combustion and intensive heat transfer, and include the following:

1. The pressurized combustion takes place entirely within a tube, whose relatively small diameter and long length preclude encountering the acoustic modes of combustion instability.

2. The heat transfer is intense, but is uniformly distributed around the tube and thus avoids unequal thermal strains and bowing.

3. The water and steam velocities can be proportioned to meet the varying needs for heat-absorbing capability along the tube and thus optimize pressure drop.

4. Development can be conducted on a single tube assembly that is a small module of a complete boiler assembly, so that the development hardware and testing expenses can be minimized.

5. The volume of water contained in the boiler at any one time can be minimized, thus providing rapid response.

6. The flue gas enclosure for the very hot combusting gases can be all metallic and entirely water cooled, thus eliminating all brick work and uncooled seals.

Both Rocketdyne and the utility recognized that the proof of the validity of the concept would require a cooperative development program. Analysis and development testing at Rocketdyne facilities was necessary to permit design and fabrication to proceed. The final proof of the concepts practicality, however, would depend upon long-term operation at the generating station. Only then would sufficient realistic operating time be accumulated.

DESIGN AND DEVELOPMENT PLAN

The cooperative design and development plan agreed upon committed Rocketdyne to a four-stage program:

1. An initial analysis, definition of concepts, and development testing phase to furnish the essential experimental base which was not already available from liquid rocket thrust chamber technology

Variflux
compact steam generator

Rocketdyne Division

PURPOSE:

REPLACE "RETIRED" BOILERS TO UTILIZE EXISTING TURBO-GENERATORS FOR PEAK POWER GENERATION

• U.S. PATENT 3,779,212

Figure 19. Variflux - The Compact Steam Generator

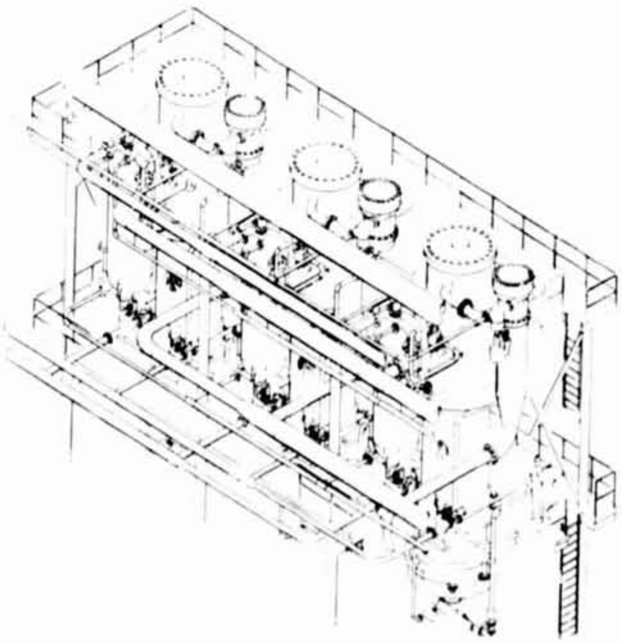


Figure 20. Multiple Rocketdyne Compact Steam Generator Modules

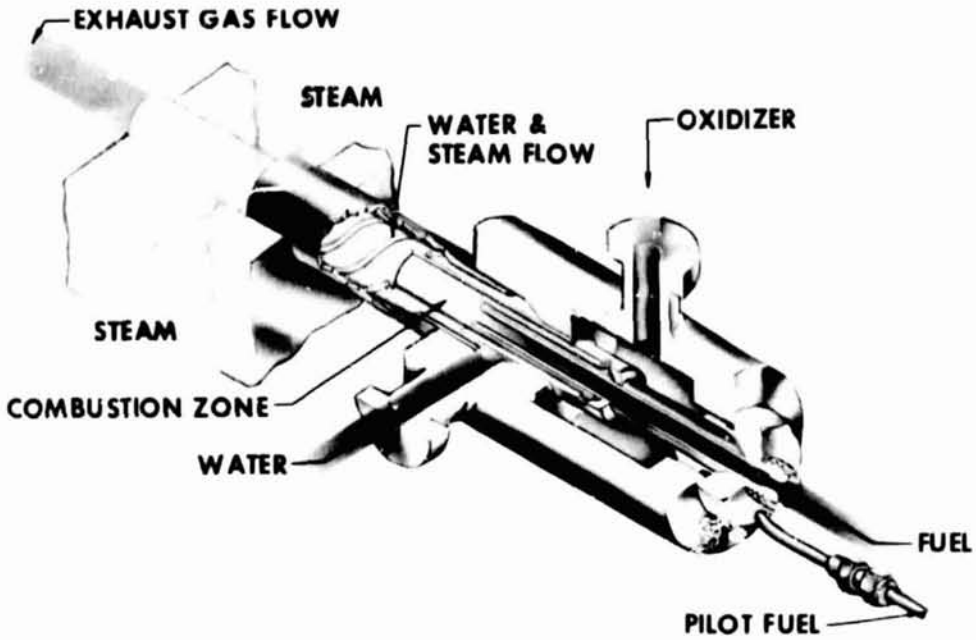


Figure 21. Basic CSG Element

2. Detailed design and fabrication of the full-scale boiler system by Rocketdyne

3. Checkout testing of the boiler system at Rockwell facilities

4. Support to the utility during installation and commissioning of the boiler system at the power station, and assistance in the resolution of problems that surface during long-term operation

The program is presently in Phase 3, the checkout testing of the full-scale boiler system at Rockwell facilities.

Component Development

The fundamental boiler concept selected for development was allied closely enough to our existing thrust chamber technology so that many aspects of its design could be proportioned on the basis of existing techniques and correlations. For instance, the burners were derived from designs used for hydrogen/oxygen rocket engine injectors, the gas-side heat transfer conditions were predicted from thrust chamber background, and the transient heat transfer and flow conditions would be modeled mathematically. However, there were also significant differences especially regarding the water-side heat transfer conditions where the water passes successively through water heating, subcooled boiling, and superheating. There were other questions on water-side flow stability. Moreover, it was considered appropriate to provide an experimental demonstration of the feasibility of the concept prior to design and fabrication of the complete boiler. For these reasons, a component development program was undertaken using equipment similar to that shown in Fig. 22. The modular nature of the boiler concept was particularly beneficial in this demonstration in that full-scale

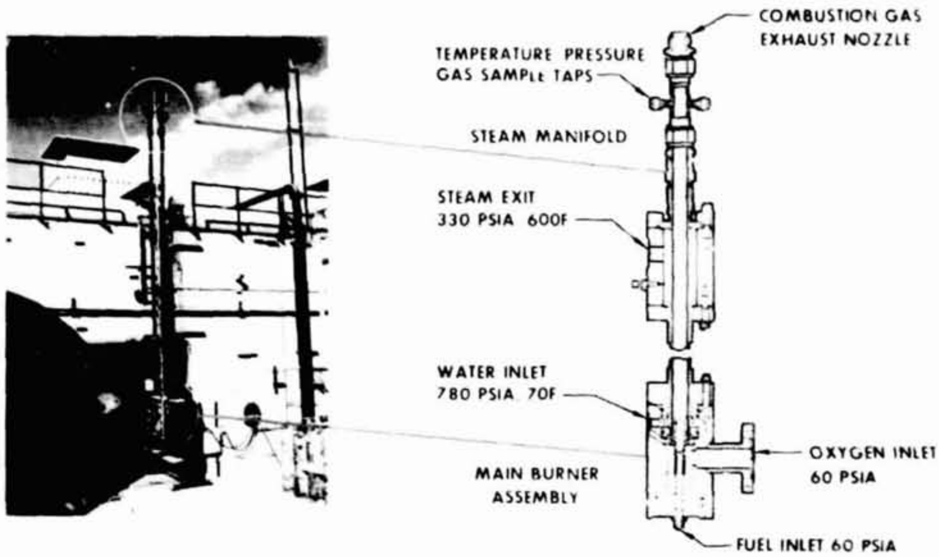


Figure 22. Compact Steam Generator Combustor Development

testing could be conducted on a single tube assembly with confidence that the same results would be obtained in each of a large number of such assemblies grouped together in a complete steam-generating unit. This fundamental development work required several months of testing, and was sufficient to complete the basic design information.

Heat Transfer

Analysis had indicated that the limiting constraint on peak heat transfer rates would be the capacity of the cooling water to maintain acceptable water-side pressure drop. Water-side heat transfer relationships were established by searching the literature (and there is relatively little boiling heat transfer information available at these high heat fluxes). Tests also were conducted with an electrically heated tube at the steam pressure and temperature conditions of the pilot plant steam turbine. Having established water-side heat absorption capability, the flue gas-side design mass flux was established on the basis of existing data and checked experimentally in the modular boiler. Results are indicated in Fig. 23. These data are typical of the shape of the heat flux curves obtained. They indicate that combustion is completed and maximum flue gas temperature obtained within the first 40 inches of combustor length. The peak heat flux at rated design conditions is about 1.0 Btu-in.^{2}/sec, which is modest for rocket engine practice, but well above conditions existing in most boilers. The average heat flux is 200,000 Btu/ft^2/hr, which is about 15 times the average flux in conventional boilers.

Ignition and Burner Design

Both the ignition system and the basic burner design concepts were based on previous rocket engine practice and found to perform quite

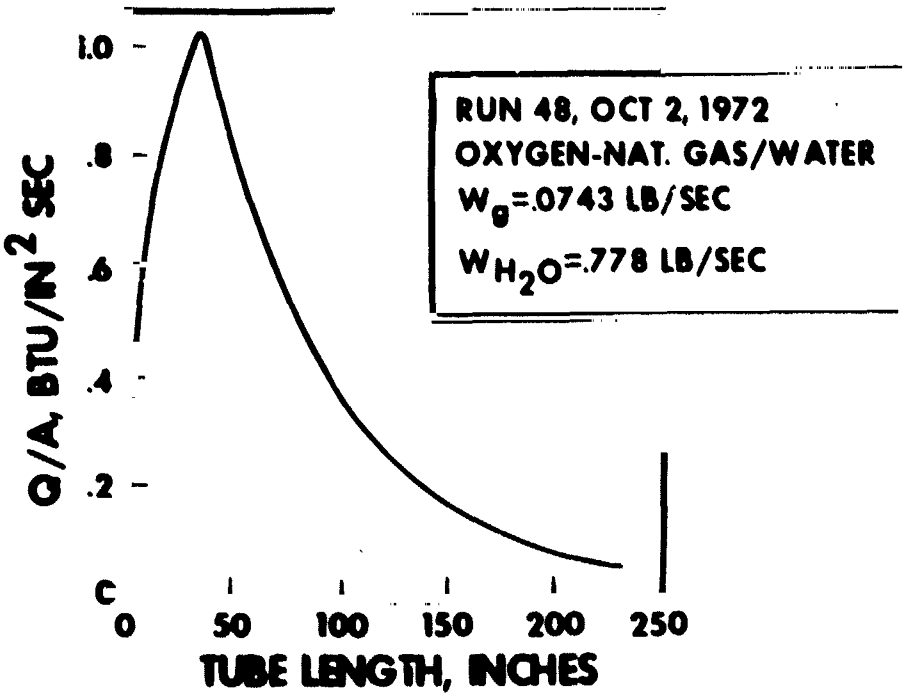


Figure 23. VFE

well. The ignition system is required to light off a number of separate burners simultaneously. Its basic concept was derived from hydrogen/oxygen rocket thrust chamber technology. The required performance targets differ from rocket engine targets in that (1) the required combustion pressure is 35 psig (which is relatively low), (2) the ratio of oxygen to fuel flow is above stoichiometric (while rocket engines run well below), (3) it is essential that the amount of carbon monoxide and hydrocarbons in the flue gas exhaust be minimized for pollution considerations, and (4) the furnace walls must not progressively foul with sooty deposits. It was found possible to meet all these constraints by incremental burner developments. Figure 24 indicates that the developed burner provides satisfactorily complete combustion with as little as 5-percent excess oxygen.

Water-Side Pressure Drop and Stability

The basic boiler concept entails "once-through flow" in which the water is progressively heated to the saturation temperature, all in one pass through the unit without recirculation. While the once-through boiler concept has been used many times before in conventional boiler practice, it is somewhat unusual to apply it at steam pressures as low as that of this pilot project, and the targeted high heat absorption rate requires a substantial pressure drop to force the water and steam through the flow circuit at sufficient velocity.

The relationship of tube pressure drop and flow at various loads, as defined by the development program, is indicated in Fig. 25. While gathering these data, the steam outlet pressure was held constant at each load, as was the steam outlet temperature. The water inlet pressure and the average density of the water-side fluid therefore increased with increasing load, resulting in the characteristic that the tube pressure drop does not follow the square law. The dotted line illustrates the important consideration that at constant heat input, the tube pressure drop varies only slightly with water flow. This characteristic makes it necessary to provide an orifice at the entrance to each tube circuit to stabilize the flow and distribute it properly among all tubes operating in parallel. Development testing made it possible to size the orifices to distribute the flow properly among all tubes operating in parallel, and to attain the desired 4:1 steam-flow throttling range.

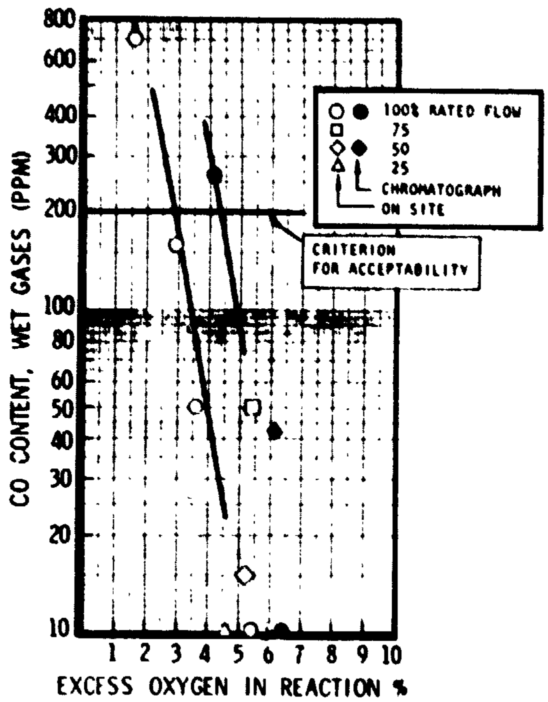


Figure 24. CSG Combustor Development (Gas Sampling Summary Propane/Oxygen)

DESIGN

The equipment supplied to the pilot installation by Rockwell International may be properly considered as a boiler system. Its essential elements are illustrated in the simplified schematic of Fig. 26. The system design task has many similarities to the task faced by the designers of a liquid rocket engine system, i.e., it involves pumping, piping, control systems, and the like. Since weight was of minor importance, it was possible to design the system to utilize available commercial equipment. In rocket engine practice, by contrast, it frequently is necessary to design and fabricate special pumps, ducting, and valves. The system is very "quick acting" and the timing of some events is quite critical, so that we elected to provide a completely automated "push button" control system. This was designed and developed by a supplier knowledgeable in boiler automation.

Rocketdyne undertook the complete design of the boiler itself; that is, the heat exchanger that generates steam. There were some

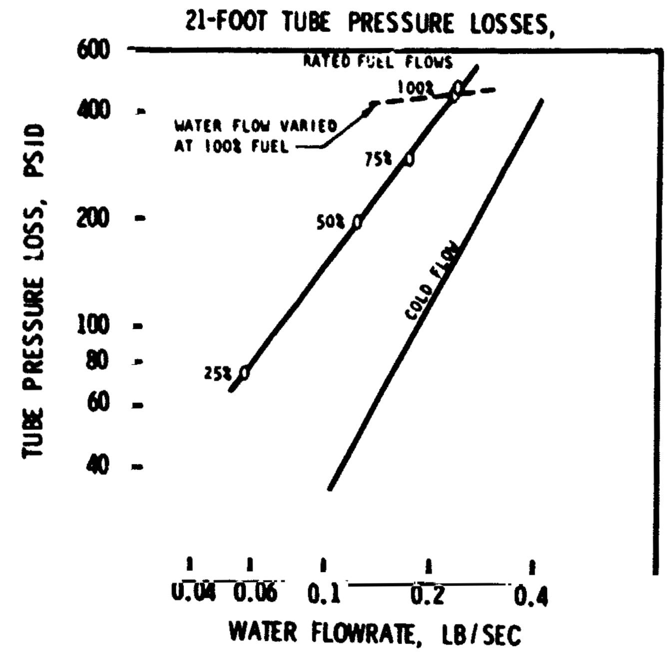


Figure 25. CSG Combustor Development (21-Foot Tube Pressure Losses

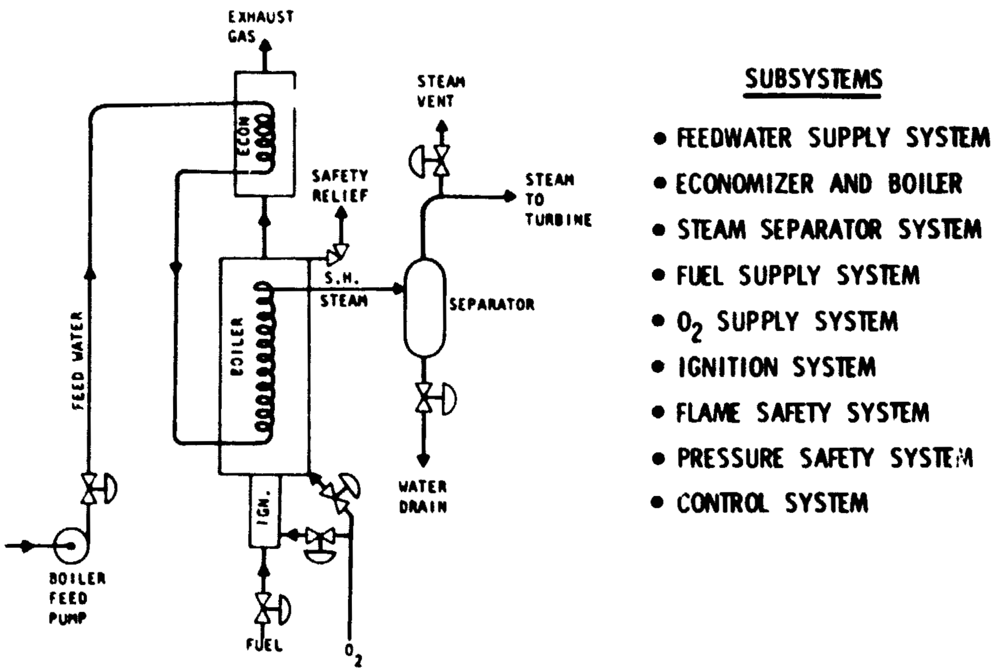


Figure 26. Compact Steam Generator System Schematic

design challenges inherent in the mechanization of the boiler concept, which we believe have been met successfully, and which are the subject of a pending patent application. The design was influenced substantially by the provisions of Section 1 of the ASME boiler and pressure vessel code. This code has the force of law in many states. Its rules govern the design of steam boilers, and their fabrication and inspection during construction. Our boiler bears little resemblance to conventional boilers, and thereby required considerable attention to the provisions of the code. In this work, we are aided by several consultants who are knowledgeable in code matters. We also found our "authorized code inspection agency," the Department of Industrial Safety of the State of California, to be careful, patient, and helpful.

FABRICATION

Our management made the basic decision that Rocketdyne would fabricate the steam-generating portion of the boiler system and would assemble all the parts. We therefore applied to the ASME for a certificate of authorization to use the "S" power boiler symbol stamp at our Canoga Park plant. This procedure is required by Section I of the boiler code for authorized manufacturers of power boilers. Our manufacturing and quality assurance facilities and personnel were audited under the direction of the ASME, and our facility was granted a certificate of authorization. Actual manufacture and quality control were carried out by our regular personnel. The progression in manufacture of the steam generator can be seen in Fig. 27 through 31. Figure 32 shows the assembled boiler system.

As seen in Fig. 33, the boiler system is designed to be transportable by truck. In this view, the outer platforms have been removed and are being transported separately. The core is an 8- by 8-foot square module which is readily transported over the road.

ASSEMBLY FUNCTIONAL CHECKOUT TESTING

In line with the overall design and development plan outlined above, the boiler assembly is undergoing a series of functional nonfiring and firing checkouts at a Rockwell facility. These tests are designed to put the assembly through its paces in terms of starting and stopping, load following, steam pressure and temperature regulation, thermal efficiency, capacity, safety limits, and other demonstrations designed to identify and correct deficiencies prior to shipment and installation at the utility plant. This checkout testing program is proceeding well.

INSTALLATION

The boiler assembly ultimately will be installed along side the turbine generator that it is to supply with steam, as indicated in Fig. 34 and 17. The planned operation at the utility includes a short checkout series to determine that the installation is correct and the equipment has not been damaged in transit. The boiler then will be operated by the utility to meet the demands placed upon a

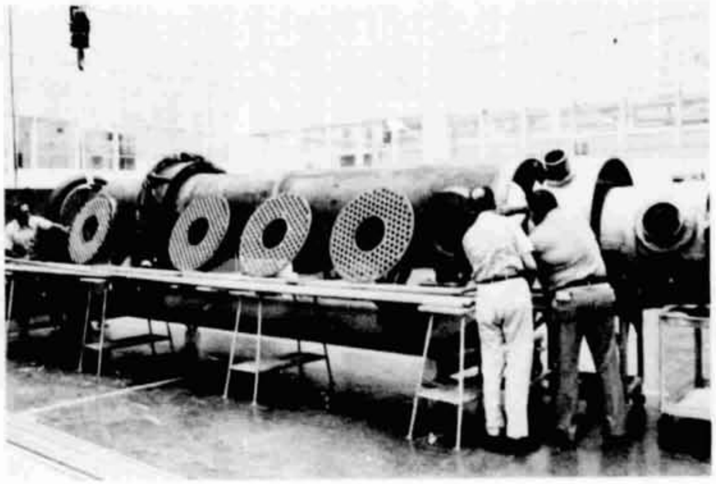


Figure 27. CSG - July 1973

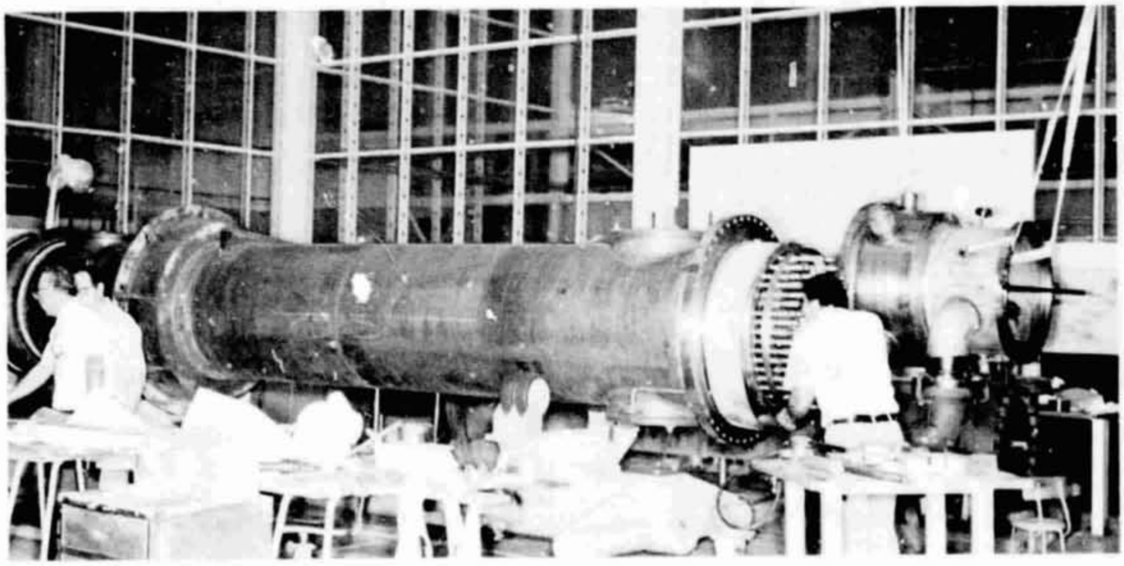


Figure 28. CSG - November 1973

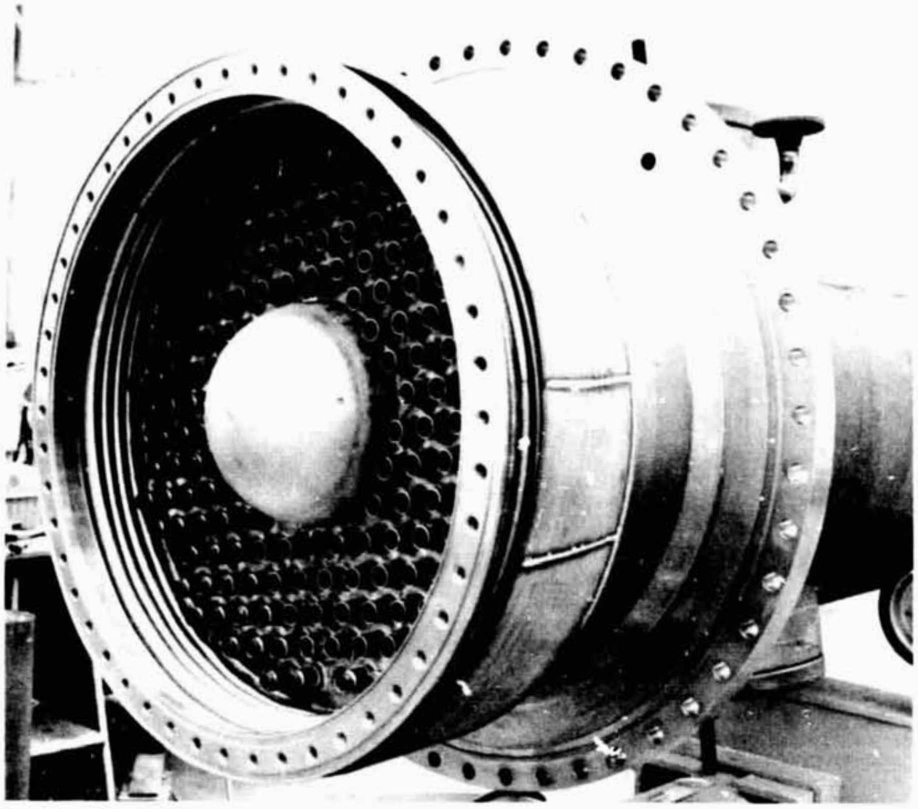


Figure 29. CSG - December 1973

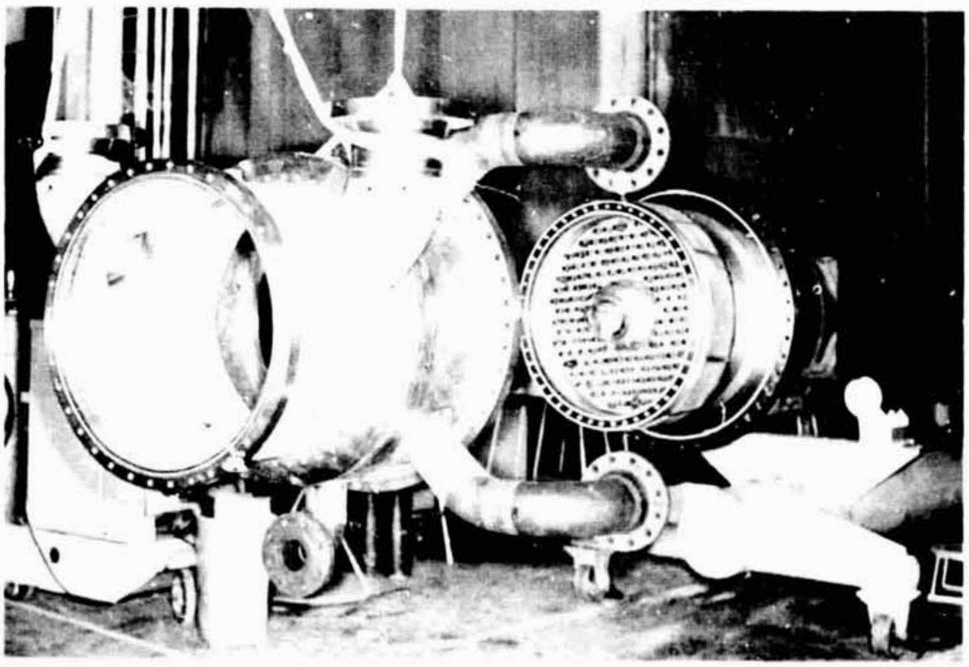


Figure 30. CSG - January 1974

Figure 31. CSG - January 1974

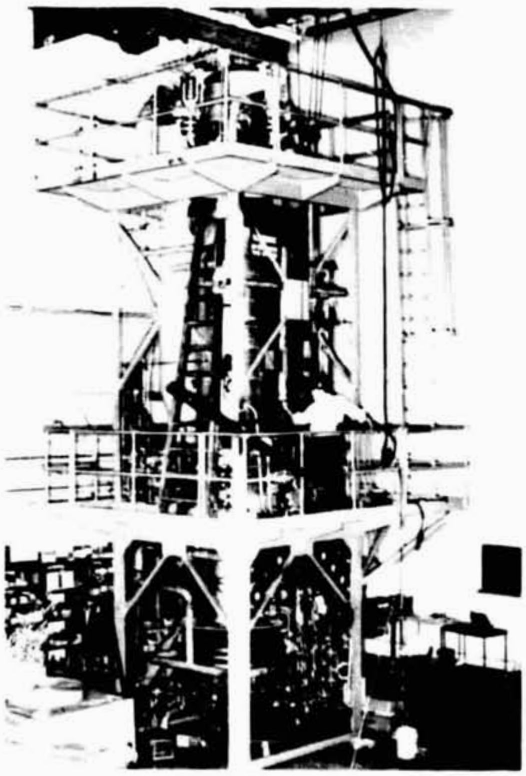


Figure 32. CSG - April 1974

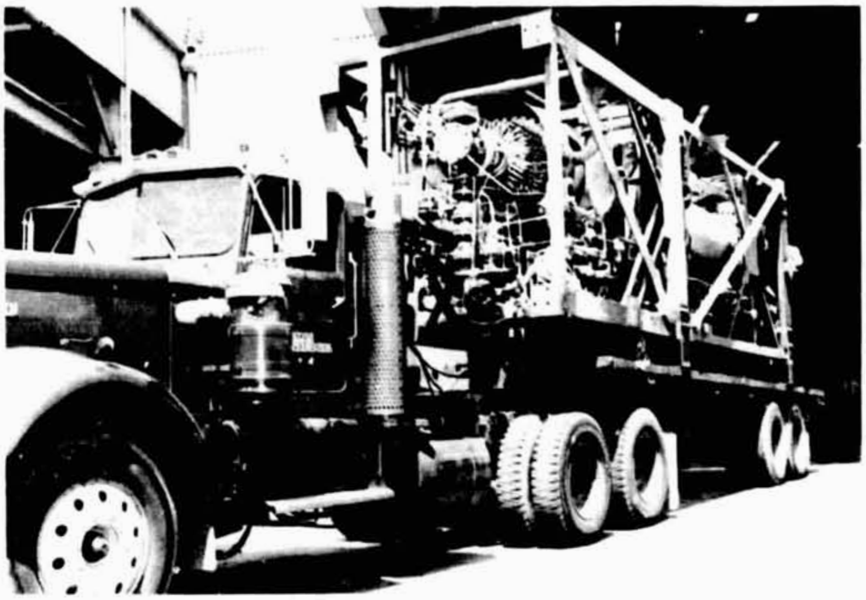


Figure 33. CSG - April 1974

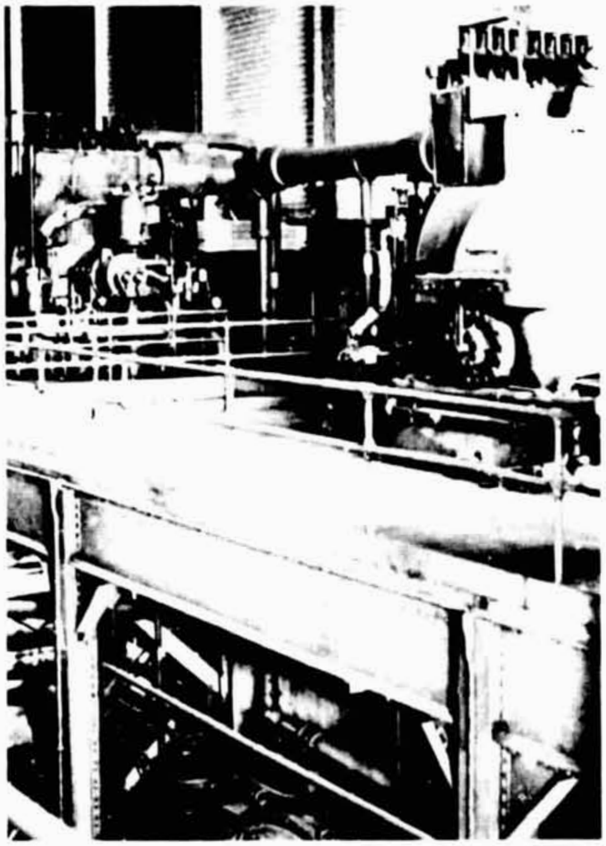


Figure 34. Joliet Station No. 9 Turbine

typical peaking installation. Operation for 4 to 6 hours a day, 5 days a week is anticipated. This long-term operation will be the ultimate test and will serve to identify areas needing improvement. The many hours of operation will assess the long-term reliability of the steam generator and its auxiliary systems, will provide experience on the maintenance of cleanliness of the flue gas side and the water side of the boiler tubes, and will permit an evaluation of the overall operability of the boiler system as a steam source for peaking power uses.

SUMMARY

This program was a major undertaking for our aerospace-type company. We found that the commercial world demands to be shown results in the form of real hardware and hard facts. R&D is not done just for the sake of technology; the end product must be obtainable and have true economic value. Commercial business is willing to expend time, money, and manpower in the pursuit of a definite goal, but it expects each participant to share in the total development effort.

You see here the finished Compact Steam Generator with its concontrols (Fig. 35 and 36). We had to re-educate our Rocketdyne team from the aerospace specification and manufacturing methods to those of the commercial boilermaker. This included understanding the boiler codes, interfacing with the state inspectors, and certification of our fully aerospace-qualified welders to the applicable boiler code and requirements. Following the completion of checkout tests, the Compact Steam Generator was shipped to our customer. The customer will complete installation in the fall of 1975 at the Joliet, Illinois, facility. Power generation will be demonstrated and will be ready for use during the winter peak demand period.

The heat transfer design that is incorporated in the Variflux Compact Steam Generator also is being considered for other systems that will use high heat flux such as methanators, for coal gasification schemes (Fig. 37) and vaporizing systems in the vaporization of liquid petroleum fuels. A current joint effort with McDonnell Douglas Company, and under contract to the National Science Foundation, will investigate the use of "tower power" (Fig. 38); this is the collection and transfer of the sun's energy for the generation of steam for future power-generating systems.

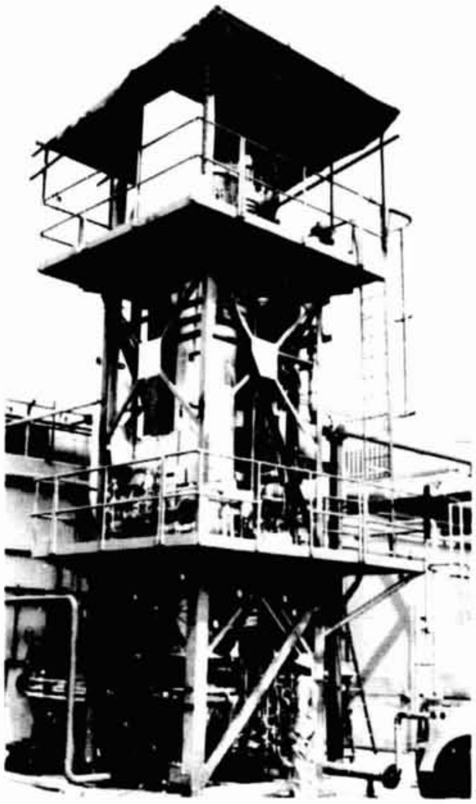


Figure 35. CSG Test Laboratory

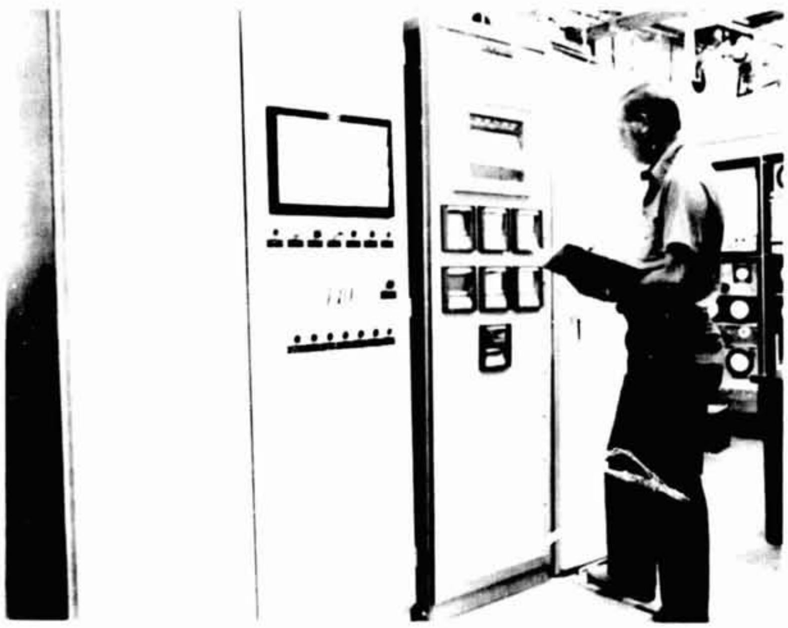


Figure 36. CSG Controller

OBJECTIVE: CONVERT COAL TO SYNTHETIC PIPELINE GAS

SPONSOR: OFFICE OF COAL RESEARCH (OCR)-DEPT. OF INTERIOR

ROCKETDYNE INTEREST:

- OCR COAL COMBUSTION PROGRAMS
- MATERIALS PROPERTIES IN HYDROGEN ENVIRONMENT
- METHANATOR FOR COAL GASIFICATION PLANTS

Figure 37. Coal Gasification

OBJECTIVE: ELECTRICAL POWER GENERATION

SPONSOR: NATIONAL SCIENCE FOUNDATION (NSF)

CONCEPT: SUNLIGHT FOCUSED ON TOWER-MOUNTED RECEIVER

- STEAM GENERATED IN RECEIVER TO DRIVE TURBOGENERATOR

ROCKETDYNE INTEREST:

- SUBCONTRACT EFFORT (RECEIVER DESIGN) FROM MDAC
- NSF SUB-SCALE RECEIVER PROGRAM IN EARLY '75

Figure 38. Solar Energy

N75 17197

APPLICATIONS OF AEROSPACE TECHNOLOGY IN THE ELECTRIC POWER INDUSTRY

F. Douglas Johnson
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The transfer of NASA technology into commercial applications is frequently expected to generate commercial products that reflect in some way the previous space hardware designs. This mode of technology transfer is, in general, a rare occurrance and has had little impact on industrial products or practices. Another mode of technology transfer is of far greater significance, namely, the nonaerospace applications of NASA advances in technical disciplines. The transfer of space technology into the electric power industry clearly demonstrates this distinction. New power-generating equipment, such as fuel cells or solar cells, that was developed for space missions, may achieve widespread commercialization in the future, but their present impact on the industry is dwarfed by the existing applications of NASA contributions to disciplines such as combustion engineering, mechanical engineering, materials science, quality assurance and computer control. Examples are presented in the paper to illustrate how space technology is used in the electric power industry and corporate strategies to acquire relevant space technology are described in our conclusion.

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APPLICATIONS OF AEROSPACE TECHNOLOGY IN THE ELECTRIC POWER INDUSTRY

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INTRODUCTION

In 1961, when we made the committment to send men to the moon and bring them back, there was a general expectation that this effort would create a giant step forward in technology and would, therefore, support the continued industrial development of our nation. Since that time the spectacular success of the Apollo program and the sophistication of the systems that made it possible have distracted us from what has become a rather prosaic expectation. Thus, it is a little startling to discover that a quiet fulfillment of this expectation was taking place while we watched the moon shots. Mission-oriented R&D by NASA and its contractors has rapidly advanced the technical disciplines that underlie many industrial sectors and several of these technical advances are being used in nonaerospace industries.

The use of space technology in the electric power industry illustrates how this technology is transferred to an unrelated industry (1). The commonality between a coal-fired power plant and a Saturn rocket is, at best, obscure. They both have high performance machinery and a control system to convert fuel into useful work but this would hardly convince a skeptic that new technology for the rocket is applicable to the power plant.

The technical solutions that were developed for problems in rocket design and production are not relevant, in general, to solving problems in electric generating equipment. The relevance of space technology is in the advancement of technical disciplines because these advances created new problem-solving capabilities that can be used by other practitioners of the same disciplines. Engineers in the electric power industry are applying new problem-solving capabilities from the space program to reduce pollution and increase reliability and efficiency for electric generating equipment. Some examples will indicate how these advances in technical disciplines, rather than space hardware, are having a significant impact on the electric power industry. We will conclude with a discussion of corporate strategies to profit from the technical advances made in the space program.

COMBUSTION ENGINEERING

Combustion analysis methods were developed for rocket propulsion systems over the last two decades by NASA and its predessor, the National Advisory Council on Aeronautics. These methods consist of computer programs to do analytic modeling of fuel vaporization, combustion kinetics and exhaust gases. For any given combination of fuel, combustor geometry, and operating environment, the combustion process is characterized by different flame zones rather than homogeneous flames. The NASA computer programs make it possible to model each flame zone accurately and then aggregate the results into a satisfactory nonhomogeneous model of the combustion process for analysis.

When the nitrogen oxide (NO_x) emission standards were created under the Clean Air Act of 1970, electric utilities were faced with a serious combustion engineering problem: how to maintain the flame temperature in boilers below 3,000°F so that NO_x emissions were minimized without lowering efficiency or increasing carbon monoxide, hydrocarbon and smoke emissions. The seriousness of the problem was underscored by the fact that California NO_x standards were used to block the construction of a new power plant for the Los Angeles Department of Water and Power. The Department's committment of over 30 million dollars was saved and construction proceeded after a group of aerospace combustion experts used the NASA combustion analysis programs to design new boiler operating procedures for the plant so that it would not exceed the legal limit for NO_x emissions. The combustion experts formed a company, KVB Engineering in Tustin, California, which has used the same computer programs to design economical procedures for reducing NO_x emissions by 40 to 70 percent in more than 100 fossil-fueled utility boilers across the nation, including those belonging to the Houston Lighting and Power Company.

One of these NASA programs, the Chemical Equilibrium Calculations program, from the Lewis Research Center in Cleveland, is among the most widely used chemical programs in the country. In addition to the KVB application in utility boilers, it is used by the Babcock and Wilcox Company in designing sulfur dioxide scrubbers for power plants and by the Bureau of Mines to model coal mine fires for the development of underground detection and quenching systems.

MECHANICAL ENGINEERING

The NASA Structural Analysis (NASTRAN) Program is a general computer program to analyze static and dynamic behavior of elastic structures. NASTRAN has been used to design space vehicles such as Skylab and aircraft components. The program was developed by the Goddard Space Flight Center in the late 1960's to provide user-oriented engineering analysis capabilities for structures of any size.

The General Atomic Company uses NASTRAN for dynamic modeling of the company's high temperature gas-cooled reactors. The primary application is in vibration analysis for the verification of hardware designs under earthquake and vibrating pipe conditions. Although most of the modeling was for the 1,000 megawatt reactors currently being developed, the program was used to model the 300 megawatt Fort St. Vrain Nuclear Generating Station located near Platteville, Colorado.

Westinghouse engineers have used NASTRAN since 1970. They became interested in the program while it was still being developed at Goddard. Some of the company's divisions use the program through the research center computing facility in Pittsburgh, while others, such as the Steam Turbine Division in Lester, Pennsylvania, have the program in their own computers. Applications include: elastic analysis of natural frequencies for steam turbine blades; transient response and thermal analysis of turbomachinery housings; and analysis of structures such as floating nuclear power plants. In most of these applications, NASTRAN performs calculations which were not economically feasible with previous computer program capabilities.

NASTRAN, as is the case with most NASA computer programs, is being disseminated at cost by the Computer Software Management and Information Center (COSMIC) at the University of Georgia, under contract to NASA. It is also available on time-sharing computers from several service companies.

MATERIALS SCIENCE

NASA scientists at the Lewis Research Center have conducted testing programs and analyses in fracture mechanics since the early 1960's. Better methods were needed to resolve the brittle fracture problems of low-weight, high-strength alloys used in space vehicles. Lewis researchers played a major role in developing an important new material parameter called plane strain fracture toughness and a related test method that is now recommended by the American Society for Testing and Materials (ASTM). With this parameter, the size of a flaw or crack in a structural component can be directly related to the service life of the structure.

In the mid-1950's there was a sudden increase in catastrophic failures of large steam turbine-generators due to brittle fracture. These failures were caused by small flaws in the turbine rotor forgings that were produced in ever increasing sizes since 1950. The immediate problem was solved by the expensive method of more stringent quality control inspection. With the increased understanding of fracture mechanics, however, better material choices and the definition of acceptable flaws have significantly reduced the rejection rate of rotor forgings while maintaining quality standards on still larger turbines. General Electric and Westinghouse used the fracture toughness test and other NASA-developed fracture mechanics technology in their successful programs to eliminate the catastrophic failure of steam turbine-generators. Researchers from both companies have participated with ASTM and Lewis researchers in developing the discipline of fracture mechanics.

NASA contributions to fracture mechanics are also recommended for nuclear power plant components by the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. Since these recommendations are expected to become requirements, most nuclear equipment manufacturers have started using the technology in design and quality control testing applications.

QUALITY ASSURANCE

Since 1960, NASA has made great progress in applying quality assurance to support the development and management of unique space hardware systems. The first NASA-wide quality assurance requirements document for contractors was issued in 1962. This document established a general quality program policy that could be applied to any major development project.

The NASA policy, and many of its requirements, were included in a Defense Department quality assurance requirement which became the basis for the new nuclear power plant licensing regulations that were issued in 1970 by the Atomic Energy Commission. During the 1960's, nuclear plants were small and very conservatively designed. With the advent of complex 1,000 megawatt nuclear plant designs in the late 1960's, the AEC maintained nuclear safety by adopting a generic quality program like the one used for Apollo.

General Electric, under contract to NASA, provided equipment and services to implement the Apollo program quality assurance requirements. GE subsequently introduced its Nuclear Quality Assurance Consulting Service to assist electric utilities in implementing the AEC requirements. This service has been used in the construction of more than a dozen nuclear power plants.

One of the largest electric utilities in North America, Ontario Hydro, is developing its own contractor specifications from NASA quality assurance documents. The utility plans to include requirements such as failure data systems and the use of reliability data in design applications for its equipment manufacturers.

COMPUTER CONTROL

The need for sophisticated computer checkout and control systems in the manned space program caused a broad range of advances in computer systems technology. One of these was the Executive Program for the Apollo Guidance Computer. This program provided near real-time capability by scheduling the jobs performed in the on-board computer. TRW adapted this Executive Program to perform a similar function in the dispatch computer systems that TRW installs for bulk power and oil field production control. Since the 1965 Northeast Blackout, there has been a rapid increase in the use of digital dispatch computers for greater reliability in electric power grids.

Our final example involves a mathematical method for designing control systems. A mathematical technique for solving certain types of equations was developed at Boeing for B-52 control systems. Control designers at General Dynamics read about the technique in a professional paper and incorporated it into a computer program that was used to design the control system for the Atlas-Centaur rocket. These control designers were reassigned to the high temperature gas-cooled reactor development project at General Dynamics. The project became a General Dynamics division, which was later sold to the Gulf Oil Company and renamed. It is now the General Atomic Company, a joint venture by Gulf and the Shell Oil Company. Through all of these corporate changes, the same group of control experts used the computer program they had developed for a rocket to design the control system that is used in gas-cooled reactors.

CONCLUSION

We have focused on the transfer of new technical capabilities from the space program to industrial applications, rather than space hardware. New power-generating equipment designs, based on space hardware such as fuel cells or solar cells, may have a significant impact on the electric power industry someday. Our examples illustrate the kind of technology from the space program which is currently used in the industry.

This distinction between two kinds of space technology, new technical capability and new equipment, is reflected in two different patterns of transfer activity. In both patterns, the goal for a commercial firm is to develop a profitable industrial property with the technology. The differences occur in what roles the technology and corporate management play in this development. For example, a fuel cell is a potential industrial property and the transfer process becomes the management of a product development project. A combustion analysis program, on the other hand, is a potential job skill that an engineer might use in developing a new product or process. Typically, the management role in this type of transfer activity has been passive except in some aerospace firms which developed corporate strategies to redirect employee skills that were acquired in the space program.

Our research has shown that new technical problem-solving capabilities from the space program are being used in a variety of industrial applications to reduce costs, to improve products, and to comply with government regulations. In contrast, we rarely find successful products that were developed from space hardware. These two results indicate that a company will more likely profit from space technology by acquiring new technical capabilities rather than by adapting space hardware.

We have found that nonaerospace companies use four important mechanisms to acquire these technical capabilities: joint ventures or contracts with aerospace firms; hiring ex-aerospace engineers; NASA dissemination programs; and professional engineering societies with members from NASA and nonaerospace industries. Nonaerospace companies with the most success in transferring NASA technology have systematic management procedures to use one or more of these mechanisms.

In conclusion, there are many successful transfers of NASA technology. They typically involve the application of new capabilities to improve industrial products and processes. The transfer process has been planned, managed and integrated into corporate strategies to achieve goals.

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Integrated Utility System Design Concept

Edward L. Hays

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The work that the NASA (National Aeronautics and Space Administration) is conducting in the utility system field has its genesis in the manned space flight program. In each of these programs we put it all together considering electrical power, water supply, heating, ventilation and air conditioning and liquid and solid waste management.

We put it all together for 33 hours in the Mercury Project. We put it all together for 14 days in the Gemini and Apollo Programs. We put it all together for 84 days in the Skylab Program. During the period of time when Mercury, Gemini and Apollo were in the design, development and flight phases we were putting it together, in conceptual design, for one to three years in the Space Station Study Activity. A review of the foregoing as it relates to putting it together in the manned space flight effort where energy and natural resource conservation and environmental quality are of fundamental importance, can be stated as follows.

Mercury, the first manned spacecraft, was designed to operate for 24 to 28 hours. Its utilities, electric power, cooling and drinking water supply, atmospheric oxygen, and contamination control were provided by nonrecoverable consumables, i. e., the power was provided by batteries, the cooling by evaporation of stored water, drinking water was stored as was the breathing oxygen, and the carbon dioxide and odors were controlled by combining with lithium hydroxide and absorption by activated charcoal, respectively; both of which were stored. Waste liquids and solids were stored and returned to earth, as were the expended batteries and lithium hydroxide cannisters. Gemini and Apollo can be considered equivalent regarding their utility and life support systems. Both spacecraft were designed for 14-day missions. In order to reduce the weight of the spacecraft, which determines the performance of the launch vehicle, careful consideration was given to reducing the expendables and consumables in the design of the utility and life support systems. Power was supplied by a hydrogen/oxygen fuel cell which, as a byproduct, produced the drinking water supply in Apollo; cooling was provided by space radiators, a nonconsumable/nonexpendable heat rejection technique; breathing oxygen supply was integrated with the electrical power system oxygen supply; carbon dioxide was controlled

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by lithium hydroxide; liquid waste was dumped; and solid waste was stored. In Skylab, another technological improvement was implemented. The electrical power was provided by solar cells which require no expendable supplies. It should be noted that all of the frequency power supplies were environmentally noncontaminating.

In the Space Station system conceptual design, greater emphasis was placed on reducing expendables, recycling materials and conservation of energy. In the conceptual design of the utility and life support system, power was provided by solar cells, cooling was effected by space radiators, recycled water was used for drinking, breathing oxygen was derived from the water supplies, and carbon dioxide was concentrated and reacted with hydrogen remaining from the water-derived oxygen to produce additional water. Liquid waste was therefore recycled and solid waste was processed to reduce its volume and produce energy. Any residual energy from the power system, solid waste system, etc., was used for other utility purposes such as vehicle heating or increasing the efficiency of other systems, i. e., the efficiency of the water recycle system was increased by using residual heat to enhance the process efficiency.

Table 1 depicts the various space vehicles' utility and life support systems and shows the design trend for reuse, recycle of energy and resource conservation practiced in the total integrated system engineering approach to utility system and life support system design.

It can be seen that the NASA has designed and operated highly efficient utility systems for many years and has been conceiving advanced systems which carefully consider resource conservation and contamination control.

As an exercise in aerospace technology application, in 1971 the NASA prepared a report describing an apartment house design with an on-site power system which recycled residual thermal energy that usually would have been wasted, and used it for heating, cooling and other utility functions. In addition, the apartment featured the incineration of its solid waste and the recovery of the energy from that system. A degree of water recycling was also incorporated into the design. In other words, a zero altitude space station was designed. The result was that in 1972, NASA began working on the MIUS (Modular Integrated Utility System) with HUD (Department of Housing and Urban Development). The MIUS designs feature hardware that can easily be bought; nothing specially designed. Figure 1 characterizes MIUS and its constraints. Figures 2 and 3 depict the conventional method of providing utilities and the MIUS concept, respectively. In conventional practice, the power is generated remote to the using site and the heat energy is rejected to cooling water. In addition, further energy loss is encountered in transmitting the power to the using site. The solid waste is either carried to landfill or incinerated without recovering the heat energy. The liquid waste is collected and processed at a remote site. The potable water is purified at a remote site. In the MIUS, all services are produced "on-site" so to speak. This permits the recovery of heat energy from the power system and the solid waste to be used for other utility functions, i. e., space heating, cooling, water heating or other utility processes such as water purification. The volume of solid waste to be disposed of is greatly reduced since the combustible components are processed for heat energy. The liquid waste is also reduced in quantity since a portion of the "on-site" processed liquid waste is recycled in cooling towers and used in subsurface irrigation. Similarly, this water use reduces the quantity of input water required. Further, the liquid waste from the site is not the classic liquid waste (sewage) but tertiary water.

The MIUS project is sponsored by HUD with the major technical studies being conducted by the NASA JSC and the AEC (Atomic Energy Commission) at Oak Ridge National Laboratory, with cooperation from the U. S. EPA (Environmental Protection Agency), and the NBS (National Bureau of Standards) of the Department of Commerce, the DoD (Department of Defense), the Department of Health, Education and Welfare, and the Office of Coal Research. The NAE (National Academy of Engineering) has established an IUSB (Integrated Utility Systems Board) to provide an independent assessment of the program. The members of this board are senior professionals representing the academic community, research sector, architectural and engineering professions, labor community, local utilities and utility regulatory agencies, local environmental and planning agencies, the investment community, and manufacturing corporations.

The NASA participation in the MIUS program is being provided by the USPO (Urban Systems Project Office) of the Johnson Space Center which was established in 1972. The office includes specialists in power generation, water processing, solid and liquid waste management, heating, ventilation and air conditioning, materials, monitoring and control instrumentation, systems integration engineering, math modeling/computer analysis, thermodynamics, and utility distribution system design. They are supported by professional architects and personnel specializing in economic analyses.

Although each of the NASA engineers assigned to the MIUS team had little experience in civil systems per se, their high degree of training and experience in systems engineering and integration of complex technological systems allowed an accelerated adaptation to their new assignments. A space suit engineer became a water and liquid waste specialist; an expendables analysis engineer became a solid waste management engineer; a structural engineer became the subsystems office manager, a guidance and control system design specialist provides management of the systems engineering office, etc.

This current work consists of two major elements. The first is to conduct integrated design and analyses (conceptual design studies) to investigate the feasibility of the MIUS concept as an alternate method of providing utility services to communities and/or community facilities having advantages over current practices. These advantages could be natural resource conservation, i. e., materials and energy, environmental quality re water and air pollution, land use benefits, i. e., make land available for use that otherwise would not be developed, and economic viability. The second element is to procure and operate, in a testing mode, a large-scale testbed of the MIUS concept in order to evaluate and test those integrated system technical details that do not lend themselves to analysis. These include materials compatibility, process instrumentation and control, predictability of water and air effluents, techniques of heat recovery, method of thermal distribution, etc.

The conceptual design studies conducted to date at JSC demonstrate the application of the MIUS concept to garden apartments, a high-rise office building, a regional shopping center, a high-rise apartment complex, a school, a hospital and a community of 110,000 population. These parametric analyses which were based on detailed point designs have established the sensitivity of application of the unit with respect to to facility type and size and associated environmental effects. The matrix of these design studies are shown in figure 4. In the case of comparing the conventional methods and the MIUS design in providing utility services to a 648 living unit garden-type apartment complex located in the Houston environment, an energy savings of 33 percent can be achieved with the MIUS design as compared to conventional practice. With this saving in energy, a 9 percent reduction in fresh water supply, 48 percent reduction wastewater effluent and 74 percent reduction in solid waste could be achieved. Furthermore, the wastewater effluent would be of a quality which would permit discharge directly to the environment via the storm water management system.

An energy savings of 23 percent and 36 percent respectively, was realized when a similar analysis was performed on a 730,000 square foot shopping center and a 12-story high-use apartment complex located in the Houston environment.

When the analysis was performed on a conceptually designed new city of 110,000 population, the energy savings was 38 percent, fresh water supply was reduced by 17.5 percent, wastewater effluent volume was reduced by 27.1 percent and the solid waste volume for ultimate land placement was reduced by 80 percent by the use of the modular integrated design system technology. Needless to say, the application of total system design concepts and and analysis, so familiar in aerospace engineering, is applicable and adaptable to this type of facility and community design and results in measurable benefits. These analytical studies should have a very measurable impact on energy and natural resource utilization, environmental quality, land use, and fundamental community design strategy.

The large scale testbed, which is the second element in the HUD NASA program, supports the analytical studies. A contract was awarded to the Hamilton Standard Division of United Aircraft Corporation early in 1973 to design and construct the testbed integrated utility system. It is called the MIST (MIUS Integration and Subsystems Test) laboratory. The facility was completed in April 1974 and is currently producing test data. In the MIST, electrical power is generated by a diesel-electric generator and the engine's waste heat is recovered for use in the heating and air conditioning and sewage treatment processes. A conventional incinerator, which meets all EPA standards, is used to burn trash and other solid wastes including sewage sludge. Here also, the waste heat is recovered for use elsewhere in the system. Air conditioning equipment is a combination of mechanical and absorption chillers and heating is a conventional hot water system. Hot and cold thermal storage tanks are also provided to improve system efficiency. Sewage treatment is accomplished in a multistep process which includes filtration, physical chemical, reverse osmosis and chlorination. The purified water is then used in the cooling tower or returned to the environment. The MIST laboratory is designed in such a manner that alternate advanced subsystems can be installed and evaluated. Examples of this are as follows: the incinerator can be replaced with a pyrolysis module; the diesel engine can be replaced by a fuel cell or supplemented with a bottoming cycle turbine; components of the heating, ventilation and air conditioning functions can be replaced by heat pumps; different concept liquid waste process equipment can be used rather than the currently installed concepts, etc.

It is believed that the Urban Systems Project Office is a unique technical capability within the NASA which can be utilized to assess technical approaches to compelling national problems associated with energy, environment and natural resource conservation. The USPO group is highly trained in the systems and their subelements due to their previous background in "total" engineering of manned spaceflight systems. This capability, as well as architectural and economic credibility, we bring to bear on current "earth people" problems. The total integrated system design and analysis permits the assessment of presently available and advanced technological concepts and provides quantitative data to permit the proper focus of technology development programs and to more intelligently select the most beneficial and viable alternate concepts to implement into the socio-economic "real" world.

Figure 1

NASA/HUD MODULAR INTEGRATED UTILITY SYSTEM

CURRENT DESIGN APPROACH

- INTEGRATION OF
  - ELECTRICAL POWER GENERATION
  - WATER PROCESSING
  - SOLID AND LIQUID WASTE MANAGEMENT
  - ENVIRONMENTAL CONDITIONING
- UTILIZATION OF RESIDUAL ENERGY FOR UTILITY FUNCTIONS
- INCORPORATION OF ONLY PRODUCTION HARDWARE ITEMS IN DESIGNS
- NO BUILDING SYSTEM CHANGES

Figure 2

CONVENTIONAL UTILITY SERVICES

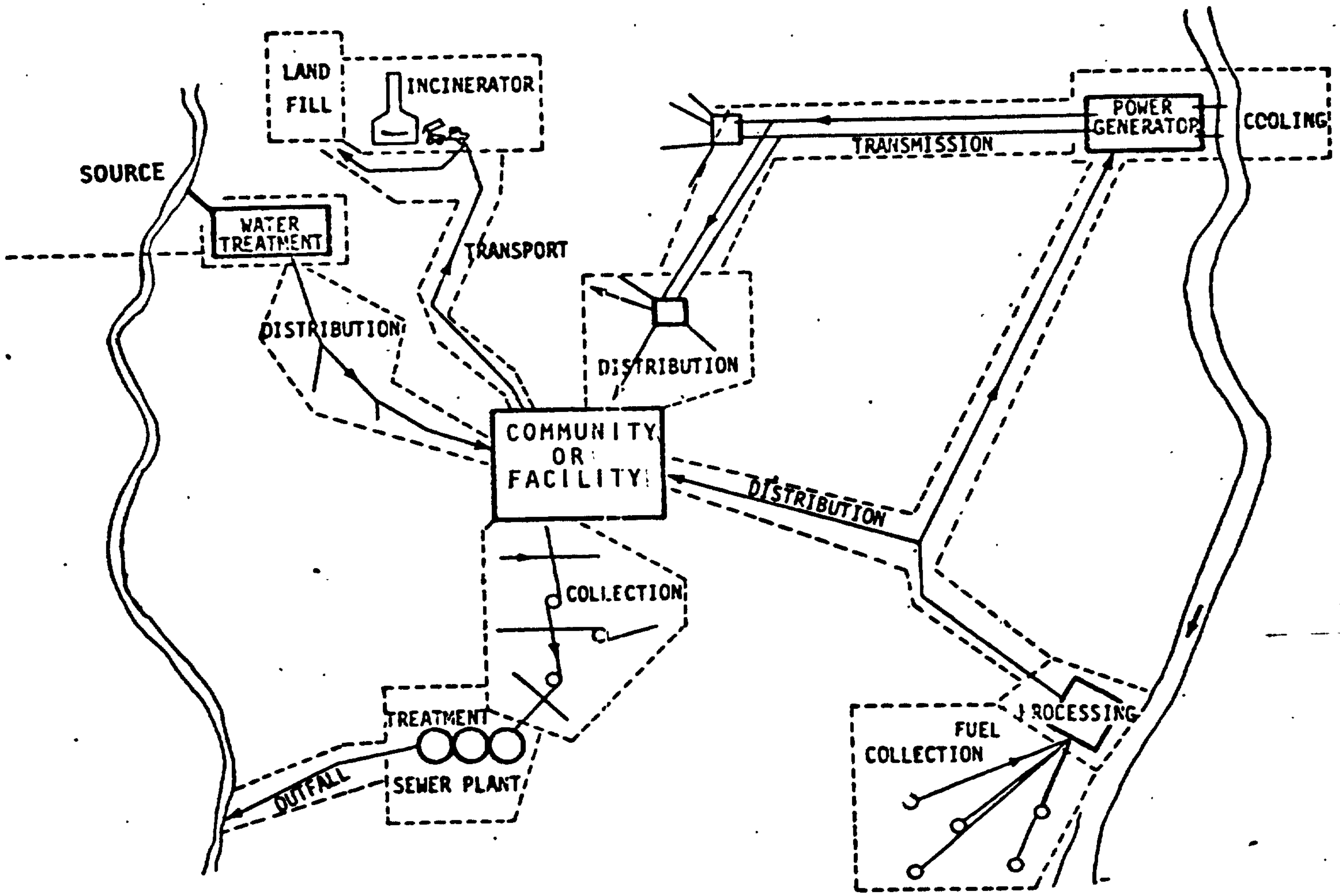
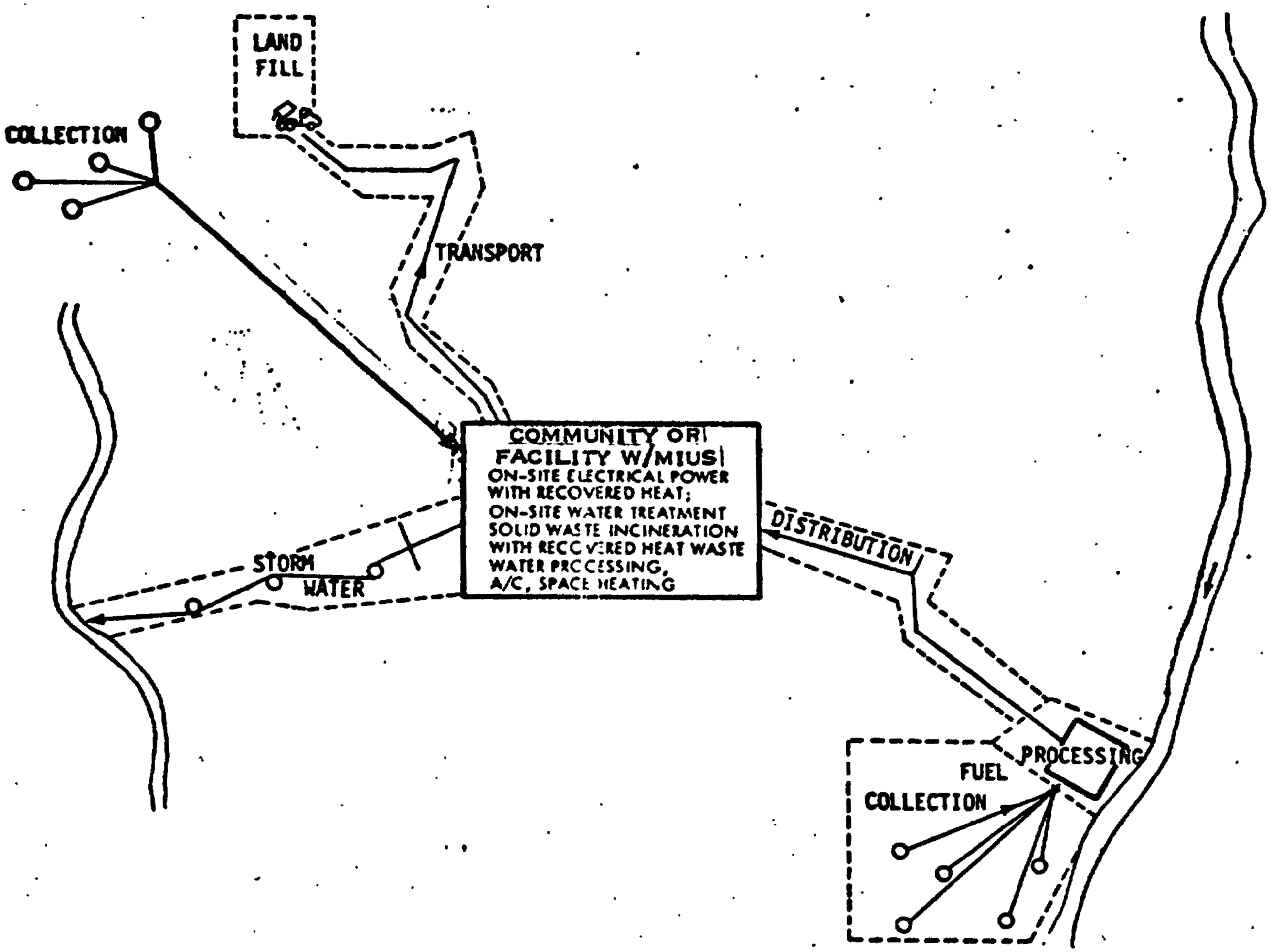


Figure 3

MIUS MODEL SERVICES



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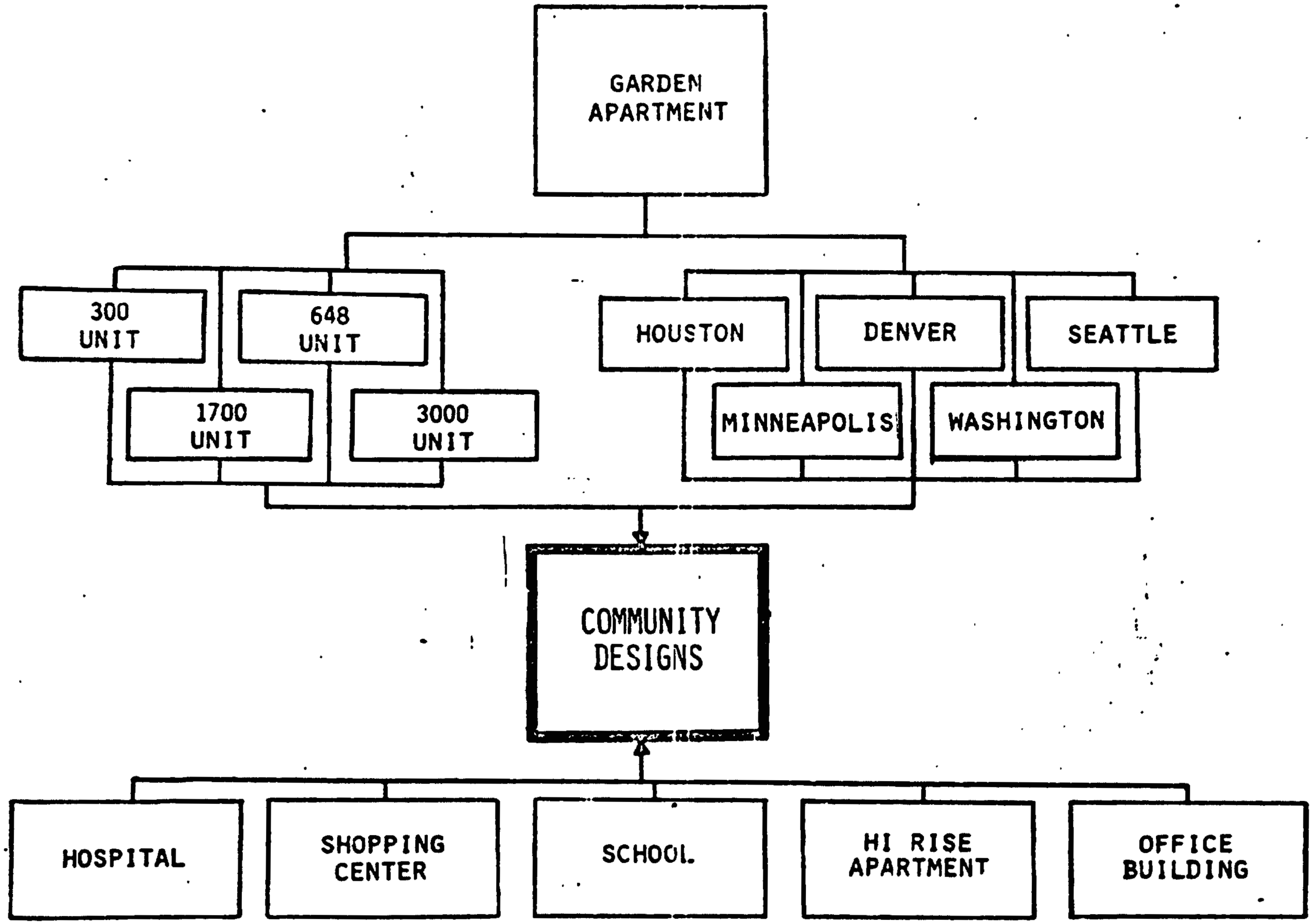
MIUS CONCEPTUAL DESIGN STUDIES



MANNED SPACEFLIGHT UTILITY SYSTEMS

Function	Manned Spaceflight Systems			
	Mercury	Gemini/Apollo	Skylab	Space Station*
Power	Batteries	H_2/O_2 Fuel Cell	Solar Cells	Solar Cells
Cooling	Evaporation of Water	Radiators + Evaporation of Water	Radiators + Evaporation of Water	Radiators
H_2O	Stored	Fuel Cell Product	Stored	Recycled
Contamination (CO_2)	Combined in Lithium Hydroxide	Combined in Lithium Hydroxide	Collected and Dumped	Recycled
Solid Waste	Stored	Stored	Stored	Energy Source
Liquid Waste	Stored	Dumped	Dumped	Recycled
Food	Stored	Stored	Stored	Stored

*Residual or wasted heat energy was to be used for other utility functions prior to dumping at a lower energy level.

Table 1

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THE MIST (MIUS INTEGRATION AND SUBSYSTEMS TEST) LABORATORY: A TESTBED FOR THE MIUS (MODULAR INTEGRATED UTILITY SYSTEM) PROGRAM

W. S. Beckham, Jr.
F. A. Keune

ABSTRACT

The MIUS program being conducted by NASA JSC is sponsored by the Department of Housing and Urban Development to develop an economically feasible integrated utility system. The MIUS concept integrates utility services in order to achieve resource, energy and environmental benefits. The NASA's role in the program is to conduct design studies to determine the feasibility of MIUS as a viable and acceptable alternate to utility service provisioning.

Toward this end, the NASA Urban Systems Project Office at JSC awarded a contract to the Hamilton Standard Division of United Aircraft Corporation, in mid 1973 to design and construct a testbed integrated utility system called the MIST laboratory. The facility was completed early in 1974 and has begun a long-term program to develop data for MIUS. A description of the MIST is presented and the critical design issues which can only be verified by test, are discussed in detail.

INTRODUCTION

In a multiple-agency program to provide the essential utility services in a new or renewal community in an improved manner with advantages in increasing the efficiency in use of energy and other natural resources, in decreasing the total impact of the community on the environment and in reducing total costs, a major project has been initiated by the U. S. Department of Housing and Urban Development to develop a MIUS (Modular Integrated Utility System). In this system it is proposed to integrate the essential community utility services for the production of electric power, space heating and cooling, potable water, and the processing of liquid (sewage) and solid (garbage and refuse) waste for maximum use in production of water, electric power, and space heating and cooling. Energy conservation is achieved in this system through the optimum transfer of energy between all basic functions within the integrated plant. The MIUS can be located near appropriate users to minimize the utility service distribution infra-structure costs which are traded against economics of scale. In addition, the approach maximizes the potential of factory assembly thereby reducing the time from planning to the delivery of services. The MIUS plant can be designed to operate independently of all existing facilities or may be grid connected to a regional power system.

The MIUS project is sponsored by HUD with the major technical studies being conducted by the National Aeronautics and Space Administration (Johnson Space Center) and the AEC (Atomic Energy Commission) at Oak Ridge National Laboratory, with cooperation from the U. S. EPA (Environmental Protection Agency), and the NBS (National Bureau of Standards) of the Department of Commerce. More recently, the DOD (Department of Defense) and the HEW (Department of Health, Education and Welfare) joined the MIUS team. The NAE (National Academy of Engineering) has established an IUSB (Integrated Utility Systems Board) to provide an independent assessment of the program. The members of this board are senior professionals representing the academic professions, labor community, local utilities, the investment community, and manufacturing corporations.

What MIUS does is to "recycle" energy by "packaging" into one processing plant all of the five utility services necessary for community development:

a. Electricity
b. Space heating and air conditioning
c. Solid waste processing
d. Liquid waste processing
e. Residential water purification

Conventional methods of generating electricity do not utilize about 65 percent of the energy input for power generation. However, this energy appears in the cycle as "excess" heat, normally rejected to water as a thermal pollutant. MIUS recovers better than half of this rejected energy and uses it for space heating, air conditioning, water heating, water treatment, and liquid waste treatment. An additional 5-10 percent fuel savings is made by processing the combustible solid waste for its energy content.

Therefore, in addition to saving energy, the MIUS concept minimizes the adverse environmental impact by reducing thermal pollution from the energy of electricity, air pollution from fuel combustion, water pollution from sewage, and land pollution from solid waste disposal.

In support of the MIUS program analytical design studies, it was decided to design and construct an integrated utility system testbed called the MIST (MIUS Integration and Subsystem Test) Laboratory. A contract was awarded to the Hamilton Standard Division of United Aircraft Corporation to design and construct the unit. Design competition occurred in June 1973. The facility was completed in April 1974 at the NASA JSC in Houston, Texas.

The current MIST configuration is composed completely of off-the-shelf hardware. The system has been designed, however, to allow incorporation of advanced component units with minimum rework.

OBJECTIVES

The primary objectives of the MIUS program are threefold:

a. To resolve key MIUS subsystem design issues.

b. To provide data for calibration and verification of analytical computer design models used in MIUS analysis and design activities.

c. To provide a flexible testbed for evaluation of future design concepts and hardware units as well as alternate modes of operation.

The systems description section reflects the various operating modes. Key issues of MIUS designs to be investigated in the initial series of tests follow the description.

MIST SYSTEM DESCRIPTION

The initial MIST unit, composed entirely of items of commerce; i.e., off-the-shelf hardware, consists of five subsystems. Figure 1 is a model of the system as it is presently configured. The power generation subsystem's central unit is a 230 KW diesel engine-generator which provides electrical power to run the internal load for MIUS simulation. Heat recovery loops from the engine jacket, oil cooler and exhaust heat exchangers provide three levels of thermal energy for use internally and for external loads. A heating and air conditioning subsystem, which includes a 25-ton absorption and a 23-1/2-ton centrifugal compression water chiller, is tied to the thermal loops from the power generation subsystem and uses the available electrical and thermal energy to provide environmental conditioning to an external load. The subsystem also includes hot and cold thermal storage capability. A solid waste management subsystem, featuring a 70-lb/hr (100-lb/hr maximum) incinerator with waste heat recovery equipment, serves to dispose of solid waste and sludge from the wastewater treatment subsystem and can be used as a thermal topping device for balance of the thermal circuits. A wastewater subsystem processes effluent waste and directs sludge to the solid waste management subsystem while returning water, which approaches potable quality for cooling tower makeup or to the environment. Principal elements in this subsystem include physical/chemical treatment units, biological waste treatment, reverse osmosis units and disinfection equipment. These subsystems are controlled and monitored by an instrumentation and controls subsystem which provides automatic sensing and/or control of energy utilization within the system, optimization of operator requirements and insurance of a minimum level of services to user functions of the MIST unit. Detailed descriptions of the subsystems follow. Table 1 lists the manufacturers of the presently installed hardware elements.

Power Generation Subsystem

The power generation subsystem generates, conditions, regulates, and controls electrical power for the simulated and internal loads of the MIST. The power generation subsystem consists of a diesel engine-generator set with waste heat recovery units on the engine exhaust stack, the engine lubrication oil, and engine water jacket loops. The characteristics of the MIST diesel engine-generator set is as follows:

a. Peak Demand	230 KW
b. Voltage	480 VAC-3 Phase
c. Frequency	60 HERTZ
d. Power Factor	0.8 Min
e. Regulation	Voltage: ± 1%
	Frequency: ± .5%

To enable the evaluation of alternate operating modes, the unit is configured such that it can be cooled in a forced-water circulation mode, or in an ebullient cooled mode. Appropriate heat recovery units are installed in each of the cooling loops to allow for the reclamation and use of the thermal energy.

Thermal energy is recovered at 130 deg F., 216,000 BTU/Hr off the oil/aftercooler; at 180 deg., or 220 deg F., 558,000 BTU/Hr off the engine jacket; and at 250 deg F., 666,000 BTU/Hr off the exhaust.

HVAC (Heating, Ventilation and Air Conditioning) Subsystem

The HVAC subsystem provides heating and cooling to the using facility. It has the capability to store and utilize thermal energy recovered from the power generation subsystem and the incinerator.

Cooling is provided by means of chilled water produced by a 25-ton absorption unit driven by 15 psig steam and 23.5-ton compressive unit. The base load is satisfied by the absorption machine and peak demands by the 5-step compressive unit. The cooling loop is equipped with a 2600-gallon cold storage tank capable of storing 288,000 BTU. To evaluate multiple modes of operation, the system can switch the storage tank to either the upstream or downstream side of the chillers. In this fashion, load on the chillers can be minimized under all operating conditions, and the ΔT recovery range of the storage range of the storage tank expanded. Chilled water delivery to the user is controlled to 44 $\pm$ 2 deg F. Total cooling capacity of the system ranges up to 48.5 tons.

Steam and/or hot water recovered through heat exchangers interfacing with the engine and incinerator is used to satisfy a 500,000 BTU/Hr space heating requirement, plus the domestic hot water demands of the using facility. In addition, thermal energy is used to enhance the operation of the wastewater treatment plant. The heating circuit contains a hot thermal storage tank of 2600 gallons, capable of storing 1,220,000 BTU.

The inclusion of thermal storage tanks in the system allows a closer matching of the load-demand profiles imposed on the various subsystems by a using facility. This will result in a reduction in energy input requirements, thermal energy wasted to the environment, and equipment size to meet a particular requirement.

A 175-ton capacity wet-cooling tower is provided to meet equipment operating limits and to allow portions of the system to be operated independently of one another for test flexibility.

Wastewater Management Subsystem

The wastewater management subsystem can process up to 7000 gallons per day of municipal sewage and subsystems blowdown water. The effluents are purified water and sludge. The sludge is used as a supplemental fuel for the incinerator. The effluent water is intended to have a quality that approaches potable water, but is used only as subsystems makeup water.

Principal elements of the subsystem include a physical/chemical treatment plant, a biological treatment plant and a reverse osmosis unit. For test purposes, the units are interconnected so that they can be used to process the waste stream individually or in any combination.

The subsystem has heat exchanges interfaced with the thermal loops so that the effects of various controllable temperature levels can be evaluated.

The output stream, of essentially potable quality, can be sterilized by chemical and/or thermal means.

Solid Waste Management Subsystem

The solid waste management subsystem consists of an incinerator, with its loader equipment, which burns solid waste and sludge, producing thermal energy which is exhausted out the stack through the HRU to produce steam. The incinerator capabilities are:

Solid Waste:
- Refuse: 300 lb/day of type 2 trash
- Sludge: 125 lb/day of 2-20 percent solids sewage sludge

Burn Rate:
- Design Point: 70 lb/hr
- Maximum: 100 lb/hr

The loader is a hydraulic ram which injects a premeasured load into the incinerator on command.

At full load, 350,000 BTU/Hr. of thermal energy in the form of 15 psig steam can be recovered for use in the thermal loop.

Control and Monitoring Subsystem

The operational control monitoring subsystem controls and monitors the various subsystems functions continuously. The system displays to the operator 33 temperature and 12 pressure measurements critical to system operation. It also displays and provides central control for electrical parameters, valve positions, and conductivity readings.

In addition to the operational instrumentation, an extensive R&D instrumentation capability has been overlaid on the system. The measurements include 42 temperature, 41 flow, 33 pressure and 5 level sensors. This instrumentation, in addition to the temperature and pressure sensors in the operational system, if fed directly to a magnetic data tape system for recording. The operator can call up for display, in analog form, any of these measurements for realtime evaluation.

KEY DESIGN ISSUES

Thermal Integration and Distribution Techniques

MIUS efficiencies are dependent on the maximum utilization of excess thermal energy. Therefore, any cost effective technique which enhances the recovery and ultimate use of waste heat aids in the ultimate improvement of the MIUS operating efficiency.

Thermal integration of MIUS subsystems requires that five thermal entities; normally, the prime mover--incinerator heat loop, cooling load loop, heating load, loop, heat rejection loop, and the WMS (Wastewater Management Subsystem) thermal loop, be operated as an integrated thermodynamic system. The use of hot and cold thermal storage, variable incinerator burn schedules, and the reclamation of low grade heat to process and heat water are primary techniques affecting efficiency of the MIUS operations. Because of the cyclic load conditions of each subsystem, their thermal characteristics must be examined for hourly, daily, and seasonal variations. Thermal balance between multiple heat loads and heat sources requires that functional characteristics of the MIUS equipment and their interfaces by analyzed under operational conditions to determine the maximum energy savings. The selected MIST thermal exchange equipment, being off-the-shelf hardware with many hours of proven operating time and reliability, must perform over the full range of load conditions in accordance with a predictable set of parameters.

The data required to determine the effectiveness of the thermal integration include:

a. Thermal energy available from the prime mover and incinerator.

b. Energy utilization and efficiency of cooling and heating.

c. Thermal energy transfer and efficiency of transfer equipment between various subsystems.

d. Thermal energy available during off-peak periods for storage and utilization during subsequent peak time.

e. Heat rejection to the environment.

The test article is instrumented to measure interfacial transfer of thermal energy between subsystems. Transfer media flow rates, temperature, and pressure for both inlet and outlet points at all interchanges and condensers are measured.

The data required to measure and assess the distribution heat gains and losses, as well as the power required to transport thermal energy, include:

a. Quantity and quality of thermal energy from the prime mover and incinerator.
b. Measure of condensate-generate and makeup rec[illegible]d in steam systems.
c. Heat loss/gain in distribution networks.
d. Power required for subsystem and system distribution and heat rejection.

Instrumentation is provided for measuring the distribution parameters of flow rates, pressures and pressure drops, temperatures and temperature changes, and pump power for steam and condensate lines, and all fluid distribution lines where thermal energy is transported and transferred.

Thermal Storage

The MIUS attempts to even out the periods of thermal energy imbalance between subsystems through the use of hot and cold thermal storage. The efficient collection and storage of thermal energy at off-peak periods for utilization during peak periods as a supplementary energy source to optimize the energy savings is a prime issue.

Multiple arrangements have been made to test storage charging and discharging, as well as storage location, upstream and downstream, of the absorption and compression chillers. Modulation of usage for chilled water and stored cold water shall be studied. Generation of chilled water for storage during off-peak hours for utilization during the subsequent peak periods will be studied to determine "peak shaving" capability. Collection and storage of hot water for heating will be made in conjunction with peak electrical loading for use during low electrical load and high heat demand. The incinerator will operate to supplement additional high grade heat requirements. Incinerator load following will be investigated. Charging and usage rates of the thermal energy tanks will be determined. Instrumentation measurements shall be made to determine the inlet and outlet temperatures, modulated flow rates, tank pressures, and capacities of the thermal energy tanks.

Mixed Mode Air Conditioning

Energy savings resulting from the combined use of absorption and compression chillers, where the absorption device carries the base load commensurate with the available high grade heat from the prime mover and incinerator, is a key MIUS issue.

Performance and operational data is needed to define optimum variable and supplementary combinations of chiller outputs. Additional information is needed to verify alternate methods of using hot and cold thermal storage in a combination absorption/compression chiller system. Data required to evaluate mixed mode air conditioning include: (1) Startup and shutdown operational parameters, (2) individual chiller coefficients of performance, and (3) combined chiller coefficients of performance.

Integration of Subsystems Controls and Displays

Since MIUS will utilize waste products of one or more subsystem (water, heat, sludge for fuel, etc.) as a primary input for another subsystem, this interdependency must be carefully controlled. The control of one subsystem process must be governed not only by the loads to be met by that process, but also by the other processes which provide the energy input. A unit may not have the luxury of shutting itself off when loads decrease below its maximum efficiency if its product is required by another subsystem. A modulation of the various subsystems will achieve an overall optimum level of operation which most effectively utilizes available energy.

The evaluation of the MIST, with respect to the operational levels of the individual units, must be accomplished such that the relationships between units can be optimized. A thorough engineering analysis of the MIST will provide these data.

At present the MIST control and monitoring equipment has a limited capability. Cost factors forced the selection of some manually operated valves and switches in the control application of the integrated subsystems. An effort to develop and describe the manual manipulations for optimum performance will be implemented. From this baseline a simulation effort can then be initiated utilizing available analytical programs. The definition of the hardware modifications to incorporate more of the automatic operations into the testbed will then be provided.

The MIST comprises several subsystems which are to be operated as an integrated unit. The display of control and monitoring information for any one of such subsystems is quite conventional as in oil, chemical, and utilities installations. However, since the MIST the parameters of one subsystem directly influences another, the information must be easily related through the displays. Groupings of related parameters in various process loops is limited in the MIST. However, a MIST installation will require such an arrangement of monitoring displays. This would allow the operator to scan a given segment of the control panel to determine status of a process. The evaluation and testing of the MIST will provide the experience in dealing with the various thermal, electrical and water treatment loops that is necessary to associate the parameters in mor easily recognized formats.

The evaluation testing of the MIST will provide the required display requirements data. These data will be largely the results of ideas for improving operations and the display relations over that which has been implemented on the MIST. New proposals and innovative techniques will be the most significant outcome of this evaluation.

Incinerator Performance Evaluation

Small, high performance, non-polluting incinerators with heat recovery capability are presently low production items. As a result, very little thermal performance and operational data exists that can be directly applied to MIUS designs. Specific subsystem-level data needed include:

a. Incinerator heat recovery efficiency.
b. Design and operational improvements to optimize efficiency.
c. Feasibility of refuse and sludge disposal in one incinerator.
d. Identification of performance with various mixtures of sludge and refuse.

System-level considerations involve determination and evaluation of incinerator performance where the incinerator is required to burn solid waste and supply steam according to preselected hourly profiles. In this case, the interfaces with other MIUS and facility load elements are extremely important. For example, the type and quantity of solid waste will influence heat production/recovery. Also, the thermal demand profile as dictated by facility type, will determine burn duration times, incinerator conditioning requirem ..ts, and quality of steam produced. In addition, the system level requirements (solid waste constituents, burn times, fuel input) that will have a direct bearing on incinerator exhaust gas emissions characteristics, is a key design issue for MIUS.

Instrumentation is provided to permit measurement of exhaust gas temperatures and flow rates, combustion air properties, boiler feed water temperatures, and incinerator fuel oil flow rate. Laboratory calorimetric analysis of input refuse, sludge and ash will be performed.

MIUS Effluent Characteristics

MIUS effluents consist of prime mover exhaust emissions, solid waste process byproducts and exhaust emissions, water supply, and wastewater treatment system effluents and unusable waste heat from prime movers and environmental conditioning systems.

A MIUS prime mover (e. g., gas turbine, diesel, or gas engine) will typically use fossil fuels (natural gas, fuel oil, coal) as the prime energy source and air as the oxidizer. Exhaust emissions of concern from such engines consist of unburned hydrocarbons, nitrogen oxides, sulfur oxides, carbon monoxide, and particulates. Because of government emission standards, engine exhaust constituents are an engine selection criteria and, therefore, a system design issue. The test article therefore includes a representative MIUS prime mover and provisions for sampling engine exhaust emissions.

A MIUS incinerator will typically burn solid waste and dewatered wastewater sludge. Elements of the exhaust emission of interest are particulates, hydrogen chloride, nitrogen oxides, and heavy metals. Current federal emission standards for incinerators specify particulate emission criteria only. Operation with acceptance environmental effects is an important MIUS consideration.

The MIUS wastewater treatment system will typically process a combination of domestic wastewater and cooling tower blowdown water. The system will utilize a combination of biological and physical/chemical processes in the purification scheme. Although no federal standards exist, Public Law 92-500 defines a national goal of the elimination of the discharge of water-carried pollutants into navigable waters by 1985. Wastewater effluent is controlled, however, by various state and local regulations which vary greatly from one area to another. In general, these regulations may control the amount of oxygen demand, nutrient, bacteria, and heavy metals which can be contained in the treated discharge. The MIUS discharge should be equal or superior to any discharge standard now used in the United States.

Closed-loop cooling tower systems have been operated successfully, as have open-loop cooling towers utilizing wastewater. The following information is required to evaluate system performance:

a. Power requirements
b. Cooling tower water quality requirements
c. Cooling tower additive requirements
d. Reverse osmosis brine quantity
e. Reverse osmosis brine disposal problems
f. Reverse osmosis concentration factors

The equipment is designed and instrumented to make the following measurements and samplings:

a. Power consumption and demand
b. Chemical additive quantity
c. Water flow rates
d. Water pressures
e. Conductivity
f. Chemical analysis

Very little work has been done in the past to investigate the advantages and disadvantages of heat utilization in the various water treatment processes. In the MIUS, waste heat is available and since the indications are that heat will improve most treatment processes, the MIST will address the use of heat for process improvement from wastewater temperature stabilization to disinfection. The required information in this area includes:

a. Disinfection potential
b. Heat quantities requirements at various differential temperatures
c. Process efficiency variation at different temperatures
d. Potential for heat drying of reverse osmosis brine and sludge

The system is instrumented to determine system thermal balance, temperatures and temperature differentials, and water flow rates. Also treated wastewater samples are taken and laboratory analysis is performed to determine the effects of thermal conditioning.

Nowhere have the processes proposed for MIUS beer utilized as a system to provide complete wastewater treatment wi h a mixed domestic and cooling tower blowdown water as the effluent and utilization of treated water as tower supply. Interface problems will be identified and studied prior to MIUS final design and minimum cost operation techniques will be established. Data and operations information to be developed include:

a. Individual process familiarization
b. Individual process operation optimization
c. Identification of process interface problems
d. Coordination of individual process flow rates
e. Evaluation of synergistic effects of multiple process treatment

Because this is a process interface test program, types of test information will include:

a. Water flow
b. Sludge volume
c. Temperature and temperature differentials
d. Disinfection completeness
e. Total chemical analysis at various points
f. Power consumption
g. Dissolved solids balance

Odor Control

A key issue in any industrial facility which interfaces with the general public is that of odor control. No level of engineering efficiency or cost effectiveness will gain public acceptance if the plant is offensive to its neighbors. Great emphasis will be placed on the development of techniques which will control the odors typically associated with engine emissions, wastewater, and solid waste treatment plants.

CONCLUSION

The initial series of tests, designed to answer the key issues previously delineated, is scheduled for the period of April through October 1974. It is planned subsequently to retrofit the unit and investigate various other promising modes of operation and hardware elements. This phase of testing is expected to continue through the first quarter of 1975. At that time, prototype hardware developed under separate activities sponsored by various government and industry groups is expected to come on line. The MIST is envisioned as an on-going laboratory test facility where innovative concepts and hardware can be tested and evaluated in a total systems application prior to commitment to full-scale deployment. All data developed in these tests will be made available to interested parties.

As the testing agency for the multiagency HUD-sponsored MIUS program, the Urban Systems Project Office of NASA JSC looks forward to working with the industry in developing technology in this field.

TABLE I

EQUIPMENT AND MANUFACTURER

Physical Chemical Treatment	MET PRO
Pumps	AURORA, MOYNO
Heat Exchangers	AMERICAN STANDARD
Reverse Osmosis	ENVIREX
Biological Treatment Plant	AUTOTROL
Incinerator	CLEAN-AIR-ATOR
Absorption Chiller	ARKLA
Compression Chiller	CARRIER
Cooling Tower	MARLEY
Thermal Storage Tanks	ADAMSON
Power Generation	CATERPILLAR
Exhaust Silencer	ENGINEERING CONTROLS
Control Valves	HONEYWELL

N75 17200

ENERGY RECOVERY FROM SOLID WASTE

Charles Dalton

C. J. Huang

Solid waste can be an asset from several different points of view. Recycling and energy recovery are attractive possibilities with both the increased raw material costs and the energy crisis causing concern for natural resources. Landfilling can remain a viable option for only a limited time.

A recent group study on the problem of solid-waste disposal provided a decision-making model for a community to use a determining the future for its solid waste. The model is a combination of the following factors: technology, legal, social, political, economic and environmental.

An assessment of local or community needs determines what form of energy recovery is desirable. A market for low-pressure steam or hot water would direct a community to recover energy from solid waste by incineration to generate steam. A fuel gas could be produced by a process known as pyrolysis if there is a local market for a low heating-value gaseous fuel. Solid waste can also be used directly as a fuel supplemental to coal in a steam generator. An evaluation of these various processes is made.

An example is given for Houston in the event that landfilling becomes unacceptable for any reason.

INTRODUCTION

Solid-waste management is usually considered to be divided into two major categories: (1) collection, including handling, storage, transport and transfer; and (2) disposal, including any accompanying treatment. Eighty percent of the solid waste management funds spent publicly goes for collection, the remainder going for disposal. Depending on whose figures you believe, the average U. S. citizen produces between 1.5 and 5 pounds of solid waste daily. The cost of both collection and disposal has been increasing along with everything else. In the decade of the 60's, the average amount (over the U. S.) of normal household solid waste increased by about 20%. During the same decade, cost of collection increased by about 25% and cost of disposal increased by about 75%.

The most popular method of rural disposal has been open dumping and burning. Urban disposal requires a more sanitary disposal technique; therefore, landfill has become the accepted urban technique for disposal. Several factors are currently influencing the thinking in connection with these traditional disposal techniques. These factors include the rising cost of disposal, the unacceptability of open dumping and burning. the unavailability of land for landfill, current shortages and rising costs of raw materials, and the energy shortage.

RECYCLING

After a few comments on recovery of usable materials, the remainder of this paper will focus on energy recovery from solid waste as a means to simplify the disposal problem. Recycling has become of major interest recently for at least two reasons: First, disposal is simplified if discarded materials are recycled and, second, production costs are often significantly lower if recycled materials are used in place of virgin materials. For example, production of aluminum from recycled stock requires about 5% of the energy used to produce the same amount of virgin aluminum. Recent export tax increases on bauxite by producing countries also make aluminum recycling more attractive.

Approximately 50% by weight (70% by volume) of all municipal solid waste is paper or paper products. This large amount of waste paper has significant potential in the recycling market. However, there are many economic factors at work in regard to the recycling of paper (see Hagerty, et al (1), p. 58). The opportunities exist but the disadvantages of recycling paper sometimes dominate the decisions.

Significant amounts of ferrous metals are recovered and recycled with relatively little effort. Other materials which have the potential for recycle, but not without some disadvantages, are glass and plastics.

A DECISION MAKING MODEL

Sanitary landfill, as stated earlier, cannot continue to be the most economic and viable means of solid-waste disposal. In the event that a community must look to alternate methods of disposal, a systems-engineering model has been proposed by van Poolen (2) to aid in the overall evaluation process. The model is shown in Figure 1. Identification of the various parameters indicated in the Figure will guide the community in recognizing its viable options in dealing with solid waste.

Riesco and Chang (2) have developed a decision-making model to aid the community in ob[illegible]aining an evaluation of the various options an[illegible] [illegible]esses available. This decision-making model a[illegible] (partially) subjective decision to be reached by [illegible]unity; it gives meaningful input to those invo[illegible]n making the final decision. This decision-making model is shown in Figure 2.

ENERGY RECOVERY FROM SOLID WASTE

Energy recovery from solid wastes can be accomplished in several different ways. The most important of these are thermal oxidation processes and biodegradation. Thermal oxidation includes incineration with and without heat recovery, pyrolysis, and solid waste burned with coal in a steam generator. Biodegradation can be defined as the reduction of refuse by the use of organic methods. The biodegradation processes can be divided into three broad areas, (1) aerobic, (2) anaerobic, and (3) biochemical conversion. Composting is an aerobic process. An example of an anaerobic process is methane production as currently practiced by the U. S. Navy at the China Lake, CA, laboratory. Biochemical processes convert cellulose to, for example, glucose as done by the U. S. Army at the Natick, MA, laboratory.

Incineration is a disposal method of long standing, usually without heat recovery. However, incinerators are not without their problems as any observer, or nearby resident, knows. Incinerators are famous for their pollutants and operating difficulties. Modern-day incinerators, such as in Montreal, Saugus (Mass.), and Chicago, have the capability of heat recovery by means of steam generation. Schulz, et al, (3) and Jackson (4) discuss these incinerators. Even though heat recovery presents a decided advantage over older incinerators, most of the new incinerators have certain disadvantages. (see Schulz, et al (3) p. I-7). These incinerators generally require some shredding, and they produce a residue which amounts to 20 to 25% by weight of the original solid waste. This residue requires a landfill for disposal. The recent incinerators produce nitrogen oxides in their stack emissions and they typically recover heat in the form of steam which must be used as generated. Schulz also notes that incinerators, even with heat recovery, have an unfavorable cost comparison and are deemed to be noncompetitive in comparison with pyrolysis units.

Pyrolysis is a process which has a relatively recent application to the disposal of solid waste. Pyrolysis can be defined as thermal decomposition in the absence of enough oxygen to provide complete combustion. There are about twenty-five pyrolysis processes which have been proposed for use in solid-waste disposal. They are all described as one of three basic types as shown in Figure 3.

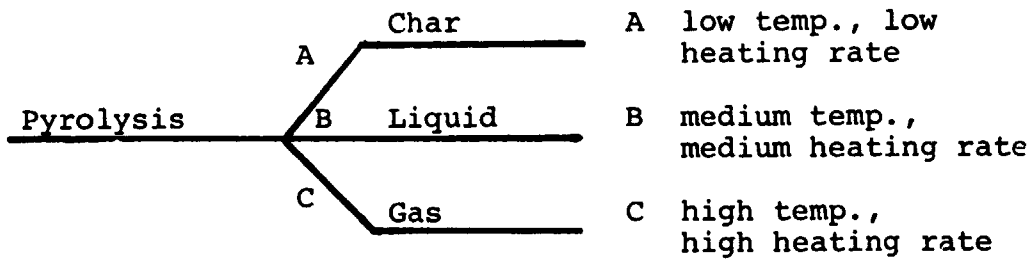

Figure 3

Garrett has a process of type B which produces a liquid fuel. Monsanto, Devco, Union Carbide and West Virginia University have processes of type C which produce a gaseous fuel. Garrett is currently building a plant (to operate at approximately 900 degrees F) at San Diego. Monsanto and Devco have current construction of pyrolysis plants in Baltimore (at approximately 1400 degrees F) and Brooklyn respectively. Union Carbide has built a 200 ton per day demonstration plant (to operate at approximately 3000 degrees F) at Charleston, West Virginia. The West Virginia University process, conceived by Professor R. C. Bailie, is still developmental but seems to have a good potential.

The advantages of pyrolyzing solid waste are numerous. A pyrolysis plant produces a relatively clean fuel, is not necessarily close to a power plant and is independent of the utility industry. Pyrolysis typically produces a high volume reduction (95% or greater) and has very little land, air, or water pollution. A variety of products such as pipeline gas, methanol, synthetic gasoline, etc., can be produced by means of pyrolysis.

The gaseous fuel produced by high temperature pyrolysis has a relatively low heating value. The Monsanto process gas has a heating value of about 120 Btu/scf with the Union Carbide process gas at about 300 Btu/scf and with the West Virginia University process gas at about 450 Btu/scf. These compare to about 1000 Btu/scf for methane.

The liquid fuel produced by medium temperature pyrolysis is both corrosive and very viscous (see Schulz (3, p. I-25)). In spite of the difficulty of handling this liquid fuel, the potential of the Garrett process looks good. In fact, the entire field of pyrolysis looks extremely good for handling the problem of solid-waste disposal. The technology needs to be developed and improved in certain parts of the processes, but the potential is good.

Another solid-waste disposal method with energy recovery is to use the waste as a supplemental fuel. This is being done in St. Louis by Union Electric in two conventional coal-fired steam-generators (Jackson (4)). The shredded solid waste is burned with coal in a mix ratio of one part solid waste to four parts of coal. Ferrous materials are separated prior to burning. This process results in significant energy recovery with about 75% volume reduction of the solid waste. The two steam generators can handle about 300 tons/day (equivalent to the waste generated by about 200,000 people) of solid waste. This rate represents an energy supply of about ten percent of the total required by the two generating units.

The potential for energy recovery with this supplemental fuel method is quite good. However, a difficulty arises when this method is considered for steam generators which are either gas-fired or oil-fired. These two types of units do not have the proper handling equipment for solid fuel. A substantial capital investment is necessary to equip these types of units with the necessary handling equipment.

Another innovative process is under development by Combustion Power Company in cooperation with the Environmental Protection Agency. Chapman and Wocasek (5) have recently discussed this process which is called the CPU-400 unit. This system takes shredded, air-classified solid waste, burns it in a fluidized bed combustor, and passes the hot gas through a gas turbine to generate electricity. The basic principles of this process are sound; however, the system has not yet performed as expected (see 2, 5).

There are numerous other processes and methods which might be discussed. However, we feel that those mentioned thus far are representative of the available technology in recovering energy in solid waste.

ECONOMICS

An economic comparison of selected process is shown in Figure 4. The basis for comparison is a 1000 ton per day plant with credits given on the basis of a natural gas cost of about 35 cents per million Btus to the utility companies of Houston. Details of the economic analysis are given in Reference (2). The model is that shown in Figure 2. The analysis is based on existing equipment and practices. For example, use of the supplemental fuel method in Houston would require substantial modification to gas-fired boilers. This cost is not included; the values in Figure 4 refer to actual operation in St. Louis with credits and debits given in terms of Houston dollars.

Based on existing site use, the values in Figure 4 indicate that the St. Louis supplemental fuel process has the lowest net cost. Closely bunched in second place are composting, the CPU-400 unit, the Garrett pyrolysis unit and the Union Carbide pyrolysis unit. The problems of composting are well known to the local population. Possible problems associated with the CPU-400 unit and the Garrett fuel oil process have already been mentioned and are expanded by Schulz, et al, (3), the NASA/ASEE study (2) and Chapman and Wocasek (5).

Details of the analysis method are found in Reference (2). Contained in Figure 5 is a list of evaluation factors that were used in preparing the economic analysis.

APPLICATION OF CONCEPTS TO HOUSTON

The NASA/ASEE study (2) presents a method of evaluating energy recovery processes in regard to a particular community. Houston was chosen as the city for which this evaluation was made. A major assumption in this effort is that, by late 1970, landfilling will not be an acceptable means of solid-waste disposal. Specific details of the evaluation procedure are available in Reference (2). In brief, the procedure involves a subjective evaluation of the factors listed in Figure 5. Even though the evaluation is subjective, the information leading to the evaluation is technically factual and is as objective as possible.

This evaluation found that the four most important factors listed in Figure 5 were the following: first, market; with Capital Investment, Operating Cost, and Public Acceptance tied for second. Based on these factors being dominant, the following four processes are judged to be those most suitable for use: (1) St. Louis supplemental fuel, (2) CPU-400 Unit, (3) Union Carbide pyrolysis, and (4) Garrett pyrolysis. Adapting the St. Louis supplemental fuel process to Houston would require a capital expenditure on a materials handling unit in getting the shredded, sorted refuse into the boiler, obtaining combustion, and removing the char. Landfill of the char would be necessary.

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OUTLINE OF SYSTEMS ANALYSIS

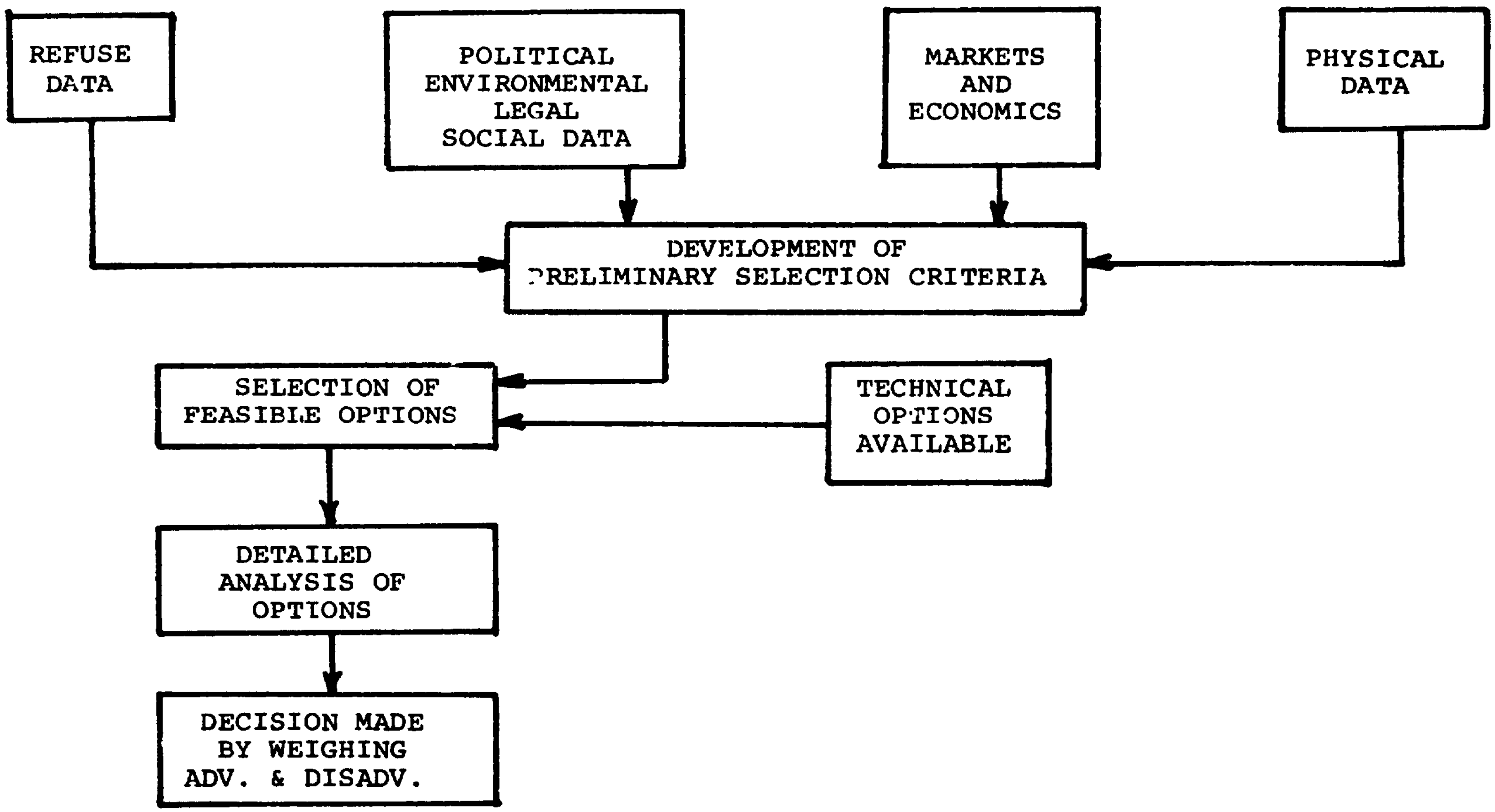

Figure 1

DECISION PROCEDURE

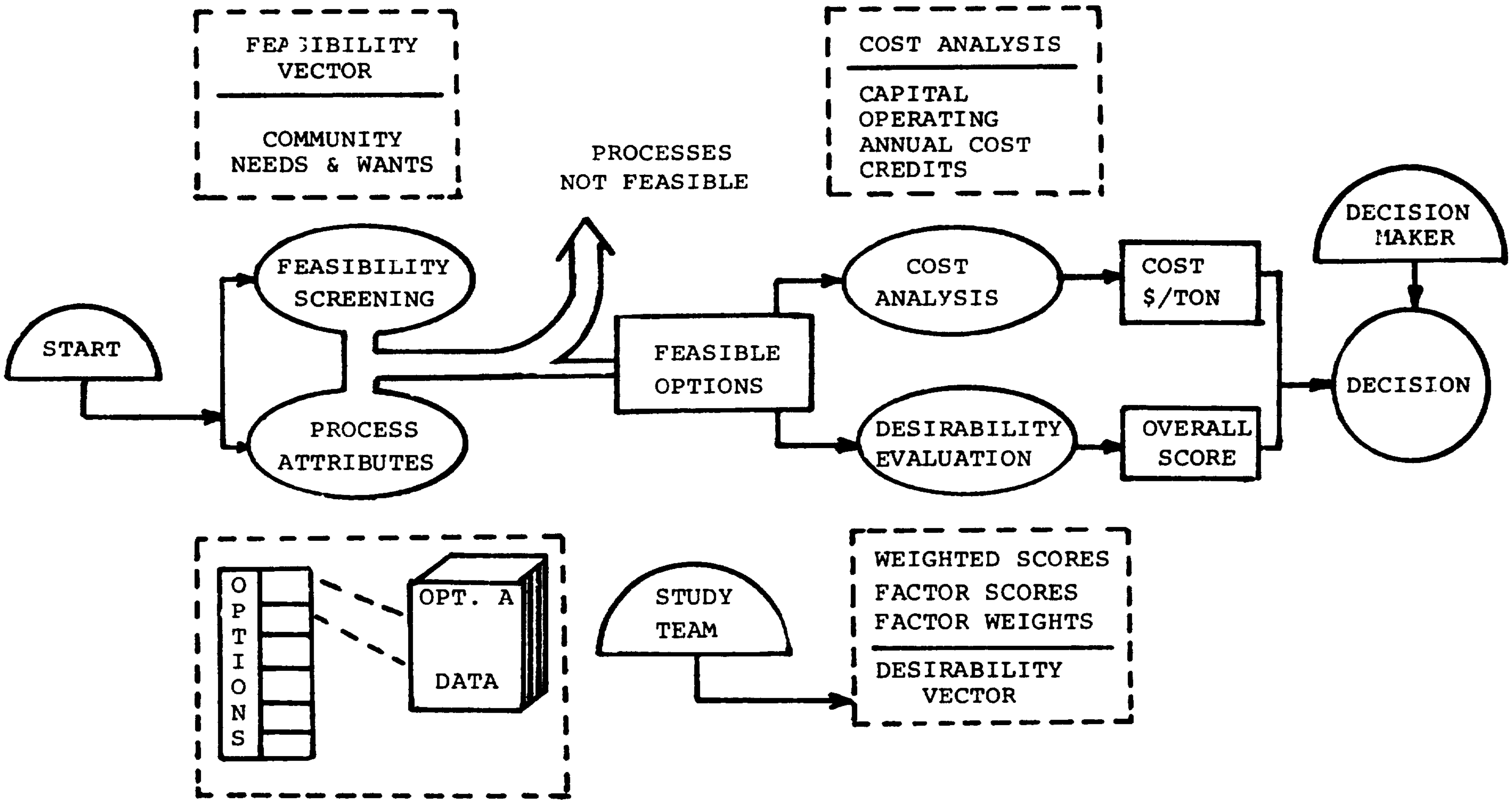

Figure 2

*ECONOMIC ANALYSIS OF SELECTED PROCESSES

Process	*Economics, $/Ton Gross Cost	Net Cost	Comments
Union Carbide	$ 8.40	$5.50	Gas Recovery and Residue Sales
Monsanto	11.90	7.30	Steam Sale & Ferrous Materials Recovery
Garrett	11.20	4.90	Liquid Recovery, Ferrous Metals, Glass, Aluminum
West Virginia University	11.00	9.70	Gas Recovery Only
Incineration With Heat Recovery	12.50	9.70	Proven Technology Emission, Pels
St. Louis Supp. Fuel	7.70	3.80	Corrosion and Erosion Problems - Good Potential
CPU-400	10.10	4.80	Too Many Difficult Tech. Probs. - Reactor, Gas Cleanup
Composting Plant	10.40	4.60	Ferrous Materials, Aluminum, Glass, Sewage Disposal, Paper Fiber

Figure 4

EVALUATION FACTORS (DESIRABILITY VECTOR)

	FACTOR	MOST DESIRABLE	LEAST DESIRABLE
1.	Market of Recovered Energy	Guaranteed by Attractive Contract	New Markets to be Created
2.	Market of By-Products	Guaranteed by Attractive Contract	New Markets to be Created
3.	Residue Disposal	None	50% or More and/or Special Disposal
4.	Environmental	No Pollutants	May Fail to Meet Some Standards
5.	Health & Safety	Completely Safe	Potential Hazards in Plant, to Public
6.	Installation Time	Will Meet Schedule	Likely to Delay Beyond Required Date
7.	Capital Investment	Minimal and/or Easily Financed	Almost Impossible to Finance
8.	Operating Cost	Low	High
9.	Management	Simple or Sub-Contracted	Difficult to Manage Plants & Labor
10.	Adaptability	Adaptable to any New Technology	Can not be Modified
11.	Public Acceptance	Attractive to Public	Strong Resistance from Public
12.	Capacity Expansion	Fully Expandable	No Room for Expansion
13.	Input Requirement	Any Composition of Refuse/Fuel	Operation Stops if Input is Inadequate
14.	Labor Requirement	Few and Unskilled	Many and Highly Skilled
15.	Plant Siting	Completely Free	Only One Possible Site
16.	Conversion Technology	Well Developed and Commercialized	Experimental
17.	Maintainability	Done Without Stopping Production	Prolonged Shutdowns Frequently
18.	Ecological Efficiency	Complete Recovery	Low Thermal Eff. & Nothing Else
19.	Back-Up and Storage	Continuous Operation Assured	No Back-Up, No Storage
20.	Sensitivity to Product Prices	Minimal Affect	Extremely Sensitive

Figure 5

N75 17201

ADAPTATIONS OF ADVANCED SAFETY AND RELIABILITY TECHNIQUES TO PETROLEUM AND OTHER INDUSTRIES

Paul E. Purser, P.E.

INTRODUCTION

Many present-day governmental practices in the areas of environmental protection, safety, and consumer protection appear to be based upon the Loevinger Theory[1]. That is, industry is considered guilty until proven innocent. Thus, many government regulations and court decisions require that industry take appropriate steps to prove the safety or acceptability of proposed actions prior to undertaking them. Industry can obtain assistance in shouldering this burden of proof by adapting various combinations of several techniques that are now available. These techniques have been developed primarily in the industries which have participated in the U. S. space and defense programs; and they have been major contributing factors in the remarkable history of reducing and controlling failures that has characterized the space program.

The present paper is intended to discuss the underlying philosophy of the general approach to failure reduction and control; to describe briefly the principal techniques of interest, to identify some successful adaptations to non-space activities, and to provide suggestions and reference sources for information leading to other possible adaptations.

DISCUSSION OF TECHNIQUES

Philosophy

The underlying philosophy of the safety and reliability techniques to be discussed is that, while it is not possible to completely eliminate all failures, it should be possible to:

- Greatly reduce the numbers of failures that do occur,
- Greatly reduce the potential for catastrophic effects of failures,
- Provide alternate equipment and procedural paths to minimize operational interruptions due to failures,
- Promote high reliability in systems that are produced in such small numbers that the desired reliability levels cannot be obtained through long-term development testing,
- Provide pre-planned guides for investigation and correction of failures to prevent recurrences.

For example, consider the Apollo 13 lunar mission in which an oxygen storage tank failed in flight approximately half way to the moon. Although careful and extensive research and development efforts went into the design and construction of the tank in question, it was realized that the tank could and might fail in flight. Thus, the techniques that we will be discussing were applied in the following steps:

- o During the basic engineering design and development of the tank to minimize the possibility of its failure;
- o During the basic engineering design of all other items equipment to prevent their being adversely affected by a tank failure;
- o During overall design of the system to provide means of assisting the crew to locate, isolate, and by pass the failure;
- o During the mission planning to provide alternative procedures that would allow continuing the mission, if possible, but at least returning the crew safely.

As a result, the crew was safely returned to earth, the source of the failure was determined even though the portion of the spacecraft that contained the tank was left behind, and corrections were made that prevented a recurrence of that failure.

Techniques of Interest

The primary techniques of interest are discussed in some detail in prior publications by this author,[2,3] and in several other government and non-government papers[4] to [10]. The following paragraphs briefly describe the techniques that appear to be the most useful and adaptable to non-space activities.

Design Reviews (DRs). Many firms use design reviews as a matter of course. Surprisingly, however, many either do not use them or else apply them in a rather cursory or desultory fashion. Basically, the DR is a structured process of technical management that provides time-phased reviews of the design progress and adequacy. DRs draw upon presentations by the designers and upon the results of some of the analyses discussed in succeeding paragraphs to assure both management and the designers that:

- o Requirements are clear, complete, and attainable.
- o Criteria are sound and logical.
- o Bounds of technology are not unduly strained.
- o Due consideration has been given to safety, hazards, reliability, interfaces, etc.
- o Any risks are being taken knowingly.
- o The design is adequate.

The DR process also provides documentation of the design logic and of management's concern for the balance between economy and ecology. Thus, it can be of value in dealing with regulatory agencies and the public.

Failure Mode and Effect Analyses (FMEAs),
Hazards Analyses (HAs), and
Single Failure Point Summaries (SFPSs). These three items are somewhat parallel and interrelated. Each should be an integral part of the design process, and their outputs should be reviewed to:

- o Determine design adequacy.
- o Identify design incompatibilities.
- o Provide a vehicle for assessing design reliability.
- o Provide a model for analyzing existing systems in design reviews, inspections and certifications, test and operations planning, failure and accident investigations, modifying and updating facilities, and in assessing and comparing similar systems.

After the facility has begun operations, the FMEA and SFPS can serve as "road maps" for any failure or accident investigations.

Certain terms must be defined prior to further discussion. For example, what are failure modes and effects, single failure points, and hazards? Failure mode is the manner in which an item fails. A valve fails open or closed, a tank overflows or leaks, etc. Failure effect is the succession of results of a failure. If a valve fails closed, the flow stops and this may overpressure a line, overfill a tank, allow a heat exchanger to overheat and interrupt a process, etc. A single failure point is a component which can fail and for which there is no redundant or back-up component. Examples of such components include:

- o Major pipeline
- o Pressure vessel (single, not manifolded)
- o Manned spacecraft heat shield
- o Ship hull
- o Engine on single-engine aircraft
- o Main structure of a dam.

A hazard is any equipment failure, procedural error, or other undesired event that can result in injury to personnel; fire, explosion, or other damage to equipment; or bad environmental effects such as oil spillage.

There are two basic types of FMEA-design and functional. Design FMEAs start at the component level within a subsystem; identify effects of component failures on subsystem, system, facility function, safety, etc.; identify failure-detection methods, alternate or shutdown procedures, time available for action; and recommend corrective action or justify acceptance. Figure 1 illustrates the general flow process for Design FMEAs (and also for HAs and SFPSs). Functional FMEAs start at the facility function level; identify major and subfunctions required; identify equipment required for each; assign criticality level to each subfunction and its associated equipment (Level 1 is loss of life); identify critical components within each equipment set for each specified criticality level; and recommend corrective action, etc.

Single failure point summaires (SFPSs) are made during the FMEA or HA, as indicated on Fig. 1, and are documented in a list for periodic review and analysis.

How are single-failure points treated? They may be accepted and rationalized on such bases as low criticality or low probability of occurrence because the component has a proved high safety margin or a proved high reliability record. They may be eliminated by redesign or corrective action such as provision of redundant components, increased margins, increased reliability, or testing to prove the safety margin or reliability.

Hazard analyses (HAs) are conducted essentially in parallel with FMEAs and SFPSs as indicated in Figure 1, but with emphasis on the existence, degree of criticality, and elimination of hazards.

HAs should disclose: Whether the component can fail. If so, does it create a hazard? How critical? How can failure or hazard be prevented? Can instrumentation error lead to hazard? Can operator error create a failure or hazard? How can that be prevented or avoided? Preventive or corrective actions that can be undertaken for hazards that are uncovered include such items as equipment redesign, actuator or switch placement and guarding, operator training, and modification of operating procedures, etc.

In all of these techniques it helps to play the "what if?" game in order to be sure that no valid risks are overlooked. The designer or analyst should consider the real effects of various failures and he should look for the real problem and not "cut off the little toes to improve the fit of a pair of tight shoes".

Operational Readiness Inspections (ORIs). These inspections are quite similar to design reviews except that they deal more with the completed hardware and with such operational factors as organization, training, procedures, etc.

ORIs provide the operations group:
- o Increased assurance of adequate design and construction
- o Early visibility into potential operating problems
- o Planning guidance for training, operations, M&R, etc.
- o Assurance of adequate support services and facilities
- o Higher confidence in start up and operation.

Failure Reporting and Analysis. The treatment of failures is an important part of developing a truly viable safety and reliability program. Too often in the past, failed components have simply been replaced and discarded in a manner roughly similar to the treatment of blown fuses in one's household electrical circuit. Further action has often been taken only when the failure is repeated almost immediately. However, much of value can be learned from proper reporting and analysis of failures. Adequate failure reports can provide a firm's engineering management with data on which to base analyses of failure effects, possible suppliers, etc. Adequate analyses of failed parts can contribute better understanding of why failures occur and can lead to improvements in reliability and safety through the use of better or more suitable parts, better design criteria, or better operational procedures.

ADAPTATIONS OF TECHNIQUES

There have been many successful non-space adaptations of these safety and reliability management techniques during the past several years. The following paragraphs briefly discuss those which this author either is familiar with or has played some part in.

Petroleum Operations

Offshore. The major thrust of adapting advanced safety and reliability techniques to offshore petroleum production and drilling operations began after the 1969 Santa Barbara Channel blowout incident. As a part of its reaction to that incident, the United States Geological Survey (USGS) southt the advice and assistance of other government agencies, technical societies, and industry. One of the first responses to the USGS was a study[11] by personnel of the National Aeronautics and Space Administration (NASA). This study recommended that the techniques discussed in the present paper be adapted to the USGS management of offshore petroleum operations. As a result, the USGS included requirements for failure reporting in its OCS Order No. 5[12] and contracted with industry for two studies[13,14] in which FMEAs and HAs were conducted on 13 different (8 types) of offshore facilities. The results of these two studies were then utilized by the petroleum industry, through a special American Petroleum Institute (API) Committee to develop a Recommended Practice document[15] for the design, installation, and operation of surface safety systems for offshore platforms. Concurrently with these efforts a Review Committee of the National Academy of Engineering has been advising the USGS on various aspects of offshore safety and has recommended further adaptation of such techniques to the USGS operations[16,17].

Meanwhile, various firms in the petroleum industry, on their own initiatives, proceeded with similar adaptation efforts. For example:

- The present author has assisted in planning a design review for a large offshore platform.
- ADCON Corp. and Mechanics Research, Inc. (West Coast consulting firms) have conducted FMEAs for oil industry clients[18].
- Shell Oil Co. and Lockheed Petroleum Services, Ltd. have utilized these techniques and other space-derived technology in the development of a subsea well-completion system[19].
- Shell Oil Co. has utilized similar techniques in deriving improved structural-design criteria for offshore platforms[20].

Onshore. In the area of onshore petroleum operations environmental protection has also been a driving force for adaptations of advanced technology. The Environmental Protection Agency (EPA) contracted with Computer Sciences Corp. for a study of oil spills from production and drilling equipment[21]. This study utilized some of the techniques being discussed and formed a major part of the base for EPA's new spill-prevention regulations[22] and for an API Bulletin[23] containing guide lines for industry's use in complying with the EPA regulations. The present author, incidentally, has found these two documents[22,23] to be quite useful in his consulting practice.

Diving and Manned Submersible Operations

The recent burgeoning interest in all types of offshore operations, including petroleum, has brought on a very rapid expansion in the civilian industrial development and use of deep-diving equipment and manned submersible vehicles. The primary interest and expertise in these fields has traditionally resided within the United States Navy. With the rapid expansion of undersea operations into the civilian arena, the Marine Technology Society foresaw, and responded to, a need for a publication[24] containing safety guidelines for the design and operation of undersea vehicles. The original volume, published in 1968, is now in the process of revision. The present author has provided the revising editors with material for an Appendix on the use of advanced safety and reliability techniques in the design and operation of diving equipment and submersible vehicles.

In addition, the present author's consulting practice includes the conduct of such analyses for a Houston-based diving equipment firm. Of course, the Shell-Lockheed project[19] referred to earlier, includes a manned, one-atmosphere, submersible chamber as a primary element and Lockheed is also using these techniques in the design of other marine equipment.

Medical Activities

Applications of new technology to various medical activities are also being successfully made as evidenced by one of the sessions of this conference. A paper[25] at the 1973 Annual Conference on Engineering in Medicine and Biology (ACEMB) discussed several adaptations of aerospace safety and reliability techniques to the field of medicine. The present author is now in the process of conducting a combined safety and functional effectiveness analysis on a remote patient monitoring and treatment system for a client.

Summation

The preceding examples undoubtedly form an incomplete listing of adaptations of aerospace safety and reliability techniques to non-space activities. They should, however, serve to illustrate the breadth and variety of potential fields of applicability for these techniques. In fact, any activity that can be treated as a "system", whether it be hardware or software, is a potential beneficiary of some portion of these analysis procedures.

SUGGESTIONS AND SOURCES OF ASSISTANCE

Suggestions

Experience gained during the past several years has indicated that some words of caution may be useful to those considering the use of the techniques under discussion. Among these items are:

- o These techniques do not constitute a panacea for all system ills; they uncover problems but do not solve them.
- o They cannot substitute for sound engineering and good judgement, they can only supplement them.

- o Despite their systematized appearance, these techniques cannot be applied by a computer; they require intelligent human thought at each step, consequently they must be adapted rather than adopted in new fields.

Sources of Assistance

The utilization of aerospace safety and reliability technology in non-space activities can take place by essentially any of the several mechanisms discussed for other areas of advanced technology in this Conference. One can rely upon varying combinations and degrees of outside assistance and internal effort.

The various documents referenced so far[1-25] plus some others[26-29] listed under the heading REFERENCES can provide a great deal of information on why, what, and when; some information on how and who; and a little information on how much cost and effort. Traditionally, NASA (both in Washington and in the various field centers) has been quite willing to discuss technology utilization problems with any interested parties and to provide advice and references to both published information and potential contractors who have experience in the particular technology of interest. The various contractors, of course, have various preferred approaches to assisting customers in the application of any new technology. The approaches can range from:

- o Offering training courses, to
- o Providing consultation and advice, to
- o Providing manpower to either assist in or perform the task, to
- o Complete "turn-key" task performance, through
- o Many variations of "joint-venture" efforts.

In essence, however, technology which can provide improvements in safety, reliability, and functional effectiveness in many types of activities is available to those who are interested in adapting and utilizing it.

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LOCATING UNDERWATER OBJECTS

C. Fitzhugh Grice

Locating an underwater object in or on the bottom is an engineering and operational problem. The solution to the problem requires a clear and precise definition of the problem itself, followed by a proper choice of instrumentation and operational procedures. An engineering and operational problem cannot be changed to fit a particular philosophy as can be done if the problem were one of a research nature. The use of a research philosophy in some past underwater search operations, has, in the opinion of the author, been responsible for the failure to achieve efficient and economic success.

DEFINING THE PROBLEM

To define the problem, several questions should be asked and answered:

1. Is the object metal?
2. If the object is metallic, is it ferrous, non-ferrous or a combination of the two?
3. What was the approximate size of the object before becoming lost?
4. Is the object likely to be intact or fragmented from impact or deterioration?

This question is not always easy to answer. Conflicting opinions from competent people can be involved. Lost aircraft can present difficulty. Depending on circumstances before entering the water, an aircraft can be nearly intact or completely fragmented. A wooden vessel lost for a number of years in the middle-to-low latitudes will probably be fragmented by marine borers.

5. Is the object likely to be on the bottom or is it more likely to be buried in the bottom?

Again, this question may not be easy to answer because of conflicting opinions. There are some who thougnt the submarine THRESHER would be completely buried in the bottom, based on the assumption that the vessel achieved a high terminal velocity before reaching bottom. This might have occurred had the hull kept its hydrodynamic shape and assumed a nose-down attitude in its fatal plunge.

Prior to the successful search in 1967 for the Civil War ironclad TECUMSEH, which was sunk during the Battle of Mobile Bay, the consensus was that the ship would be largely buried for two reasons; (1) more than a century had past since she sank and (2) she had not already been found.

6. Has a previous search been made for the object?

If the answer is yes, what methods, equipment and operational procedures were used? The probable reasons for failure to find the object should be evaluated.

OPERATIONAL PROBLEMS AND CONDITIONS

After the problem has been thoroughly defined, operational problems and conditions should be evaluated:

1. How large is the probable target area?

Many times this is the most difficult question to be answered. An answer may require a careful and extensive study of all available records; particularly if the object has been lost for many years.

The Civil War vessel TECUMSEH was found approximately 3 1/2 hours after the search operation began primarily because of the excellent archival research done by the Smithsonian Institution prior to the search.

If the object has been recently lost, the probable target area must be determined from eye witness reports (if any), estimates based on all available information pertaining to the last known location of the object prior to the loss, and the causes which lead to the loss.

2. Where is the target area located with respect to land?

3. What navigational aids are available?

There are few "landmarks" in the water. The lack of adequate navigational aids has hindered many search operations.

4. What is the water depth within the target area?

5. Are adequate navigational and bathymetric maps of the area available?

6. What type of search vessel should be used?

Answers to the preceeding questions will have a significant bearing on the search vessel requirement. Water depth will determine the handling gear necessary for the search instrumentation. Distance from land will determine the ship's endurance requirements, along with navigational equipment needed.

CHOICE OF SEARCH INSTRUMENTATION

Rarely are two underwater search problems alike. The best choice of instruments will depend on the particular problem. At this point, a review of some problem definition questions is in order:

1. Is the object metal? If so, the object will have a signature that can be detected. If the object is non-metallic, a signature, per se, will probably not exist.

2. If metallic, is the object ferrous, non-ferrous, or

a combination of the two? A ferrous object will have a magnetic signature and an electric signature. A non-ferrous object in water will have an electric signature, known as the spontaneous or self-potential (SP).

Metal Finding Instrumentation

This class of instruments and techniques includes the magnetometer, underwater metal detectors and the self-potential technique. The SP and magnetometer are passive instruments and techniques; they measure an existing signature.

The SP technique measures the electric field caused by metal in water; the magnetometer detects the alteration in the local magnetic field caused by the presence of a ferrous object.

Acoustic (Sonar) Instrumentation

Included here are high-resolution side-scanning sonars and sub-bottom profiling equipment.

Optical Instrumentation

This broad category includes closed circuit television, cameras, divers and submersible vehicle observers.

Navigational Aids

Included here are ship-to-shore electronic positioning systems, satellite navigation and acoustic transponders for bottom navigation.

Mechanical Techniques

Drag cables, sweep-wire technique and bottom grapples would be included here.

METAL-FINDING INSTRUMENTS

Self-Potential (SP)

Stated simply, the SP search technique consists of measuring the electric field which results when a metallic object is immersed in naturally-occuring water, with the water acting as an electrolyte.

Almost any metallic object will become polarized when immersed in a naturally-occuring water (particularly salt water) because of the dissimilarities of the alloys, or metals, or in the case of a homogenous metallic structure, because of the imperfections in the grain structure. If the object is elongated, it becomes a dipole, with a measurable electric field existing in the water.

If the object is composed of dissimilar metals, the electric field will be much stronger.

An electrical dipole will not be set up by dissimilar metals that are near each other in water but not metallically connected. Each piece of metal will probably polarize and have its own weak electric field.

The SP technique of finding underwater objects is one of the oldest "electronic" methods, requires the least sophisticated instrumentation and is probably one of the least known techniques. This technique was used in 1930 to find lost practice torpedoes for the French Navy.

The SP equipment basically consists of a pair of electrodes towed in the water and a recording millivoltmeter. There are no "standard" electrode spacings or configurations--the electrode spacing and towing technique must be selected for the particular job to be done.

The technology for measuring and recording millivolt signals has advanced considerably since the 1930 experiments. Depending on the noise level of the search vessel and associated gear, anomalies with amplitudes considerably less than 5 millivolts can be recorded and interpreted.

The SP technique was used by the author to locate the TECUMSEH. The recorded electric signature from the TECUMSEH was only 2.5 millivolts peak-to-peak. The wooden-hulled diesel-powered vessel used for the search operation created such a low electrical noise level that the servo-driven chart recorder actually "stepped". Conversely, the electrical noise level of the high-speed metal-hulled Coast Guard cutter used by the author on another search operation was in excess of 5 millivolts, causing some interpretation problems.

From experience, it has been found that the SP anomaly from a metallic object in water can be measured at a distance of 5 to 10 times the net dipole length of the object. This depends on the metal(s) involved, the water conductivity, the electrical noise level of the search vessel and the operational configuration of the electrodes. The net dipole length will determine the width of a search pattern designed for complete target area coverage.

Metallic objects completely buried in the bottom have been found using the SP technique. However, the SP technique is not recommended for objects known to be completely buried.

Considered in the usual "product line" frame of reference, there is no SP search equipment,per se, for sale by anyone.

While the SP technique is simple and can be quite effective, the success of the method depends to a large extent on the operational and interpretative expertise of the user.

Magnetometers

The magnetic field of the earth is shaped as though it were caused by a giant bar magnet about one-third of the earth's diameter in length, situated near the earth's center and tilted about 20 degrees from the earth's spin axis.

The magnetic field is weak, varying from about 0.7 oersted at the magnetic poles to about 0.25 oersted at some points on the magnetic equator. For oceanographic work, the gamma has been adopted as the unit of magnetic measurement. The gamma represents 1/100,000 of one oersted.

A sensor which can convert the magnetic field intensity to a readily-measurable quantity is called a magnetometer. A magnetometer which measures the magnitude of the magnetic field only along its axis of orientation is called a component sensor. A magnetometer relatively insensitive to its orientation is called a total field sensor.

Component Sensors. Disregarding the "loop-scanner" type of instrument, there are two basic types of component sensors in general use; the fluxgate magnetometer and the variable-mu magnetometer.

The fluxgate magnetometer uses an oscillator to drive the primary of a magnetic core. The magnetic field to be measured aids the A.C. field over one-half cycle and opposes it for the other half-cycle. With proper primary and/or secondary winding procedure, the secondary winding output will consist of even harmonics of the fundamental oscillator frequency; usually filtered to present only the second harmonic. The voltage amplitude of this harmonic is proportional to the strength of the field to be measured.

For underwater search operations, a single component sensor is not practical. Any orientation change of the sensor would result in a change of output. Two magnetometer sensors can be spaced some distance apart with the output signals "series-opposed" or subtracted. Such a device is called a gradiometer magnetometer.

A gradiometer made of two component sensors requires extremely precise alignment of the two sensors to avoid an apparent gradient if the device is not perfectly stable while being towed. A functional gradiometer requires sensors of very high sensitivity to be able to measure small differences in intensity between the two ends of the gradiometer.

Grice Ocean Engineering, Inc. is presently building a prototype high-sensitivity fluxgate gradiometer magnetometer, incorporating some ideas contained in NASA TECH BRIEF 70-10347, "Two-Axis Fluxgate Magnetometer". Laboratory tests of the prototype are encouraging; each sensor has an output of approximately 100 microvolts per gamma. Field tests are scheduled for later during 1974.

Total Field Sensors. Sensors which are responsive to the total magnetic field have been called atomic magnetometers, since they all make use of atomic interaction to measure the magnetic field. Some types of atomic magnetometers are the proton precession, and the optically-pumped devices such as the rubidium-vapor, cesium-vapor and metastable helium sensors.

The sensitivity of the proton precession magnetometer is good, with the ability to resolve a change of 1 gamma in any field. Proton precession magnetometers are now available from a number of manufacturers and are extensively used in oceanographic work, including underwater search operations.

The sensitivity of optically-pumped magnetometers is very high; the rubidium magnetometer in a fixed position is reported to be able to resolve a change of approximately 0.002 gammas in a field of 50,000 gammas. The optically-pumped magnetometer is not used extensively in underwater search operations.

Underwater Metal Detectors

In the discussion of the SP and magnetometer, we were dealing with passive devices -- the inherent electrical and magnetic characteristics of the object being sought are responsible for the signals detected.

Underwater metal detectors use an active technique to find a submerged metal object, energy is transmitted and a portion of the energy is returned by the object.

Underwater metal detectors are similar in principle of operation to metal detectors used on land; designed or altered for service underwater. Because of the high conductivity of salt water, marine metal detectors make use of relatively low operating frequencies.

There are three basic types of metal detectors: Beat Frequency, Induction-Balance and Transmitter-Receiver. The optimum choice of a metal detector is the induction-balance type; this type has excellent small target resolution and good-to-excellent depth penetration.

The basic laws behind inductive coupling shows why metal location over appreciable distances is a major problem. The received signal produced by an inductively coupled target will normally be proportional to the cube of the target diameter and inversely proportional to the sixth power of the target depth.

If the choice of operating frequency is appropriate for an induction-balance or transmitter-receiver metal detector, the phase information contained in a target signal can be quite useful. Non-ferrous targets and non-conductive ferrous targets produce signals (called "X" and "R" signals) that are separated in phase by 90°. Conductive ferrous targets, such as ordinary iron, produce a signal whose phase lies between the pure "X" and "R" signals; the phase being highly dependent on the operating frequency.

Grice Ocean Engineering, Inc. is currently marketing an underwater metal detector, with dual earphones used to reproduce the "X" and "R" target signals; hence allowing the user to distinguish between ferrous and non-ferrous targets. This metal detector has a range of approximately 8 feet for large targets, such as pipelines, and excellent small target resolution. On a recent expedition to Mexico, this metal detector found targets ranging in size from bobby pins to a cast iron sailing vessel mast socket buried about 4 feet in the bottom. (A prototype land version of the underwater "stereo" metal detector also used on the same expedition found a cargo chest from a 1739 shipwreck).

ACOUSTIC (SONAR) EQUIPMENT

The only form of radiation known to penetrate water for reasonable distances is sound. Other forms of radiation are absorbed within a few hundred feet.

Acoustic equipment useful for underwater object location can be divided into three basic groups:

1. Vertical beam sonar
2. Side scan sonar
3. Rotating beam sonar

Each has specialized advantages and applications.

Vertical Beam Sonar

Vertical beam sonar is the simplest and most widely used sonar search technique for locating projections from bottom. Conventional shipboard echo sounding equipment designed for bottom depth determination will provide an echo from an object protruding above bottom, with varying degrees of resolution depending upon the characteristics of the equipment. With adequate peak power and a sufficiently low operating frequency, penetration into the bottom can be obtained; the depth of penetration depending upon the sound energy, operating frequency and bottom characteristics.

The vertical beam sonar search technique has a restricted search range as information comes only from that area of the bottom covered by the sound beam. Parallel runs, or traverse, must be close enough so that every part of the area under search will be investigated. In shallow water, this can be critical, as traverses must be spaced only a few feet apart.

To provide an acoustic echo, the target thickness would have to be 1/4 wavelength, or greater, of the sound wave in the target. For example, assume a metal target and a 12 Khz sonar. With a velocity of sound through metal of approzimately 6,000 meters per second, 1/4 wavelength would be approximately 12 centimeters. Therefore the target would have to be at least 12 cm. thick to return a usuable echo.

The minimum lateral dimensions of the target would depend upon the speed of the search vessel as related to the pulse repetition rate of the sonar and the depth of the water which determines the ratio of the target area to insonified area. The deeper the water, the larger the target will have to be to return an identifiable echo.

Side Scan Sonar

Side-scanning sonar devices generally consist of a transducer housed in a streamlined body, called a fish, towed behind the surveying vessel.

Sound pulses of high frequency and short pulse duration are emitted from one or both sides of the fish. The sound beam strikes the ocean floor in a scanning pattern much as a slanted beam of light elevated above the topography would sidelight the panorama below it. When the sound reaches the ocean bottom, the pattern reflected back indicates the bottom topography. Each reflected sound pulse is displayed by an oscilloscope or a paper recorder (usually). Elevations produce shadow zones behind them, relative to the sound source. The length of the shadow depends upon the height and overall size of the elevation and its distance from the sonar source. Depressions produce shadows just beyond the rim closest to the sonar source. Smooth topography is indicated by uninterrupted even lines.

To utilize the side scan technique properly, the transducer should be reasonably close to bottom. The distance off the bottom is a function of the range coverage desired; in general it will vary from a few hundred feet to several thousand feet.

Side scan sonar search techniques are useful only for targets known to be on or above the bottom.

Rotating Beam Sonar

The rotating beam sonar technique is a variation of the side scan technique. The transducer is usually attached to the search vessel and can be "aimed" in the manner of a searchlight.

The rotating beam technique allows you to "see" ahead of the traverse lines and allows target detection in advance of vessel arrival. The target can also be scanned for size and shape determination.

Sonar Search Summary

There is no single sonar system best for all search problems. First, no sonar equipment will positively distinguish metal from non-metal. However, if the target is non-metallic, a sonar search technique might be the best solution.

Vertical beam sonar provides information about a particular object, such as its height above the sea floor, or below the sea bottom if the proper penetrating sonar is used. The vertical beam method is a slow search technique for coverage of a wide area.

Side-scanning sonar allows you to survey a wide area in a short time with targets being displayed in their approximate relative positions. The rotating beam search technique allows a large area to be rapidly surveyed.

OPTICAL INSTRUMENTS

A visual search technique involves basically an optical sensor. Man, for example, operating as a diver or as an observer in a submersible, would be an optical sensor.

Underwater optical sensors leave much to be desired as effective search instruments. Range is severely limited due to light scatter and suspended matter.

In recent years, underwater cameras and television systems have been improved; however as search instruments, their range is still too limited for practical search operations.

NAVIGATIONAL AIDS

The lack of adequate navigation is one of the major deterrents to underwater search operations. This does not mean that adequate navigational aids are unavailable. Many times the relationship of the search problem to precise navigation is not given the attention it deserves. The navigational requirement is not necessarily a matter of "absolute" position -- but rather a matter of repeatability.

The requirement is to be able to leave a spot in the ocean (or water) and later to be able to return to the same spot.

Navigational requirements can be froken into two parts:

1. Vessel location
2. Location of the towed instrument array with respect to the towing vessel.

The required accuracy is related to target size.

Navigational aids for surface vessels can be divided roughly into three types:

1. Electronic positioning systems
2. Visual navigation
3. Acoustical navigation

There are a number of electronic positioning systems presently in service, all reported to have good accuracy within the designed range of operation.

Visual ranging and positioning does not provide the speed or ease of operation afforded by the electronic positioning systems. However, it can be effective, providing the target area is suitably located for its use. Visual ranging involves line-of-sight fixes on known points. These points can be shore based or they can be buoys that have been set for this purpose.

Acoustical navigation can be divided into two groups; those used to fix the position of the vessel with respect to a bottom datum point, and those used to determine the position of the towed sensor array with respect to the vessel.

Both groups of acoustical navigation require one or more bottom-mounted (or towed) sonar pingers or one or more physically-separated shipboard receivers so that the relative positions can be calculated.

The use of acoustical techniques for navigational control can become rather sophisticated and complex.

MECHANICAL TECHNIQUES

One method of finding a sunken object is to snag the object by dragging a wire, cable, or grapnel(s) on bottom. This method has been used successfully in areas where the bottom characteristics are reasonably uniform and where the target is known to be at least partially above bottom.

Before the TECUMSEH was located with the SP technique, an effort had been made by dragging a chain between two surface vessels on parallel courses. As it turned out, the only part of the vessel still above bottom was a portion of the starboard bilge keel, a target that could not be easily snagged (like trying to snag a football by dragging a string down the length of the ball).

SUMMARY

Underwater search instrumentation and techniques have been outlined. However, the necessity of adequate "homework" prior to the search cannot be over-emphasized. Define the problem thoroughly first, then proceed from there.

THE INITIATIVES OF THE LOS ALAMOS SCIENTIFIC LABORATORY IN THE TRANSFER OF A NEW EXCAVATION TECHNOLOGY

R.J. Hanold, C.A. Bankston, J.C. Rowley, W.W. Long

INTRODUCTION

The expertise of the Los Alamos Scientific Laboratory as a research and development organization is internationally recognized as a result of its many diverse accomplishments since its beginning in 1943. Its origin in a time of crisis in World War II, and its isolation at that time, required that the technical facilities and staff be capable of a broad range of activities ranging from basic science to the design, fabrication, and testing of intricate devices. By engaging in fundamental research activities in many fields, the Laboratory has achieved the ability to utilize quickly and efficiently the results of basic research conducted throughout the free world. It was also important, from its earliest years, for Los Alamos to encourage full exchange of technical information among its staff so that the results of basic research could be translated into completed and tested systems. The Laboratory is operated by the University of California under contract to the Atomic Energy Commission and has assumed a broad spectrum of responsibilities in major AEC programs and those of other government agencies. Since the completion of the wartime assignment to develop, test, manufacture, and provide a nuclear device, the largest single programmatic activity has been nuclear weapon development. With this defense oriented posture, providing the widest practical and appropriate dissemination of information concerning its activities and results has not typically been a problem.

THE TECHNOLOGY

Subterrene Design and Operating Concepts

The Subterrene is a system, invented and patented by Los Alamos scientists, for making vertical or horizontal holes in rocks and soils by progressive local melting.[1] Most rocks, including the very hard igneous rocks which are particularly difficult to penetrate mechanically, melt at temperatures far below the melting points of refractory metals such as molybdenum and tungsten. The rock melt produced can be chilled to a glass and formed into a dense, strong, firmly attached hole lining that is clearly discernible in the sample shown in Fig. 1. Thus, by the use of a melting penetrator, permanently self-supporting holes can be made even in unconsolidated sediments. The energy utilized to form a hole of a particular size and line it with rock glass is estimated to be greater for a Subterrene than for a conventional rotary drill, but this should be more than balanced by savings in material, labor, and operating costs.

The general principle of Subterrene operation can be explained with the aid of a simplified sectional drawing shown in Fig. 2. The smooth-faced penetrator, which plays the role of the drill bit, is made of a refractory metal and heated electrically by means of a pyrographite resistance-heating element. Thermal energy is transferred from the heater to a graphite thermal receptor by radiation and is then distributed throughout the penetrator by conduction. The heated portion of the device is thermally insulated from the stem advancing section by a layer of a special pyrolytic graphite.

In operation the hot penetrator is forced into the ground by exerting a downward thrust on the stem. The surrounding rock is melted and the thrusted penetrator forces the liquid rock-melt outward around the penetrator and stem where it is cooled. The melt then freezes to form a hard, obsidian-like glass lining on the wall of the hole, sealing and supporting it. The operation just described is that of the "melting-consolidating" type of Subterrene penetrator designed especially for making holes in porous rock or soft ground. Because the glass-lining formed when the rock-melt solidifies is more dense, and hence occupies a smaller volume than did the original porous rock, the molten debris from the hole can be entirely consolidated in the dense glass lining thus completely eliminating the debris removal operation necessary in conventional drilling techniques.

Holes in dense rock are produced with a "universal extruding" Subterrene which can also be used in porous rocks to make holes with a thinner glass lining. The essential structural difference from the melting-consolidating design is that the heated penetrator is not a solid conical body but has the form of a ring or torus with a small hole in the center as shown in Fig. 3. Part of the rock-melt is forced upward and outward and upon cooling forms the hard glass-like lining of the hole. Most of the melt, however, is forced up through the central hole in the penetrator into what is called the "extrusion zone". In the upper part of this zone the melt is cooled and solidified; the extruded solid debris is then carried to the surface by the cooling gas flow.

Special Features and Potential Applications of the Subterrene

With the Subterrene concept the three major facets of excavation, namely, rock fracturing, debris removal, and wall stabilization, are attacked in a single integrated operation. In loose or porous formations the debris removal operation is eliminated by density consolidation. Another unique advantage of the Subterrene system concept is that the holes are automatically lined with a hard glass-like material. It may thus be possible to eliminate the costly and time-consuming procedure of inserting and cementing metal casings typically associated with wells drilled with rotary bits.[2]

Studies made at Los Alamos combined with a survey of potential users in industry have revealed a large number of potential applications of the Subterrene. The system's inherent ability to make holes of precise diameter could be utilized in producing holes for anchoring structures such as bridges, TV towers, and transmission line towers. Emplacement holes for anchoring pipeline supports could be readily melted in difficult materials such as Alaskan permafrost. Loose gravel and other unconsolidated formations are difficult to drill and stabilize with conventional rotary equipment. The Subterrene, which would leave a glass-lined hole, provides a solution to this difficulty. Conversely, hard abrasive rocks can also be penetrated because the melting temperature, not the hardness or abrasiveness, determines the usefulness of the Subterrene.

From the viewpoint of the energy research and development programs at Los Alamos, two potential uses are of special interest. The first involves melting holes in hot rocks for the extraction of geothermal energy. Since the penetration of the Subterrene depends on the melting of the rock, the high in situ temperatures will be beneficial in saving thermal energy and increasing the penetration rate. The second is related to the LASL program for developing underground superconducting transmission lines for electrical power. At present, such lines would have to be laid in trenches which could only be dug with considerable environmental disruption. With a Subterrene, however, horizontal holes could be melted with a minimum disturbance of the ground surface.

ORIGIN OF THE TECHNOLOGY

During the past decade many innovative and ingenious ideas related to improving drilling technology have been proposed and investigated. While rock has been drilled and fractured with everything from laser beams to artillery cannons, little impact has been made on the primary method of rotary drilling. Since the drilling of wells still employs the basic technology of many years ago, the motivation for the technologist to look at other ways to make deep holes in the earth's crust is high.

The basic notion of developing an excavation tool based upon the melting of rocks and soils was generated by the need for very deep drilling as proposed in the original Mohole Project. The rock melting idea recognized that very deep in the earth extremely high temperatures - approaching rock melting points - would be encountered. Therefore a tool that formed the borehole by melting could uniquely solve this problem. The refractory materials and thermal engineering expertise that have been brought to bear on the subsequent R&D effort were spun-off from the AEC-NASA nuclear rocket propulsion program (Rover) which originated at LASL. In fact, the idea of electrically heating refractory metal penetrators came directly from an experimental heat transfer apparatus in which the fission heating of nuclear fuel elements was simulated by electrical resistance heating. The experience in thermal and mechanical design of such components is directly related to the analysis and testing of high temperature rock-melting penetrators. Research activities on metal and graphite core nuclear propulsion reactors for the Rover Program resulted in significant high temperature materials science technology developments. Of particular importance were the development and property determinations of specialized nonisotropic graphite composites currently used for heating elements and insulators in Subterrene penetrators.

DISSEMINATION OF THE TECHNOLOGY

It has been stated[3] that the dissemination of technical information is not identical with technology transfer. Not only is it possible, but in many cases even probable, that vast amounts of technical material can be disseminated without ever achieving a marriage between the problems of the users and the proposed technological solutions. Despite this obvious pitfall, what technologist with a potential solution to an existing problem would not begin the arduous task of technology transfer by advertising his system by word of mouth and written documents? It appears abundantly clear that the technologist must take the initiative in this matter. His task is to clearly delineate the problem areas, establish a definite need for his product or system, and then rise to the occasion of educating and persuading the decision makers into accepting his solution.[3]

For the general field of drilling and excavation technology, clearly delineating some of the major problem areas was a straightforward task. To name only a few, the following problems seemed significant:

- High costs associated with geothermal energy drilling.
- High costs associated with drilling deep wells, particularly as a result of trip time spent making downhole equipment changes.
- Hole stability problems in weak caving ground.
- High cutter costs and low lifetime when boring in very hard abrasive rock.
- Maintaining a sustained advance rate when boring in wet and variable loose ground.

Armed with data such as that depicted in Figs. 4 and 5, the first part of the case is prepared. Establishing a definite need for the new product or system is usually construed to mean having a design, perhaps even a working laboratory or field scale demonstration model, that offers a technological or economic incentive to the user in one or more of the significant problem areas. The technologist is now faced with the problem of educating and persuading the decision makers into accepting his solution. The first major step in this latter problem is often faced squarely in preparing a technical proposal for research and development work to a likely funding agency. Success in this endeavor, however, only qualifies one to undertake the real challenge of technology dissemination and transfer.

The technology dissemination efforts expended by members of the Subterrene program at Los Alamos have been extensive in both scope and depth. Approximately 40 technical papers and reports have been written by the project staff on all phases of Subterrene activities for distribution and presentation at various technical society meetings. These reports continue to be in demand and are forwarded to all interested organizations and individuals. The Subterrene was featured on the front covers of the June 1973 issue of "Mining Engineering" and the July 1973 issue of "Water Well Journal". Both issues contained accompanying articles. An article entitled "Subterrene Rock Melting Devices" was prepared at the request of the editor of "Tunnels and Tunnelling" magazine and appeared in the January-February 1974 issue of this internationally distributed publication. This publication is also the news outlet for the British Tunnelling Society. In conjunction with the application of rock-melting techniques to large diameter tunneling machines, all major U.S. tunnel-boring machine manufacturers were visited and briefed on the Subterrene concept. Technical comments and suggestions from their engineering staffs were utilized as guidelines in the conceptual study of a Nuclear Subterrene Tunneling Machine.

Technical briefings presented to interested individuals and groups by the Subterrene staff continue at the rate of about ten per month. Interested individuals and groups include members of the United States Congress, representatives of major industrial concerns, representatives of the armed forces, utility and power distribution specialists, drilling and oil-field specialists, University professors, professional engineers, and college students. For use at meetings which cannot be attended by a member of the technical staff, a short documentary color film on the Subterrene concept has been produced with narration via cassette tape.

Recognizing the importance of industrial participation and the desire for joint ventures, discussions held with Westinghouse Corp. led to an Industrial Staff Member being assigned to the LASL Subterrene project. In addition, a Technology Advisory Panel was structured and formed with the following initial membership:

- Chairman - A person with broad engineering experience.
- One member from a Federal Agency with interest and responsibilities in tunneling and excavation.
- A University professor from a civil, mining, or geological engineering department with well-recognized expertise in excavation technology.
- An economist with expertise in excavation technology.
- Three representatives from related industries.

The function of this panel is to overview all aspects of the Subterrene Program and provide balanced technical input and guidance on program direction, goals, technical achievements, significant shortcomings, and technology transfer efforts directed toward ultimate commercial utilization. To provide specific assistance in the area of the geological sciences, a Geosciences Advisory Panel has been formed which meets periodically at Los Alamos and addresses those issues which may have a significant impact on the technical success of the Subterrene.

Initial impact in the area of public demonstrations has been achieved through the use of a mobile Subterrene field-demonstration unit which performed successfully before several groups in Washington, DC. The demonstrations were held at the U.S. Army's Engineering Proving Grounds quarry area at Fort Belvoir, VA. Among the estimated 300 persons who attended one of the four scheduled demonstrations were representatives from Congress, U.S. Government agencies, the news media, equipment manufacturers, and excavation firms. A similar demonstration was conducted shortly thereafter at the Denver Federal Center in Denver, CO.

Direct assistance in identifying potential application areas for Subterrene technology was sought from Government agencies, Universities, industrial firms and industrial research centers through the mechanism of a survey applications letter. Portions of this letter are reproduced below:

> *"One of our tasks is to prepare an initial report on potential applications of rock melting for the practical problems of tunneling, excavating and hole boring.*
>
> *Therefore, we are attempting to survey those companies with well-recognized capabilities in the successful application of present-day excavation technology. We are particularly interested in the ways in which a potential rock-melting device might complement or supplement current equipment or methods. We are also interested in soliciting the ideas for applications relative to the practical needs of the manufacturer, contractor and engineer.*
>
> *We would greatly appreciate the cooperation of your organization in advising us of any applicati that rock melting may have for your present excavatio rations, or for planned projects".*

In addition to the specific suggestions and reservations that were received as a result of this survey letter, the Subterrene staff became convinced through numerous discussions, letters, and phone calls, that the contacts shared two almost universal responses to the rock-melting concept:

- The idea was recognized as a total-systems approach to the problems of drilling and tunneling and not as just another means of breaking rocks.

- Although the approach was at first considered radical by many pragmatic-minded excavation practitioners, their reactions were almost always positive and even enthusiastic. Support for continued development of the technique was nearly unanimous.

TRANSFER OF THE TECHNOLOGY

If the technologist had the same aptitude in adopting the correct marketing posture as he possessed in providing the technical stimulus for innovation, the challenge of the technology transfer task would be greatly reduced. Providing the essential ingredients for the marriage between his technological output and the cravings of his customers is often an unrecognized task of first magnitude. With regard to technology transfer and the petroleum industry, Brown[4] has stated that overcoming existing barriers with new technology will only take place if it offers advantages which can ultimately be translated into more efficient operations. The petroleum industry, like many other large industries, justifiably prides itself on its self sufficiency and competence and therefore resistance can be expected if anyone outside their confines starts telling it how to get the job done.[4]

The first significant step in the Subterrene technology transfer program occurred when eight water drainage holes were melted with a field demonstration unit at the Rainbow House and Tyuonyi archaeological ruins at Bandelier National Monument in New Mexico in cooperation with the National Park Service. By utilizing a consolidation penetrator, the required glass-lined drainage holes were made without creating debris or endangering the ruins from mechanical vibrations. Specifically, this operation has shown the following:

- Subterrenes can be operated successfully under field conditions and in areas remote from the laboratory.

- The consolidating penetrator can make its way through alluvial formations containing some moderately sized basaltic rocks by thermally fracturing the rocks and forcing the melt into the surrounding soil through the cracks.

- The Subterrene rock-melting unit was turned over to the National Park Service (NPS) after completion of the first five holes at Bandelier and after suitable training of NPS personnel. The NPS subsequently melted three more holes with minimal LASL supervision.

A Subterrene field demonstration unit was sent to the city of Tacoma, WA to participate in their Technology Transfer Field Days Demonstration at their request. After performing for the general public, the unit was viewed and operated by personnel associated with underground utility emplacements. Such demonstrations, particularly when they involve the production of useful holes by nonlaboratory work crews, are felt to be significant advances in the technology transfer arena. A brief summary of these activities is presented in Table I.

This technology is still facing, however, some of the difficult questions which arise in disseminating technological achieve-

TABLE I

LASL INITIATIVES IN TECHNOLOGY DISSEMINATION AND TRANSFER

DOCUMENTATION	BRIEFINGS	ADVISORY PANELS	DEMONSTRATIONS
LASL Reports	Technical Society Presentations.	Technology Advisory Panel	Rock Melting Demonstrations for Visitors at LASL
Technical Society Reports	All Interested Visitors to LASL	Geosciences Advisory Panel	Washington, DC Field Demonstrations
Extensive Mailing List for Reports	Visiting Lecture Tours	Industrial Staff Members	Denver Federal Center Field Demonstrations
Applications Survey Letters	Prospective Funding Agency Briefings	National Science Foundation Program Managers	Tacoma, WA Technology Transfer Field Days
Journal Covers and Articles	Major Tunnel-Boring Machine Manufacturers	Internal LASL Staff Reviews	Drainage Holes at Bandelier National Monument
Subterrene Film			
Replies to Industrial Inquiries			

ments which result from federally funded R&D projects. In particular, the areas of patents and exclusive licensing agreements are paramount. The current concept of granting "non-exclusive" licenses to stimulate commercialization of government patented technology is generally unacceptable to industry and under this procedure government owned patents by the thousands lie dormant. Unused government patents constitute more than just a simple waste of valuable resources since their very existence can exert a significant negative influence on those private sectors which might be qualified to exploit the covered technology for profit.[5] It is not difficult to comprehend why few commercial firms are interested in investing their funds or developing a market for items whose patent rights they do not control, since subsequent competition could get unfair advantage of this initial investment "for free". A postulated solution might consist of granting exclusive licenses for defined purposes within the patent, each with a specific performance clause, and including protection for subsequent government use, for any particular government patent.[5] The intended payoff to the government and the taxpayers that financed the R&D would be the timely and effective injection of the technology into the U.S. economy.

The impact of this patent problem on new technology has been illustrated in the Subterrene program. What has appeared to be keen interest on the part of industrial organizations has slowly ebbed away in light of their inability to obtain any form of exclusive licensing or protection of their proposed investments. An exception appears to be the formation of a company called Subterrene Systems, Inc. which intends to produce commercialized rock-melting penetrator components. This problem has been encountered from the proposed development of special purpose rock-melting penetrator assemblies for use by commercial organizations down to the acquisition of an industrial staff member to work at LASL, the donating organizations demanding some protection of their investment. While the solution of this problem lies outside the realm of the technologist, its eventual outcome has a significant impact on his ability to complete his technology transfer task.

In conclusion it appears that all of the preliminary steps in achieving the transfer of a new technology have been accomplished by the Subterrene staff. The technical needs were identified in depth, the applicable aerospace technology was directed toward the development and testing of a new system, and a vast program in technology dissemination was implemented. To consumate the marriage, however, a large scale commercial utilization of the technology is required.

ACKNOWLEDGEMENTS

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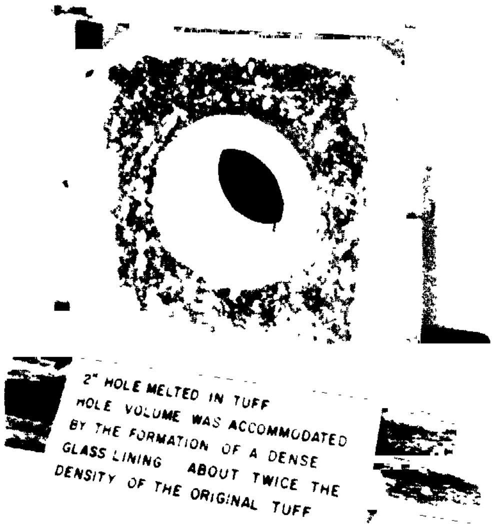

Fig. 1. Cross section of Subterrene melted hole in tuff showing thick rock-glass lining.

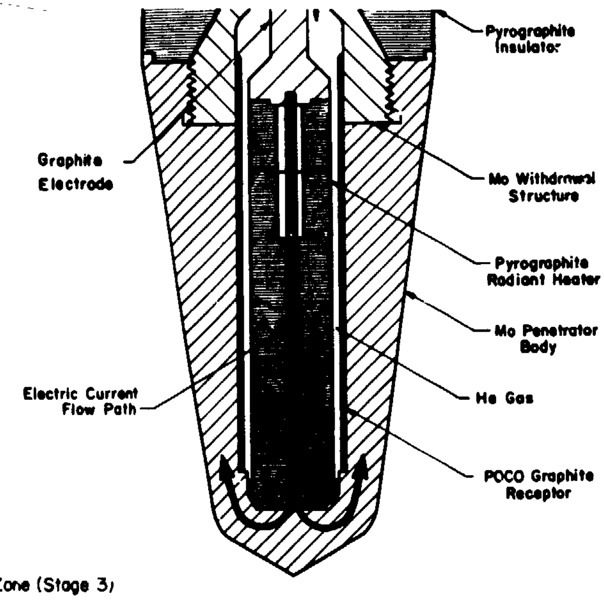

Fig. 2. Cross section of a melting consolidating penetrator design.

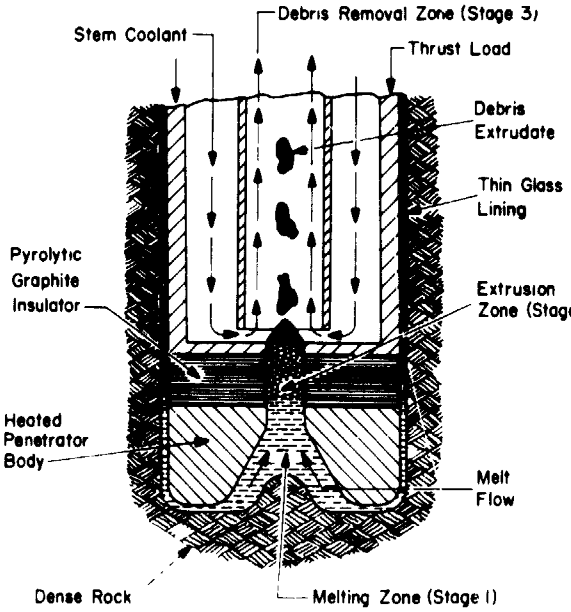

Fig. 3. Universal extruding penetrator concept.

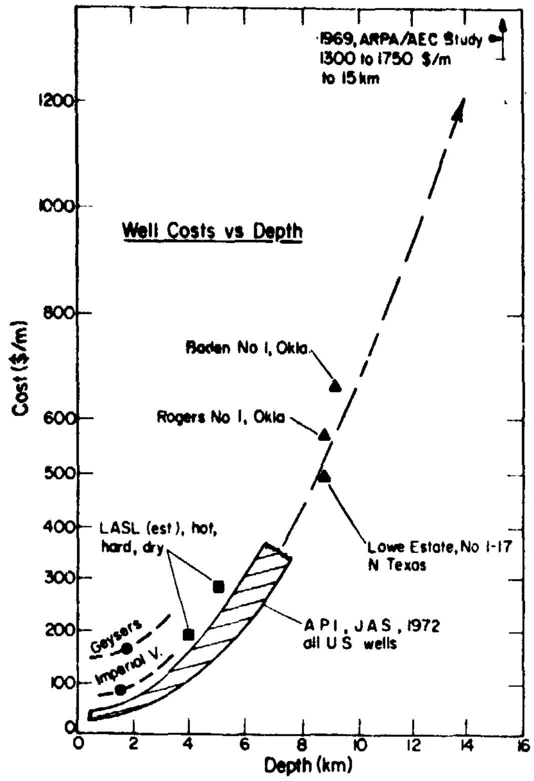

Fig. 4. Well costs as a function of depth.

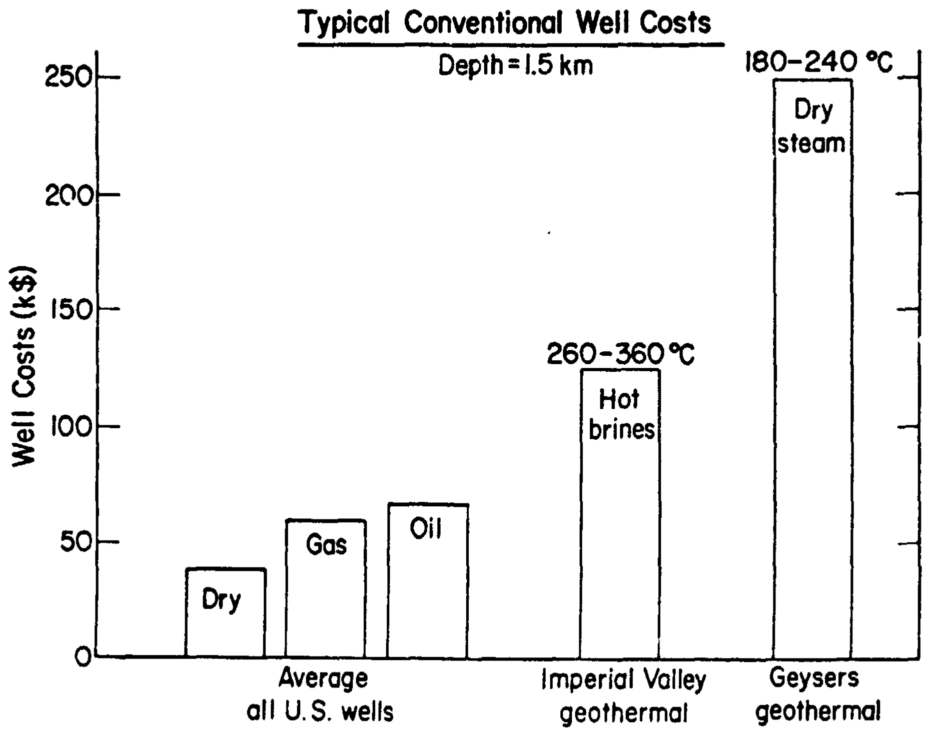

Fig. 5. Typical well costs for different applications.

THIRD SESSION

INFORMATION AND DATA SYSTEMS

SNEAK CIRCUIT ANALYSIS OF INSTRUMENTATION & CONTROL SYSTEMS

John P. Rankin

Alfred M. Williams

Sneak Circuit Analysis was begun in late 1967 by The Boeing Company as part of the Apollo Technical Integration and Evaluation contract with NASA's Manned Spacecraft Center in Houston. An analysis of the NASA Skylab was performed for the Martin Marietta Company beginning in 1972 and lasting through 1974. Most recently the analysis of the Space Shuttle has begun through a contract with Rockwell International. The use of this technology in non-aerospace industries has been initiated with analyses of Instrumentation and Control systems of facilities such as the AEC Hanford Works and Savannah River Plant.

Sneak Circuits are latent paths in electrical designs that generally exhibit unapparent cause-effect relationships and may inhibit a desired operation or initiate an unintended action. Some sneaks are evidenced as "glitches," or spurious operational modes. Historically, sneak circuits have escaped rigid design screens and resulted in delay or loss of revenue after occurrence during operation or detection in tests. As shown through five years of Boeing experience in formal sneak circuit analysis in aerospace, commercial, and nuclear industries, sneak circuits have distinct characteristics in all electrical systems. These characteristics enable formal analysis techniques to detect sneak existence in electrical designs before committing hardware to production, test, or operation. The analysis is based upon simple topological recognition characteristics and treats all normal and abnormal modes equally.

The initial effort in 1967 and 1968 evolved from critical concern for crew safety and involved detailed review of historical incidents of sneak circuits in various electrical systems. For the study, a sneak circuit was defined as "... a designed-in signal or current path which causes an unwanted function to occur or which inhibits a wanted function."[1] The definition was meant to exclude component failures and electrostatic, electromagnetic, or leakage paths as causative factors. It also excluded improper system performance due to marginal parametric factors or slightly out-of-tolerance conditions.

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The review involved a number of unexpected occurrences suspected of resulting from sneak circuits. Notable incidents were:

1. missiles accidentally launched,
2. bombs accidentally armed and dropped,
3. aircraft electrical system "unannounced failures" leading to crashes,
4. electrocution of an electric utility lineman, and
5. hydraulic analog wherein fire alarms were falsely initiated at a public shcool by the automatic sprinkler monitoring system.

One conclusion from the incident investigations was that sneaks are universal in complex electrical systems and their analogs. Historically, they happen and then are corrected. The remainder of this article will describe the evolvement and implementation of a systematic means for detecting the sneak prone designs of an electrical system which could result in such unplanned modes so that they can be prevented prior to occurrence.

MERCURY-REDSTONE INCIDENT

On November 21, 1961, the Redstone booster's engine roared to life, and the vehicle began to lift off the pad. Suddenly, after a "flight" of a few inches, the engine inexplicably cut off The booster settled back onto the pad. The Mercury capsule jettisoned and came to rest about 1200 ft. away. Damage was slight, and both the booster and the Mercury capsule were subsequently used in other tests. However, a potentially explosive condition existed on the pad, and the area had to remain clear for 28 hrs. for the Redstone batteries to drain down and the liquid oxygen to evaporate. Investigation showed that no components had failed. A sneak circuit had occurred to shut off the engine, and this in turn initiated the capsule jettison. As the booster lifted from the pad, a ground tail plug disconnected about 29 msec prior to control umbilical disconnect. The disconnect timing interrupted the normal return path to missile skin for the launch complex equipment. Thus for several milliseconds the current flowed through a sneak return path, as shown in Fig. 1. The sneak was of sufficient duration to operate the engine cutoff coil and create a surprise abort.

Study of the reluctant Redstone circuit in Fig. 1 shows that characteristics of the sneak were an interrupted ground (return) path and current reversal conducted through a suppressor diode. Additionally, the ground path interruption can be considered a timing problem similar to a relay race. However, these characteristics are merely specific clues relating to the incident. Recognition of the sneak potential of the circuit as a general case is attained by drawing the circuit as shown in Fig. 2. The approach is "topological" in the sense that unswitchable (unremovable) power is always assumed to be at the tope of the "tree" and unswitchable ground at the bottom. Figure 2 shows two trees because, barring short-circuit modes, the ignition coil circuit cannot affect the cutoff coil circuitry; that is, it is hard-wired to power above the highest level of switching in the cutoff circuit.

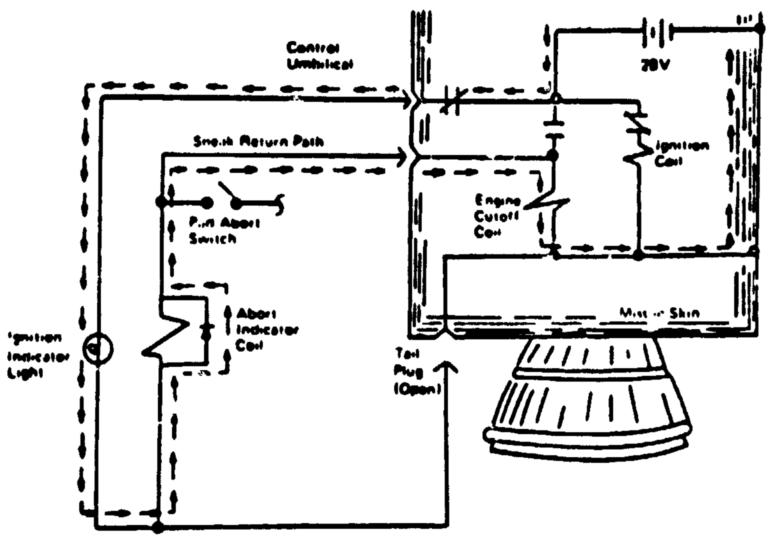


Fig. 1. The reluctant Redstone sneak circuit.

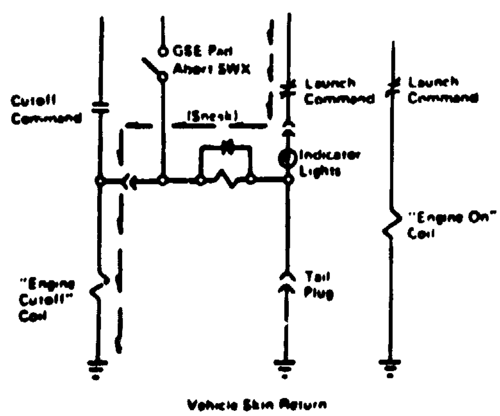


Fig. 2. "Topological tree" drawings of Redstone circuit.

Inspection shows that there is no way for a sneak to occur in the ignition coil circuit. It can only fail, or it may not be enabled when required, which is typical of single-line trees. However, the cutoff coil tree is somewhat more involved. Its "H" pattern should be immediately noted. Further inspection shows that current can reverse through the horizontal branch, depending upon switch configurations. (In this context anything that is designed to interrupt path continuity is considered to be a switch. This includes manual switches, umbilical disconnects, relay contacts, fuses, circuit breakers, transistors, and other solid-state switches.) Thus current reversal is typical of "H" patterns in topological trees. However, the probability and magnitude of reverse current of course depends upon many factors, including switches in the vertical branches, interlocks on switch operations, relative impedances in the branches, and existence of diodes or other current limiters.

The principal lesson to be learned from this example is that topological tree orientation provides a pattern recognition basis for application of specific sneak clues. Clues can be stated many ways and are quite numerous, as derived from the literature search plus Ap[illegible] experience. In fact, the number of clues and many ways of s[illegible]g them can become confusing for most analysts. Fortunately, topological pattern recognition provides an ordering of clue application that keeps the analysis simple. For example, few people immediately see the sneak possibility in Fig. 1 when the sneak path is not highlighted with arrows. However, if an analyst is forewarned that "H" patterns lead to reverse current possibilities (depending upon timing, etc., per a set of specific clues), then the sneak is readily apparent in the topological tree of Fig. 2 even without arrows Thus the reluctant Redstone provided the breakthrough for sneak circuit analysis development around topological recognition criteria.

TOPOLOGICAL TECHNIQUES

The Redstone example illustrates only one of four possible basic patterns to be considered in the topological approach to sneak circuit analysis. Before the technique is further detailed, however, it is necessary to redefine the scope of the analysis to its current use. The historical definition remains valid in that a sneak circuit is still taken to be a latent path that causes an unwanted function or inhibits a desired function without regard to component failure. However, the path may consist of wires, components, software interfaces, people (as switch manipulators), and energy (as links between coils and their contacts, for example). The sneak path will cause current or energy to flow along an unexpected route created by power supply cross ties, unanticipated ground switch operations, etc. Sneak timing may be involved to cause current or energy flow or to inhibit a f[illegible]ction at an unexpected time as in the case of simultaneous opposing commands. Sneak indications may give ambiguous or false display of system operation and cause confusion or fail to give warnings. Finally, sneak labels on control and display panels may cause operator confusion and result in application of improper stimuli or inhibits.

As previously stated, failed components are not specifically included, nor are electromagnetic interferences or parametric concerns of marginal voltages, impedances, frequencies, etc. This is not to imply that the topological technique will not be helpful in dealing with such matters; it just has not been done to date on a complete and formal basis. Such concerns, in general, address component selection in design implementations, whereas sneak circuit analysis has traditionally delved into identification of all possible modes of operation or inhibits of a system.

Sneak cirucit analysis is based upon the postulate that all topological trees consist of one or more of the four possible topographs, which can be assessed for sneak potential at each node as illustrated in the general examples given below.

Single-Line (No-Node) Topograph

The only sneak possibilities (clues) for the single-line topograph (Fig. 3) are: (1) switch S1 will be open when load L1 is desired, (2) S1 will be closed when L1 is not desired, and (3) the label of S1 may not reflect the true function of L1. Obviously, such sneaks are rarely encountered due to their simplicity. Of course, this is the elementary case and is given primarily as the default case, which covers circuitry not included by the other topographs.

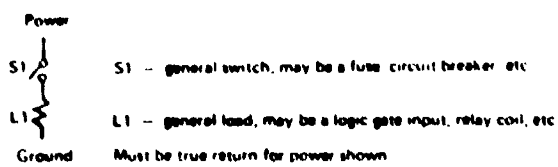


Fig. 3 Single-line (no-node) topograph.

This topograph and its clue (1) perhaps could have been used to predict the potential for incidents such as that at the Oyster Creek plant wherein secondary containment (vent closure) capability was lost while a nonrelated circuit breaker was pulled for routine maintenance.[2] It seems that the breaker module included a vent closure enabling contact set, which therefore was physically removed (open) during periods that vent closure perhaps could be needed. The same clue may also have applied to the inoperable standby liquid control system problem at Oyster Creek[3] and other such potential problems as specified in various responses to the AEC letter of December 22, 1972, which outlined the Oyster Creek problems as follows:

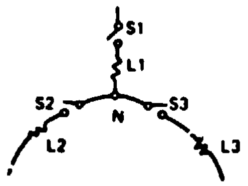
"Two incidents have occurred at a nuclear power plant that indicate a deficiency in the control circuit design that warrants a review of the control cirucits of all facilities to assure that these types of deficiencies do not exist or are corrected if they do exist. Both incidents involved the inadvertent disabling of a component by racking out the circuit breaker for a different component. In one case, this caused the loss of capability to isolate secondary containment when this capability was required. In the second case, the racking out of a breaker for one pump disabled not only the pump being removed from service but also its redundant counterpart. Both of these occurrences resulted from the use of auxiliary contacts on the movable portion of the circuit breakers in the control circuits of other components. When the breaker is racked out, the control circuit employing these contacts is opened and may be rendered inoperable."[4]

In both of these cases, switch S1 would topologically represent the physically removed (open) contact set or interlock. and L1 would represent the secondary containment vent closure solenoids on the standby pump.

Double-Ground Node Topograph

One sneak possibility of the pattern of this topograph (Fig. 4) becomes obvious when constructing the tree. If neither ground is the true return for the power supply, then there is a distinct possibility that the grounds will be at different absolute potentials. Under such conditions current can flow through L2 and L3, assuming S2 and S3 are closed, even if S1 is open to remove power. A few of the more straightforward concerns (clues) are:

1. S1 open: L1, L2, and/or L3 desired;
2. S2 open: L2 desired (and inverse of S1, S2 closed; L2 not desired);
3. S3 open: L3 desired (and inverse);
4. circuit loading through L2 bypasses L3 (or inverse);
5. label of S2 may fail to reflect the true function or control of L2 (same for S3-L3);
6. label of S1 may reflect the function of only part of the circuit, say L2 and not L3, or vice versa.



Note General switches "S" represent any current interrupter and general loads "L" may have impedance from 0 to whatever limits are applied to the scope of the analysis. Each may represent the equivalent of many individual components in series as seen by node "N" within any given topological tree.

Fig. 4. Double-ground node topograph.

There are more complicated clues for this node topograph. For example, L2 could be an indicator required to monitor operation of L3. Yet, if S3 is open (L3 off), the indicator (L2) can falsely state that L3 is on. Such a clue would possibly be used to recognize the potential for false indication and subsequent lack of alarm which was part of the Oak Ridge Research Reactor emergency cooling failure problem.[5] This particular problem was caused by seven common mode failures or errors in three identical channels; so the mere preidentification of this one part of the problem would probably not have led to a warning against all contributing factors experienced simultaneously in that incident. Particularly, an analyst could perhaps see the effects on the circuit of the various component failures but he would not suppose so many simultaneous failures and errors to be probable ("worth reporting") nor detect wiring errors wherein the system is not connected as prescribed by the installation drawings.

However, this article does not purport to enumerate all problem facets which the technique can or cannot address. That is a matter of scope of the task to stay within "practical" bounds. Furthermore, the purpose here is not to list all the sneak circuit clues for each node topograph; the clues can best be learned through application. The intent is to show that there is an orderly approach to sneak potential identification in topological trees through complete assessment of the topographs representing each node. Representative clues are given to illustrate the overall techniques.

Double-Power Node Topograph

In the double-power node topograph (Figure 5), again, one sneak possibility should be immediately evident. That is, if the power supplies are at different voltages, current can flow from one to the other and affect L1 and L2 even with S3 open. Such a power-to-power path is also potentially hazardous for other reasons. For example, with L1 and L2 near zero impedance, equipment damage can result for even small voltage differentials, and the connection negates redundancy provisions if the power points represent a primary bus and its backup. Otherwise, the applicable clues are similar to those for the double-ground node topograph with slight reorientation. One example is that opening S1 may be intended to disable L3, but S2 can still enable the load. Such networks, after tagging out the breakers (S1), electrocute people working in the load area (L3) without tagging out the breakers represented by S2. Of course, the entire problem appears so simple as to be almost absurd at the node topograph level, but unfortunately it is all too often hidden in volumes of drawing sheets in industry.

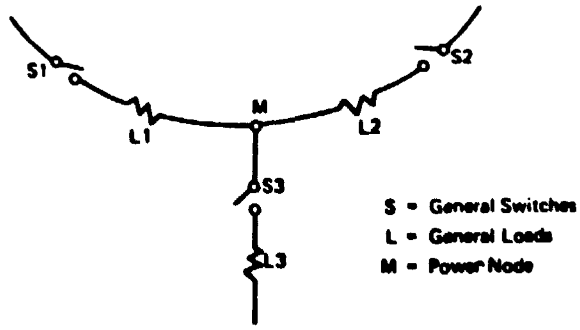


Fig. 5. Double-power node topograph.

"H" Node Topograph

The Redstone historical example has already illustrated the unique "reversing current" characteristic of the "H" topograpn (Fig. 6). During sneak circuit analysis in all types of industry, the reverse-current clue has consistently identified high potential for sneak paths and timing. In fact, all categories of sneaks are likely to occur within the "H" topograph. Similar clues as given for the other topcgraphs apply but with a greater number of interrelationships due to the compound nature of the "H." That is, the "H" is equivalent to both double-ground and double-power topographs at nodes N and M. The "H" is required, however, when a ground-seeking branch of the topograph for any node contains another node which in turn can lead to power via a different route. About 42% of all critical sneak circuits found by Boeing analyses in all industries can be attributed to the "H" pattern. Such a design configuration should be avoided whenever possible.

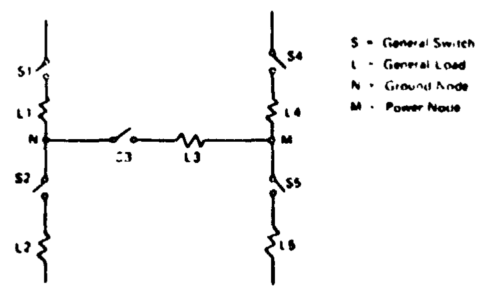


Fig. 6. "H" node topograph.

It is this pattern, coupled with failures of diodes in the cross-connection, which shows potential for problems as described in *Nuclear Safety* of November-December 1971, Failure of N Reactor Primary Scram System.[6] In this case the rod safety system failed to respond to a scram signal, and the backup ball safety system shut down the reactor. In fact, this leads to a "by-product" of sneak circuit analysis - potential electrical single failure modes and susceptibility to some types of common mode failures are detectable in topological trees using the node topograph approach. Reports to illustrate these types of conditions found by sneak circuit analysis after completion of other design checks, tests, and evaluations are given in Refs. 7 to 10.

DATA REQUIREMENTS FOR TOPOLOGICAL ANALYSIS

The node topograph approach discussed above is designed to break down topological trees, no matter how large or complex, so that an orderly analysis can be undertaken. Application of all clues associated with each topograph will ensure that no sneaks are overlooked, but the elementary concepts presented above may be deceptively simple. Some readers may even be wondering what is new about the whole process. After all, systems designers have always made "topological" sketches for their own use, so topological trees have always been around. However, the problem in large projects is that the system designers do not really design all the system, in particular, they are usually not responsible for wire routings and detailed manufacturing hookup specifications. The configuration tends to get out of hand, and all too often what the system designer intended is not exactly what is built. Of course, extensive checks and balances should reveal any discrepancies, but still sneaks have always slipped through in most major projects. Occasionally, the cause can be traced to "designer perspective;" that is, sneak circuits can "hide" within drawings. Part of what is new about the topological technique is the idea itself that sneak circuits can be identified through formal analysis using topological trees, node topographs, and clue applications to overcome perspective limitations. Many sneaks have been found within original designs where the designers fail to anticipate all possible operational modes of the circuits or try to protect the system through stipulated operating procedures. Unfortunately, such procedures have a knack for getting lost in the paperwork or deliberately ignored. Obviously, the problem is greatly compounded in multicontractor environments with the high change rates and personnel turnover that are typical of many large projects.

Moreover, by the time supportive engineering analyses are conducted, the system designer's "topological trees" are not available. In addition, as previously stated, they show design intent rather than "as-built" information. System functional schematics may or may not be provided, but they also are rarely current or complete and usually contain many errors or discrepancies from the manufacturing data. In fact, for NASA's Apollo and Skylab sneak circuit analyses, dependence upon functional or integrated schematics was ruled out as being too prone to error. System schematics are "for reference only." Sneak analysis from preliminary system schematics can be beneficial in avoiding production of hardware with built-in hazards, but eventually the construction drawings should be used to make a final check of the design implementation.

The detail schematics used for manufacturing instructions and installation are generally dependable, but they are not in a form that facilitates analysis of circuits. These drawings are accurate because they specify exactly what is built, contingent upon quality control checks, tests, and inspections. Regrettably, they rarely show complete circuits. They are laid out to facilitate hookups by technicians without regard to circuit or segment function. As a result, analysis directly from the detail schematics is nearly impossible. There are so many details and unapparent continuities that an analyst becomes quickly entangled and lost in the maze. Yet, these are the data that must be used if analytical results are to be based upon true electrical continuity. Thus, it can be seen that ther is more to the task than just knowledge of clues and node topographs in topological trees. That "something else" that makes it all work in a large, complex project is automation.

AUTOMATED SNEAK CIRCUIT ANALYSIS

Automation has been used in sneak circuit analysis since 1970 as the basic method of tree production from manufacturing detail data.[11] Computer programs have been developed to allow encoding of simple continuities in discrete "from-to" segments from the detail schematics and wire lists. The encoding can be accomplished without knowledge of circuit function. The computer connects associated points into paths and collects the paths into node sets. The node sets represent interconnected nodes which make up each circuit, and reports are generated by the computer to enable the analyst to easily sketch accurate topological trees. The reports offer selective levels of detail through which simple overviews can be provided and immediately supplemented with whatever amount of additional data is desired. The computer reports also provide complete indexing of every component and data point to its associated topological tree. Such features are especially useful in cross-indexing functionally related or interdependent trees, incorporating changes, and troubleshooting during operational support. The cross reference indexes also provide one means of addressing common mode failures while analyzing network trees. Finally, a significant by-product of automation from detail data is that schematic errors are disclosed between detail specifications and in functional or integrated drawings when compared with the computer output. Such errors in documentation obviously can affect other analyses.

RESULTS ON NASA PROJECTS

Application of the computer-aided sneak circuit analysis technique has produced some impressive results. The findings on many projects are somewhat surprising when one considers that the analysis is generally performed after design, development, test, and engineering. Fortunately, the analysis of some projects was begun earlier in the design and manufacturing phases, so that while apparently more problems are found, they can be more readily corrected. Likewise, some problems identified during early analysis would have been found during tests, but surprises in testing should be minimized. Table I quantitizes the results of Boeing sneak circuit analysis tasks on NASA projects as of August 31, 1974.

Some of the programs, notably Apollo and the Saturn IC launch vehicle, represented mature systems which had already passed traditional design checks and evaluations before sneak circuit analysis was undertaken. Still, significant results were obtained. The "after-the-fact" results reaffirm that sneak circuit analysis is not the type of activity conducted in the normal design, fabrication, development, and testing cycle by the designer, draftsman, checker, or test conductor. Experience indicates that only random sneak circuits are surfaced unless a more concentrated effort is applied.

Furthermore, the number of sneak circuits and drawing errors found after other checks points up the value of sneak circuit analysis done from an independent view. Finally, the number of problems detected in those programs involving multiple contractors, high change rates, or complex systems indicates that such programs can benefit most from sneak circuit analysis, especially if started in the preliminary design phases so to allow early (paper) solutions to the problems.

TABLE I. SNEAK CIRCUIT ANALYSIS APPLICATIONS AND RESULTS ON NASA PROJECTS

Project	Customer or Agency	Date Applied	Results	
			Drawing Errors	Sneak Conditions
Apollo Spacecraft [7,8]	JSC	1968-72	200	159
Lunar Rover (LRV)	JSC	1970-72	N/A	5
Apollo Lunar Surface Experiments Package (ALSEP) [7]	JSC	1970-72	N/A	3
MSC 20-ft Vacuum Chamber Facility	JSC	1972	N/A	1
Skylab [10]	MSFC/MCC	1971-73	500	3,000
App[illegible]ions [illegible]gy Satel-[illegible]	GSFC	1972-74	50	80
Apollo-Soyuz Test Program (ASTP)	JSC	1973-75	49	16
Saturn IC (Boeing Michoud) [12]	MSFC	1971-73	30	24
Space Shuttle	JSC/RI	1974-79	151	52
Viking Lander	LRC	1974	23	14

N/A = Not Applicable

APPLICATION TO INSTRUMENTATION AND CONTROL SYSTEM

Sneak circuit analysis have been performed on a number of Instrumentation and Control Systems. The results of these analyses have been impressive and indicate that this NASA/Boeing developed technology not only applies but that many of the benefits of the analysis also can be realized.

Many of the conditions surrounding these projects were identical to those which existed on NASA projects in that the analysis was performed after design, development, and test. The analysis of the Savannah River and N Reactor was conducted after these systems had been operating for an extended time.

Both analyses employed the same computer aided topological techniques used on NASA projects. The results obtained (see Table II) indicated that latent conditions did exist and that testing and other analyses had failed to identify all these conditions. In addition, the results indicate that sneak circuit analysis was not a part of the activity conducted in the design and construction of these systems.

The analysis conducted of the FFTF control rod mechanism was performed on preliminary designs. The value of these results are significant since the conditions they identified were corrected by revising drawings. On another Instrumentation and Control project Sneak Circuit Analysis became a serial part of the design process; thus the conditions identified were corrected prior to the hardware construction.

As on NASA projects, an independent view of the design through the application of sneak circuit analysis proved beneficial even after other checks had been made, especially on the complex instrumentation and controls systems employed on nuclear reactors.

TABLE II. APPLICATION OF SNEAK CIRCUIT ANALYSIS TO INSTRUMENTATION AND CONTROL SYSTEMS

Project	Customer or Agency	Date Applied	Results	
			Drawing Errors	Sneak Conditions
Savannah River[9] (Nuclear Plant) (portions of reactor coolant monitoring system)	AEC/ Dupont	1972	30	15
Fast Flux Test Facility (control rod driver mechanism only)	Westinghouse, Hanford Co.	1973	N/A	7
N Reactor[13] (emergency Cooling, Rod Control & Safety & Ball Control & Safety Systems)	AEC Richland, Washington	1974	13	8[illegible]

N/A = Not Applicable

CONCLUSION

The automated sneak circuit analysis has demonstrated that it will disclose latent paths, conflicting control problems, ambiguous system readouts, and the effects of false switch labels on system operators. It further reveals errors in documentation, such as wire connection errors in production schematics and lack of adequate caution notes in operating procedures. In addition to these outputs, the analysis uncovers potential single failure points, along with some types of common mode failures; highlights possible significant design improvements; and produces a computerized data base with electrical topological tree diagrams which are useful for troubleshooting, maintenance, and field modification work.

Sneak circuit analysis has been shown to be a formalized approach based upon topological techniques. The trees employed are produced from manufacturing detail data processed by a computer to orderly completion. Finally, the analysis techniques applied on a variety of NASA programs have been shown to be particularly applicable to industrial instrumentation and control systems.

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N75 17205

AUTOMATED ANALYSIS OF VIDEO DATA

Donald J. Hafner

SUMMARY

The Electro-optical Viewing System (EVS) program involved integrating low light television and scanning infrared sub-systems into the B-52 aircraft, along with providing the required logistic support. A major segment of the logistics effort entails the development of test equipment, which over the past several years, has become increasingly automated in nature. Historically, testing of video imagery generation and processing equipments has utilized manual observation and evaluation of monitor displays, and in many instances is time consuming and qualitative in nature. Semi-automated approaches, which provide test pattern setup and switching, and presentation of evaluation criteria, still require visual inspection and analysis of displays (television monitors) with attendant resolution and consistency problems. To obviate these problems, a software/hardware system has been designed and developed to perform automated video imagery analysis.

Key elements comprising the analysis system are: sampling oscilloscope, programmable trigger unit, central computer and software processing library. The function of the scope and trigger unit, in conjunction with the control computer, is to digitize the selected portion of the video image and store as amplitude and time data in computer memory. Evaluation of the video data, analogus to interpretation of a visual image, is accomplished by the processing software. Images are resolved to within 1 TV line vertically and 1/460 TV line (75 nsec) horizontally. To date, the described system has been used to test and fault isolate a synthetic video generation device used in the EVS system.

BACKGROUND

Troubleshooting of malfunctioning Line Replaceable Units (LRU's) or "black boxes" has been performed in the past by removing the suspected offender from the aircraft, connecting it to a "hot bench" and conducting manual testing to identify the failed module. However, more recently, the trend in testing philosophy has been toward increased use of automatic test systems for ground checkout of airborne equipment. With the Air Force procurement of the B-52 EVS, Boeing Wichita was contracted to provide this type of checkout capability by developing computer controlled, automatic test equipment to support this new system. The EVS system, shown schematically in Figure 1, consists of a low light level television sensor, a forward looking infrared sensor, a Symbol Signal Generator (SSG), crew monitors and interfacing equipment designed to integrate EVS into the B-52 weapon system.

The purpose of EVS is to provide the crew with "real world" images of terrain and targets forward of the airplane to complement the navigation and terrain avoidance radar displays. The four TV monitors provide cockpit displays for the pilot, copilot, navigator and radar navigator viewing.

Development of automated equipment to checkout many of the EVS units involved, to a high degree, design of an integrated hardware/software system to checkout what are primarily video units. While automatic checkout of video devices is not new, development of a generalized method of automatically checking over 100 fixed and movable geometric and character images generated by the SSG unit using a minimum of specialized test equipment proved to be a challenge. While a small degree of operator interaction with the test set is still required, ground rules dictated that it be minimized. To illustrate the potential for automated video image analysis, this paper discusses the methodology developed to check the complex video waveforms output from the SSG, the unit providing symbol and character overlays for the B-52 crew monitors.

EVS F311018 LRU TEST SET

The F311018 test set, developed by Boeing to provide EVS system checkout, is shown in Figure 2. It consists of a five-bay console comprising power supplies, stimuli, switching and measurement instruments under control of the integral mini-computer located in the right-most bay. The test program to check out one of the 14 EVS LRU's is loaded into memory by the paper tape reader in the same bay. Operator interface is provided by the KSR-37 teletype in the form of test results, commands to the operator and requests for input information. All LRU's tested connect to the test set at a common interface located in the second bay from the left. Test adapters, one per LRU, mate the LRU's to the interface.

SYMBOL SIGNAL GENERATOR

The EVS receives analog and discrete signals from interfacing B-52 systems from which it generates display video consisting of geometric and numerical symbols. This symbol video is then mixed with TV or IR video by the video distribution unit (see Figure 1) and routed to 4 crew member monitors to provide one of several possible displays as typified by Figure 3.

The SSG is synchronized to the EVS TV system by Vertical Drive, Horizontal Drive, and 13.44 MHZ clock pulses generated by the video distribution unit to provide a monitor presentation compatible with a 2:1 interlaced 875 line raster scan format. Locations of all symbols are specified in a Vertical (V)/Horizontal (H) coordinate system with 2 raster lines (1 per field) comprising a vertical resolution element. Horizontal element size is established as the reciprocal of the 13.44 MHZ clock (or approximately 74 nanoseconds). The image as viewed on the monitor is thus composed of 420 vertical by 460 horizontal or approximately 190,000 discrete picture elements.

The EVS test set is required to automatically check approximately 90 fixed and 20 movable characters generated by this LRU.

GENERAL TEST FORMAT

Major test set elements involved in checking symbol video are shown in Figure 4. The SSG is powered up and furnished timing and selected simulated B-52 systems input based on the specific test being performed. The appropriate SSG video output terminal is then connected to the vertical input of the Tektronix 568 sampling oscilloscope and the programmable trigger generator is connected to the horizontal channel to provide sweep triggering. The trigger generator and sampling scope are then programmed, the waveform is sampled and resulting voltage levels stored in the computer. When sufficient samples have been obtained, the stored data is analyzed and test pass/fail results determined.

APPLICABLE TEST SET ELEMENTS

Computer

Test set operation is under control of a Hewlett Packard 2100 mini computer (2nd unit from top, right hand bay, Fig. 2), configured with 32K words of core memory.

Sampling Scope

While similar in general appearance and waveform display function to a conventional oscilloscope, the sampling scope (second unit from top of the center bay, Fig. 2) differs significantly in that:

1) its functions can be programmed under computer control, and
2) the displayed waveform can be sampled and digitized to form a set of up to 1000 10-bit words, each representing a voltage level along the monitored waveform, sampled at equally spaced intervals.

Setup is performed under computer control, supervised by the SSG test program, which must compute and specify the 10 scope setup parameters (including vertical scaling, sweep speed, time delay, etc.) for each symbol part checked. Once set up, the sampling scope assumes control, transferring the waveform samples to computer memory as they are obtained. The waveform thus stored has a resolution of 1 part in a 1000 and an accuracy of 3% along both the voltage and time axes.

Sync Generator

This unit supplies timing signals as required to support various LRU tests. For the SSG tests considered here it is programmed and connected to supply vertical drive, horizontal drive and 13.44 MHZ clock pulses to the SSG.

Programmable Trigger

The programmable trigger is phase locked to the sync generator and can be programmed to provide a trigger to the sampling scope at any one of 16 equally spaced positions along any TV raster line or group of raster lines in either or both TV fields. Given the V/H coordinates of an SSG symbol, the test program can calculate the programmable trigger setup and appropriate scope delay to sample any element of the symbol.

TEST PROGRAM

Details of the video sampling and analysis technique used in the test program are illustrated by a specific example in Figure 5. To check the integrity of the digit 5 on the radar altitude scale, test number 3221 calls subroutine SYMB as shown in the figure. Each element of the character 5 is then sampled column wise and stored in a 5 x 9 array for subsequent analysis.

Figure 6 is a flow diagram for the same example. Once the specified character and its position coordinates have been established, switches are closed to connect the SSG and programmable trigger to the waveform analyzer and processing begins. Timing to read in the first column of the character (5 in this case) is computed from the V and H coordinate data. The programmable trigger setup and waveform analyzer setup including appropriate sweep delay is accomplished using the computed timing information. A column of data (9 points in this case) is then read and stored in memory. The process is repeated for the required number of columns (5 in this case). The array of stored voltages is then examined for highs in the proper elements and the test passes if this condition is met. Symbols which can vary a few resolution elements from the nominal location are overscanned to allow for these tolerances. A symbol correlation routine is used to establish the presence or absence of the required symbol. If this action fails to produce the symbol image, the test is failed and control is returned to the test program.

The SSG test program contains approximately 345 automatic video tests similar to the above in addition to power supply checks, several manual observations and 40 possible adjustments. Faults are isolated to the card level. Test time for the automatic video checks is approximately 30 minutes. This test system is presently providing field level support for the B-52 Electro-Optical Viewing System at approximately 15 SAC bases scattered across the U.S.

This technique of video image analysis, while illustrated by a specific example herein is general in nature and is judged applicable to a wide variety of applications involving automatic video data and image analysis.

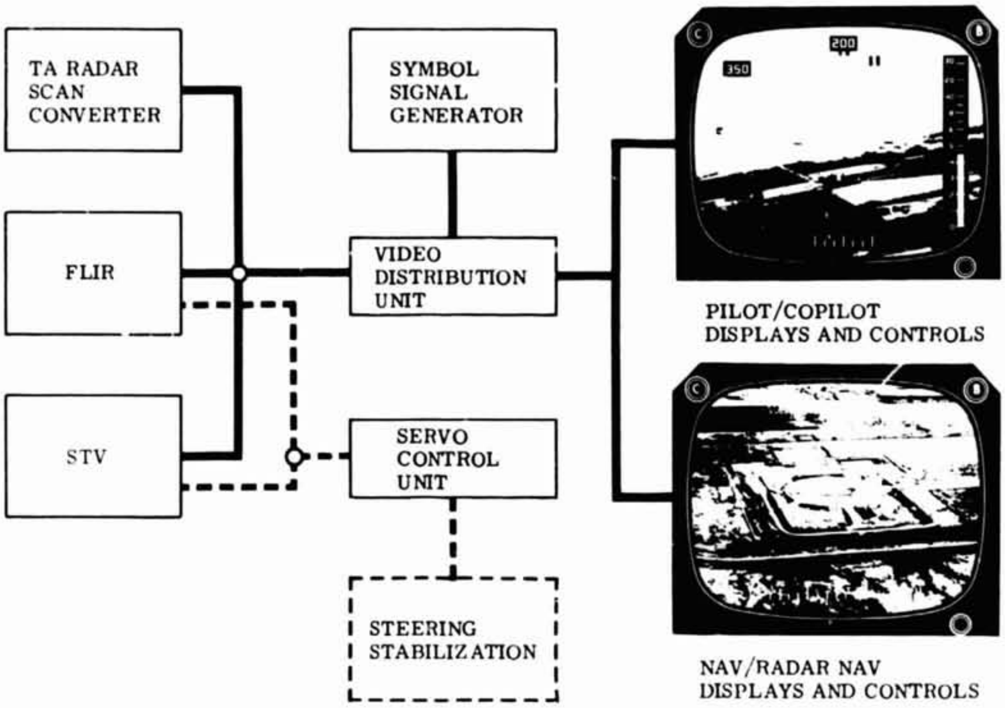

FIGURE 1 B-52 ELECTRO OPTICAL VIEWING SYSTEM

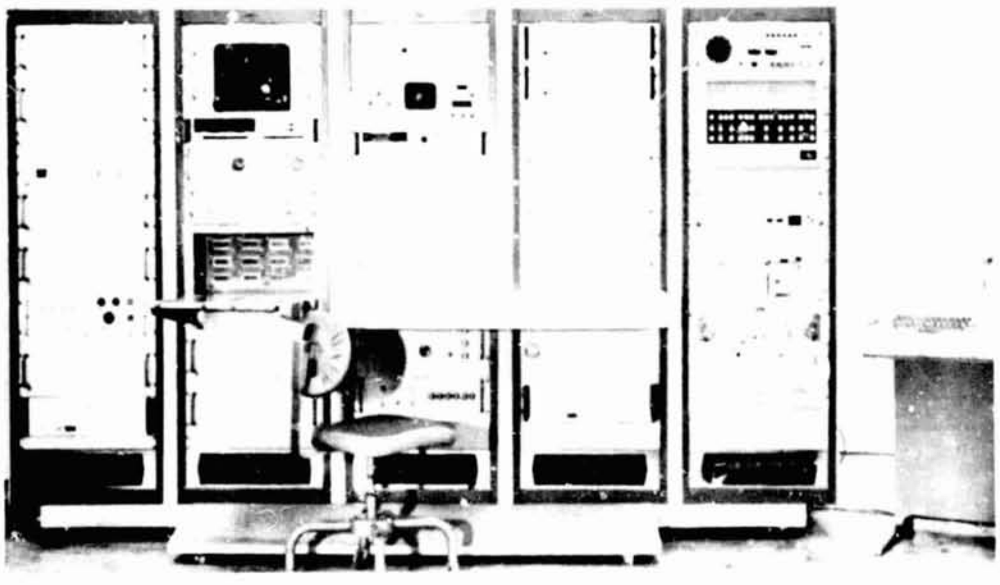

FIGURE 2 F311018 LRU TEST SET

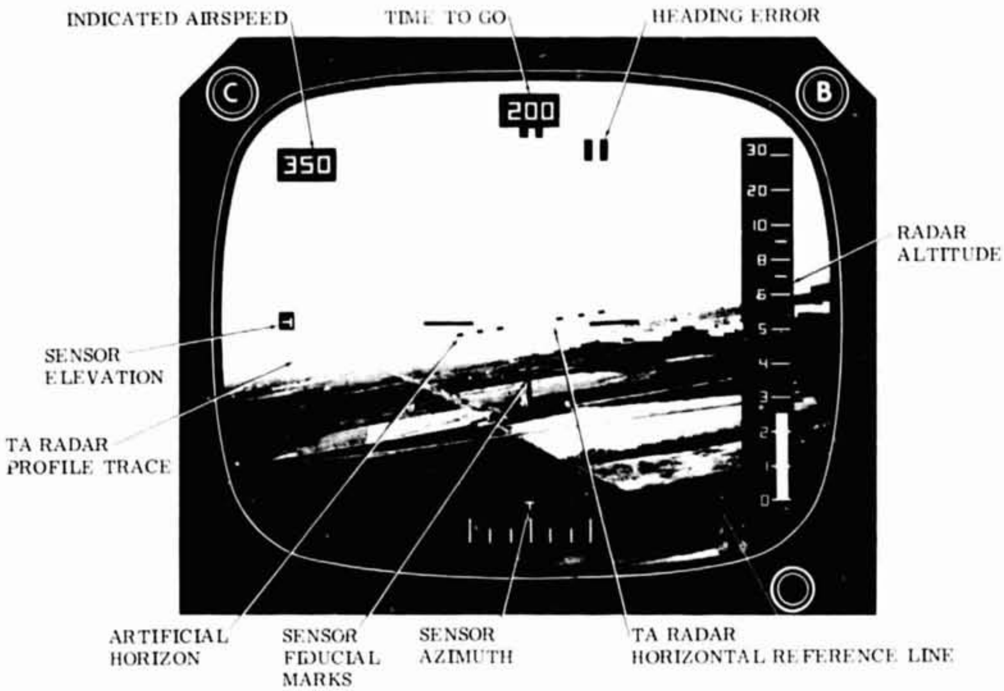

FIGURE 3 TYPICAL SSG SYMBOLS ON PILOT'S MONITOR

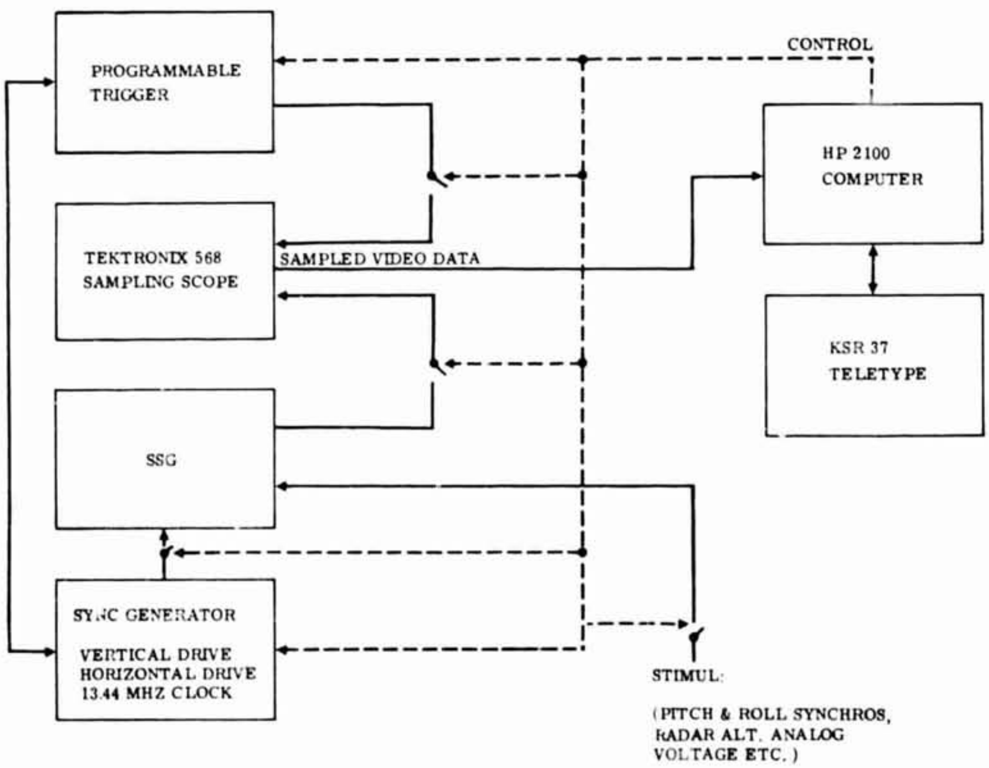

FIGURE 4 TEST SETUP

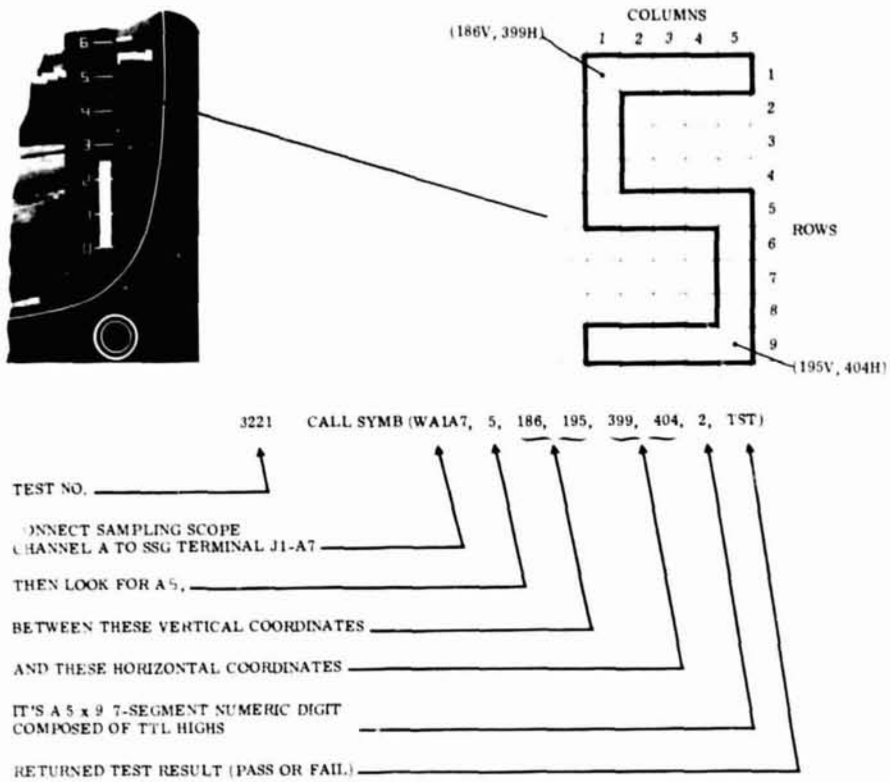

FIGURE 5 TYPICAL CHARACTER TEST

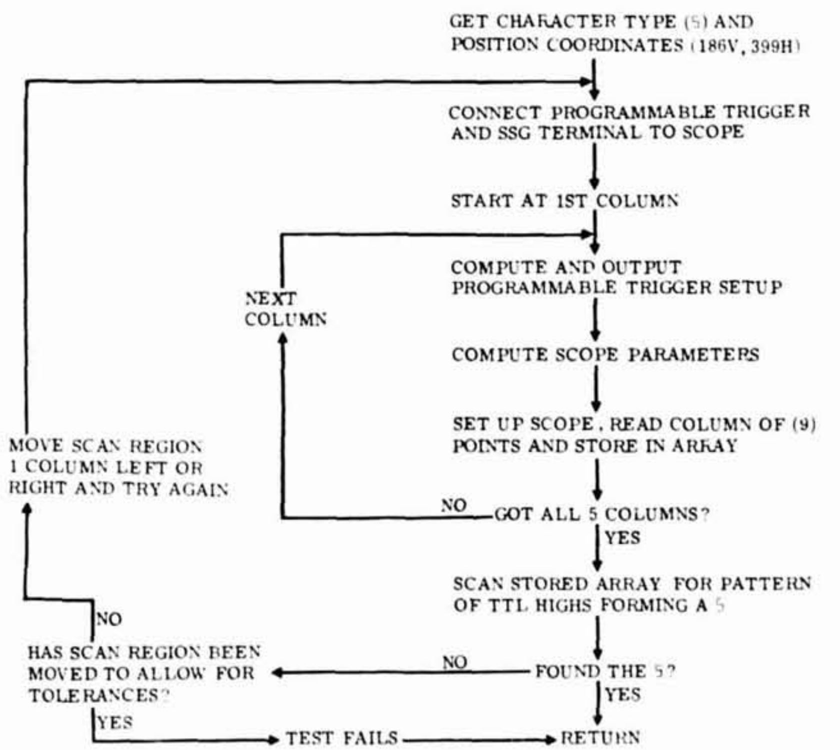

FIGURE 6 VIDEO ANALYSIS FLOW

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APPLICATION OF NARROW-BAND TELEVISION TO INDUSTRIAL AND COMMERCIAL COMMUNICATIONS

Bernard C. Embrey, Jr.
Glen R. Southworth

The standard closed-circuit or commercial television systems transmit 30 complete images each second resulting in achieving the illusion of motion in the viewers eye. To do this, these systems require at least 4 MHz of information bandwidth to transmit a television picture of the quality which the public is accustomed to viewing. This is a very large amount of spectrum when compared, for example, with that required to transmit "broadcast quality" voice information--between about 5 KHz and 9 KHz. Further, there are considerably higher costs involved in transmitting and receiving a 4 MHz television signal--both in the power required and the complexity of the equipment needed at both ends.

For many applications, especially when the subject is stationary, slow-scan television can be used. Slow-scan television is essentially a video system that requires typically one second or more for transmission of a single frame of information (actually any rate less than the standard would qualify). This can be compared to using a slide projector versus a movie projector. Moreover, the slow-scan television technique requires only a fraction of the information bandwidth of the standard video system thus facilitating its use with much less sophisticated equipment and power.

It became very evident to NASA engineers early in the space program that the transmission of visual information from space would be extremely useful both as a data gathering tool and as an information dissemination means to the public. However, extensive work would have to be undertaken to devise a means to severely reduce the size, weight and power of the system to be used onboard the spacecraft. By utilizing a slow-scan television technique coupled with various other parameters dependent upon the particular mission's requirements, it appeared that television from space would be feasible. The reduced complexity of the equipment would contribute to a smaller and lighter overall system, while the power requirements of the transmitter would be sharply reduced via the narrow-band approach. However, there was obviously much development necessary before a working system would be attained.

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Various studies were undertaken and prototype systems developed. Among the variables that were necessary to be evaluated were: (a) the scene content including the lighting conditions, contrast, amount of motion within the scene, monochrome or color, etc.; (b) the resolution required; (c) the allowable bandwidth of the transmission system; (d) the modulation technique to be employed; (e) the scanning technique required as a result of a combination of the above requirements; and (f) the requirement to transmit visual information from deep space with minimal noise degradation.

Both analog and digital systems were developed and evaluated. One of the most promising analog systems evolved from an early study performed by the Hughes Aerospace Group (References 1 and 2). This study primarily concerned itself with evaluating various methods of converting an optical display into a minimum bandwidth video signal that could best be used for transmission from deep space; i.e., that would be the least susceptible to video noise. Three processing methods were compared: multiple interlace, edge detection and frame correlation. The conclusion was basically that the multiple interlace system offered decided advantages over the other systems.

This system reduces the required video transmission bandwidth (to approximately 100 KHz) by employing the reduced resolution characteristic of the human eye when viewing objects that are moving within the field-of-view. The bandwidth required by a standard high resolution-high frame rate video system is decreased by either reducing the resolution of the picture transmitted for objects moving relative to the field-of-view (not reducing the frame rate), or reducing the frame rate but keeping the resolution high for static scenes. The latter case is achieved by superimposing a number of low resolution, high frame rate pictures. Instead of a variable intensity line for the reproduced picture, the elements are variable intensity dots. These low resolution frames were pseudo-randomly selected for encoding at the transmitting end. The meshing of these frames at the receiving end becomes the multiple interlaced fields which compose the high resolution picture. The major advantages of this system are that either situation may be employed as the scene content varies and that this selection may be made at the receiving end of the system. The primary disadvantage is that although the equipment required at the transmitting end is not very complex, the receiving equipment includes a decoder, a storage device, and a scan converter all of which are special purpose, relatively complex units. The sampling technique employed in this system has been more or less used in many other systems presently being sold commercially, some of which will be discussed later.

The unmanned deep-space exploration program has employed television quite extensively throughout its history on the Lunar Orbiters, the Surveyors, the Mariners, etc. As these systems must operate with minimal power, the television pictures must be transmitted via a very narrow transmission bandwidth. Typically, these systems take single frames of television data and code the individual elements into a sequence of binary digits that represent the level of light intensity. These data are stored on onboard tape recorders and played back for transmission to the ground at a later time at very slow data rates. For instance, each television picture recorded during the Mariner IV mission to Mars in 1964 (Reference 3) contained 40,000 picture elements each encoded into a 6-bit word--240,000 bits of data. The transmission of one of these pictures took about 10-1/2 hours--less than 7 bits per second.

One of the major efforts at JPL (Jet Propulsion Laboratory) to develop the systems for very deep space video transmission was performed by Ball Brothers Research Corporation during a series of research and development contracts that culminated in a video-modulation test system (Reference 4). This system was designed to generate a high-quality video signal with the resolution controllable from approximately 100 x 100 picture elements to more than 1000 x 1000 elements. The output signal was therefore variable from a bandwidth as narrow as 100 cycles to as wide as 8 KHz--all within the audio spectrum.

These efforts to design and build narrow-band video systems for use in space systems have not only stimulated the organization directly involved in developing improvements and advancements in the state-of-the-art, but also many other groups who in order to stay abreast of the field have performed in-house efforts in the same area. Also, specific portions of the overall system are advanced and improved within their individual segments of the industry. Such items as superior television image tubes, modulation techniques and devices, data encoders and decoders, etc., have seen tremendous advancements both as a direct and indirect result of the space systems evolvement. Reliability and quality control--of major importance in a system designed to operate millions of miles from earth--procedures have been greatly improved. All of these benefits are transferred into other fields such as medicine, computer processing for industry, security, transportation, etc.

Due to its major impact on all segments of industry and the demand for major, rapid advancements, the Apollo program has been considered by many observers to have been the greatest single stimulus to a very broad spectrum of the technological community. The pictures of astronaut Neil Armstrong's first steps onto the surface of the moon were provided by a slow-scan television camera that was capable of two selectable scan rates--a reduced resolution 10-frame-per-second primary rate and a high resolution 0.625-frame-per-second rate for use in taking very detailed scientific pictures that had no motion in the scene. The necessity for a slow-scan camera was due to an available transmit bandwidth of only 500 KHz. Later spacecraft were able to take advantage of increased ground station capability and a higher transmission bandwidth--early mission testing showed it to be closer to 1.5 MHz--to employ a standard frame rate field-sequential color camera. However, it should be noted that this still resulted in a narrow-band system since each color was updated only 20 times a second and the available bandwidth still limited the attainable resolution.

NASA's continuing efforts in the compressed video area of development will be applicable to future spacecraft requirements.

One future spacecraft application of narrow-band television in the Shuttle era is the possibility of including an uplink text and graphics subsystem. This system would have the capability to receive, store, display and hardcopy any type of written or pictorial message the ground controllers might need to send to the astronauts. However, at present neither the requirement nor the method of implementation has been definitized. But as motion within the scene is not seen as a requirement, the narrow-band television system offers a very good candidate method of implementation.

A detailed look at a good example of NASA's influence in stimulating development within the industry in the narrow-band television field and the resulting transferral into other useful commercial avenues of application is described in the following portion of this article.

In the fall of 1960 Ball Brothers Research Corporation formed a small group called the Digital Television Department. Dr. David Stacey, director of engineering for the company, established as guidelines: first, to seek NASA and other government agency contracts; secondly, to establish methods of translating capabilities and knowledge, directly or indirectly derived from such contracts, into commercially useful products. Roy Salaman headed the new department and brought a wealth of knowledge in the then new and exotic field of encoding television images into digital form. Some of the goals to be sought after by the group included highly efficient transmission of television images, perhaps allowing ten or more television stations to operate in the spectrum space now used for a single channel, or possibly leading to the recording of a complete television program on a phonograph record. Computer scrambling of pictures was another area of interest, as it was felt that this might be essential in the eventual usage of person-to-person television communications in critical industrial, government, or medical applications. Third, transmission of TV signals in digital form would allow very long distance, noise free, communications.

The first contract received by the new Digital Television group was from the Jet Propulsion Laboratory in Pasadena, California. Termed MARFE, an acronym for Mars Feasibility study, the contract involved the use of Delta Modulation encoding techniques as applied to single frame television pictures. The resulting activity on the part of the fledgling Digital TV department could be described as intense, and resulted in a series of breadboard hardware devices including encoders and specialized test instruments. The end results of the study, in today's terms, were not particularly sophisticated, but gave the Ball staff members a good solid grounding in the theory and hardware involved in this new area of technology.

Company funding of internal research by the TV group also played an important role, and in the spring of 1961 a high speed encoder capable of digitizing and reconstructing standard commercial TV signals was publicly demonstrated at a communications conference in Washington, D. C. Shortly after that the company was heavily involved in laying the technical groundwork and preparing proposals for the Apollo Television subsystem. This activity persisted for several years and, though not resulting in actual contracts, greatly enhanced the department capabilities and provided the distribution of a number of potentially useful concepts throughout the industry.

In the 1960-65 period, technical innovation in the Ball Brothers Digital TV group was kept at a high level by the following factors:

1. direct contracts from NASA and other agencies

2. in-house project funding

3. proposal efforts

The last item is quite significant as in many instances a proposal might not have resulted in a contract award but did stimulate a great deal of creative thinking and frequently the generation of laboratory hardware to back up assertions or to demonstrate actual feasibility.

In 1964 Ball Brothers Research started to translate new technology into commercial products in terms of high speed digital television systems capable of handling NTSC color signals, a new generation of TV special effects generators, versatile, high quality, laboratory television systems, and prototype equipment for the transmission of TV pictures over standard "dial up" phone lines.

Ball Brothers has continued to be highly active in the commercial marketplace to date, but in 1965 a series of spinoffs commenced which has resulted in the formation of more than 15 small companies. One of the first of these was Colorado Video, formed in March 1965 on the following premises:

1. That television technology had a great deal of potential in the field of instrumentation, both for the display of data and for the processing of visual information by computer.

2. That video techniques might be successfully applied to a number of industrial problems, particularly in the area of automatic inspection of manufactured goods by a combination of TV camera and signal processing equipment.

3. That an extremely large market might eventually exist in the transmission of still TV pictures over ordinary phone lines, rapid retrieval of images for personal use, and many other communications applications in industry, teaching, medicine, and government.

The basic philosophy of Colorado Video was that it would be a hardware house, designing and manufacturing video instruments, initially for research laboratories, under the following subrationalizations:

a. That there was no existing market for this type of equipment, and consequently CVI would have to depend upon imaginative engineers in NASA, Universities, and industry for initial support.

b. That by interreaction with this kind of customer, the CVI technical staff could provide a continuous product development program while searching for viable markets.

Over the years support has come directly from NASA in terms of hardware purchases from the Johnson Space Center, JPL, Marshall Space Flight Center, Langley, Edwards, and Goddard centers. Indirectly, equipment purchases through NASA contractors such as the University of Arizona, MIT, Philco-Ford, and many others have been very significant in the expansion of CVI's product line and technical capabilities.

The most important area of CVI's work is in narrow-band television, or compressed video. Normal broadcast television signals require approximately 4 MHz of spectrum space, or the equivalent of more than 1000 telephone conversations. 60 nearly identical pictures are transmitted every second and a great deal of wasted information is generated even in a single picture. Compressed video, on the other hand, may involve the removal of picture redundancies either in time or space to provide far lower bandwidth requirements. A number of significant advantages result: first, transmission range may be greatly extended; second, many communication channels may be fitted into the space required by a normal TV picture; third, compressed video signals are easily computer processed.

There are a number of methods of generating narrow-band television signals, but economics and the wide availability of existing television terminal equipment such as cameras, monitors, and related devices, have strongly indicated the desirability of converting standard TV signals to narrow bandwidths, then, after transmission or processing, reconversion to standard TV format for viewing of information on conventional low cost television sets.

The main approach to bandwidth compression taken by Colorado Video which stems from the earlier NASA-related developments is first to sample original television signals--that is, break them down into a series of dots--then process individual picture elements in a variety of ways to achieve low data rates. Reconversion of the compressed video signals back into standard television images is accomplished by means of a magnetic disc memory, an area of technology which provides relatively low cost, large capacity picture storage in either color or black and white.

The potential communications applications of compressed video are very far reaching. From a personal standpoint, it now seems likely that this form of point-to-point video service will be available quite a bit sooner than the widely advertised "Picture-Phone." This is because of the fact that the cost of setting up a new, wideband, switched video service is incredible, while compressed video signals may be easily transmitted over the presently existing telephone network. Similarly, the spectrum space required by compressed video signals is of the order of 1/1000th of that of conventional TV, with resultant savings in transmission cost. Compressed video signals are also easily recorded and computer processed, thus making the filing of large amounts of visual information a practicality.

In the medical field alone the use of compressed video may turn out to be of great benefit to the small and medium sized community. Specialists tend to congregate at major hospitals in large cities, with the result that expert diagnostic assistance is usually not available in outlying areas. Transmission of compressed video images over existing voice grade circuits will allow a physician to remotely observe wounds, fractures, and other forms of external disabilities. Similarly, X-ray, nuclear, ultrasound, thermographic, and other forms of images may be readily transmitted and diagnosed, perhaps with the assistance of a large central computer. Reverse channel picture transmission may be used to provide emergency instructions, for equipment repair assistance (highly skilled technicians aren't necessarily found in small towns, either), to provide medical training programs, and to give the local medical personnel access to central data files.

A small program in California involving the remote diagnosis of nuclear imagery was considered quite successful. Another project at the University of Wisconsin has involved formal medical instruction via phone lines. The Veterans Administration is now readying a multi-level diagnostic research project involving color transmission over both phone lines and satellite. The University of Nebraska is currently evaluating remote X-ray analysis, and a scattering of medical research projects in the U.S. and Canada are awaiting funding. Colorado Video is also working with medical firms here and abroad to introduce commercial grade compressed video equipment to hospitals and clinics.

In education the utilization of compressed video signal transmission for teaching purposes has involved Colorado State University, South Bend Public School System, Michigan Technological University, Northwestern University, Southern Illinois University, and the University of Missouri at Rolla. Two of these schools have used ordinary telephone lines, while the others have been experimenting with the broadcasting of compressed video signals over the subcarrier channels of FM radio stations. This allows a station to carry its normal programming while simultaneously transmitting still pictures, together with an instructor's comments, to groups of students anywhere within the service area of the station.

Approximately seven seconds are required to transmit a picture over the FM station subcarrier, with image clarity about equal to that of a home TV set. The equipment required is relatively simple, easy to install, and easy to operate. Transmission costs are much lower than with conventional educational television stations, and the media is not nearly as difficult to adapt to, inasmuch as the lecturer needs primarily to be sure that he has something worthwhile to say, and brings along a number of pertinent illustrations.

A brief sampling of other applications can include remote sensing such as traffic control, ship movements, radar remoting, and weather observation. A pilot "Weather Watch" installation has been in operation at Stampede Pass, Washington, for over a year now, and allows aviators at Boeing Field, Seattle, to look at a TV screen showing pictures of actual conditions at the pass.

Security uses of compressed video include signature verification, identification, gate observation, area surveillance, and malfunction analysis. The ability to actually view a picture of the situation at a remote location can be critical in regards to the response taken to an alarm. As one user put it: "It's not very efficient to drive seven miles out into the desert to chase off a few jack rabbits or a coyote. If we can see an actual picture of an intruder, or perhaps fire or wind damage, then we know how to respond."

In general communications, the potential uses of compressed video are as varied as human contacts: business conferencing, exchange of technical or scientific data, insurance claim adjustment, silent paging, troubleshooting, remote viewing of real estate or construction sites, and many more. The important thing is that we don't have to wait for the whole world to be newly wired; the technology is being used now and should expand greatly in the next decade.

It is important to note that there are also many non-communications uses of compressed video. Industrial inspection and control by means of specially processed TV signals is an extremely interesting area, with firms such as IBM, General Motors, Western Electric, Bell Telephone Laboratories, General Electric, Ford Motor Company, Owens-Illinois, Signalite, Philips, Corning, Proctor & Gamble, RCA, Polaroid, Bendix, Brown-Boveri, American Optical, Consolidated Edison, Grumman, Pharmacia, Kodak, and others utilizing CVI equipment for applications such as automatic inspection of parts, intrusion detection, pattern recognition, non-contact measurements, waveform analysis, computer machining of components, and remote observation.

The combination of television camera and computer provides very special opportunities in data processing, relieving humans from tedious inspection tasks in industry and also allowing for the enhancement of images and extraction of information beyond the capabilities of the human mind and eye.

Colorado Video also works with medical research institutions throughout the world, and provides instruments for image analysis and computer input/output. A few typical projects include:

- Computer analysis of red blood cells at the Presbyterian St. Luke's Hospital in Chicago.

- Measurements of heart chamber volume by means of video densitometry at the Chedoke Hospital in Toronto.

- Analysis of human limb movement at the University of Washington.

- Measurement of blood cell wall diameter at the University of Virginia.

- Computer controlled machining of artificial limbs at the University of British Columbia.

- Analysis of blood cell clumping at the University of California, San Diego.

- Computer analysis of cell colonies at the University of California, Berkeley.

At present, Colorado Video has a product line of over 40 video instruments which are sold throughout the world. In many instances, CVI provides an intermediate stage of technology transfer, providing relatively low cost hardware to research scientists and engineers operating in many areas of investigation.

In conclusion, experience has shown that technology transfer may operate in many complex ways. Colorado Video is only one of a large number of firms started by NASA "graduates" with the courage and vision to attempt to translate knowledge and capabilities gained in the space program into tangible products and services for the benefit of mankind.

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N75 17207

IMAGE DATA PROCESSING OF EARTH RESOURCES MANAGEMENT

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The Earth Resources Technology Satellite (ERTS-1) was launched on July 23, 1972. Since that date, the vehicle has been acquiring and transmitting to earth a vast amount of information relating to the earth's resources. Scientifi·· investigators throughout the world have been analyzing photographic products produced from this data with significant results. Recently, there has been a major shift of emphasis from the visual analysis of photo products to the use of sophisticated digital information extraction techniques. Specialized equipment, such as the GE IMAGE 100 System, has been developed that operates directly from Computer Compatible Tapes, (CCT's), which contain preprocessed digital data acquired from the ERTS spacecraft. Analysis of CCT data avoids the losses in image resolution and quality which are inherent to all photo processing techniques, thereby greatly increasing the utility of ERTS data. Future ground processing systems will turn out fully corrected (radiometric and geometric) digital tapes which will further increase the utility of ERTS data.

This paper is presented in two parts: the first part deals with the subject of present and future generations of image processing and information extraction systems under development at the General Electric Company; the second part describes in more detail the design and operation of GE's interactive multispectral information extraction systems, IMAGE 100, and discusses results of analyses of ERTS data over a number of U.S. sites.

RESOURCE MANAGEMENT & REMOTE SENSING

The intelligent use of our natural and man-made resources, the control of pollution and waste, the prediction and control of weather, the development and management of food production and the efficient, planned use of land space are several constituents of a process generally referred to as "resource management". The pervading theme of this process is one of knowledge of the problem, decision, action, and observation or "monitoring" of effectiveness of action taken.

The various interrelationships which exist among our resources and environment, and the variety and magnitude of the pressures to which they are subjected, presents a situation which is extremely difficult to understand, let alone control. One of the most powerful tools available today is that of remote sensing of the environment by aircraft and satellite. The launch of NASA ERTS-1 spacecraft on July 23, 1972 has resulted in the ability to collect enormous amounts of data from large areas of the globe quickly and accurately, and to provide this data to the users in an organized form. From this data the user can deduce much of the information needed to understand the resource which he must manage. The flow of this data is shown in Figure 1.

The ability to collect remotely sensed earth resources data far exceeds the present capability to process the data such that it can be utilized in an effective manner. This situation has occurred because as advances in data acquisition techniques have been made (e.g., higher resolution sensors, spaceborne platforms, etc.) the technology for processing the data has advanced at a much slower rate. The state of the art in data acquisition from

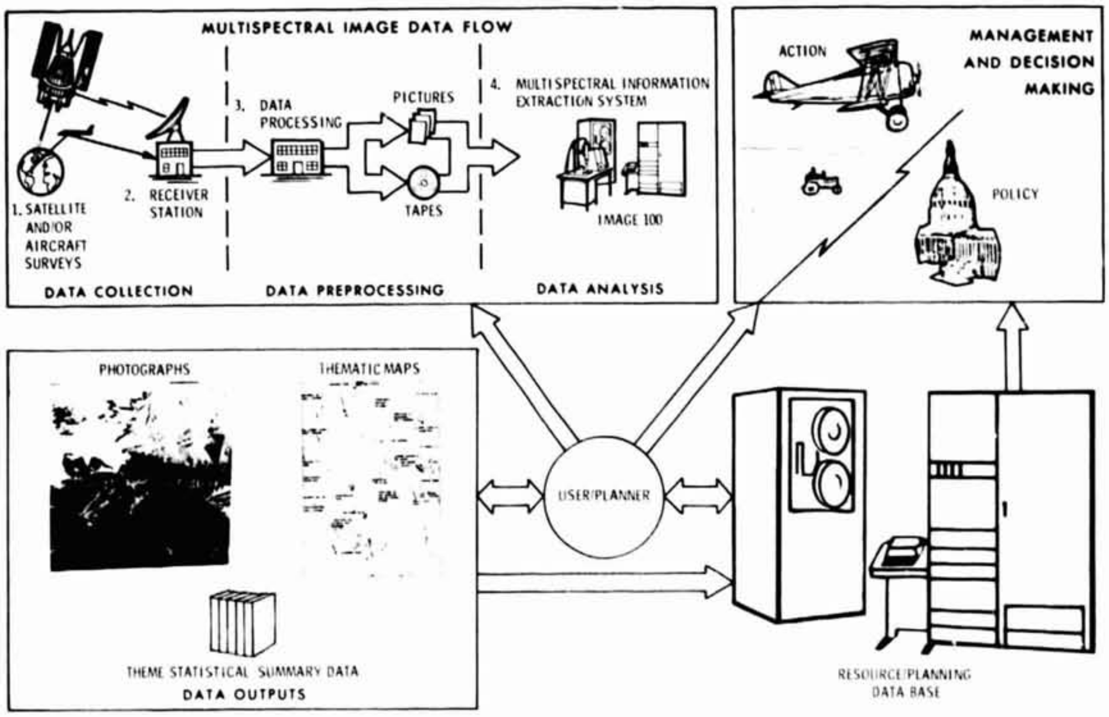


Figure 1. Earth Resources Data Systems

space will continue to advance rapidly over the next decade, but unless the image processing technology advances at a much faster rate, the utility of the data will be severely limited. In addition, while current user emphasis is on spectral processing of multiband imagery, future applications will increasingly involve temporal as well as spectral analysis in which images must be registered to extremely high accuracies. Images acquired at different times will contain different geometric and radiometric errors, be from different origins, at different scales, and may even be derived from different sensors. Methods for providing the necessary corrections and registration must be evaluated and reduced to practical hardware and software.

IMAGE PROCESSING

Figure 2 depicts the generic image processing system which consists of two primary functions, preprocessing and extractive processing, plus the auxiliary functions of storage, reproduction and distribution. Preprocessing shown in Figure 3 includes all those operations which are necessary to retrieve the desired information (i.e., approximate distinguishing characteristics) from sensor data which has been radiometrically and geometrically contaminated by "noise" during the collection process. Extractive processing includes all those operations which convert the approximate distinguishing characteristics to user oriented parameters, shown in Figure 4. The auxiliary functions of data storage, reproduction and distribution occur throughout preprocessing and extraction processing and greatly affect their manner of implementation.

The number of applications derived from data produced by the Earth Resources

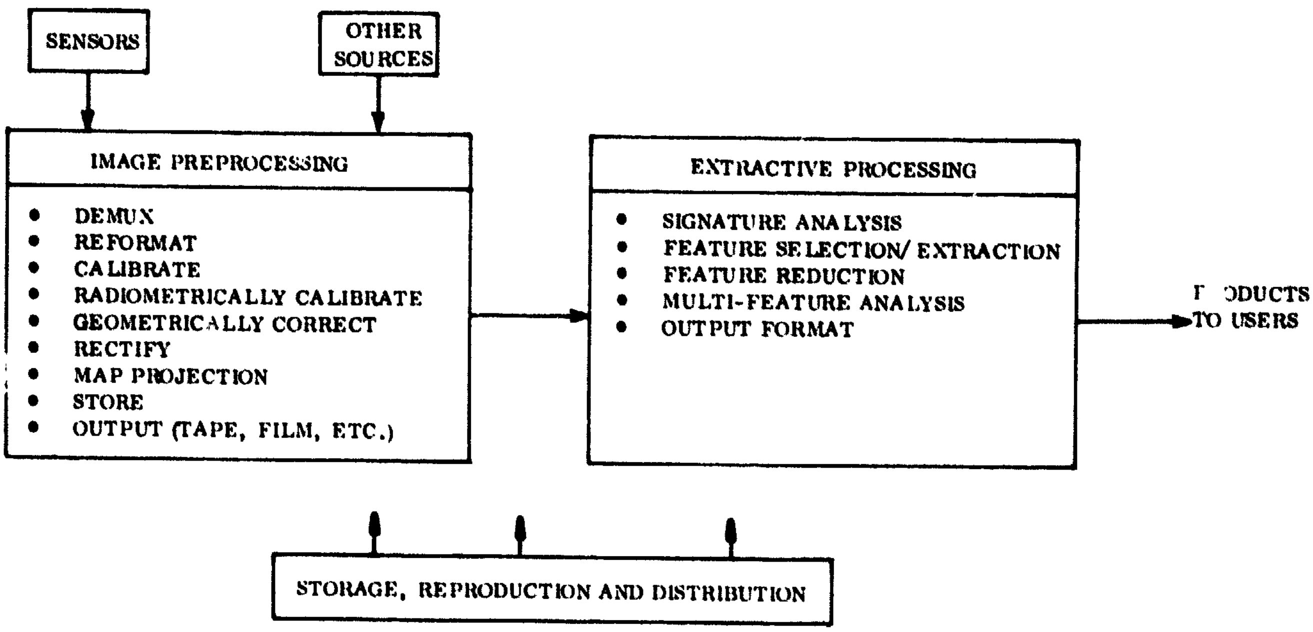


Figure 2. Image Processing

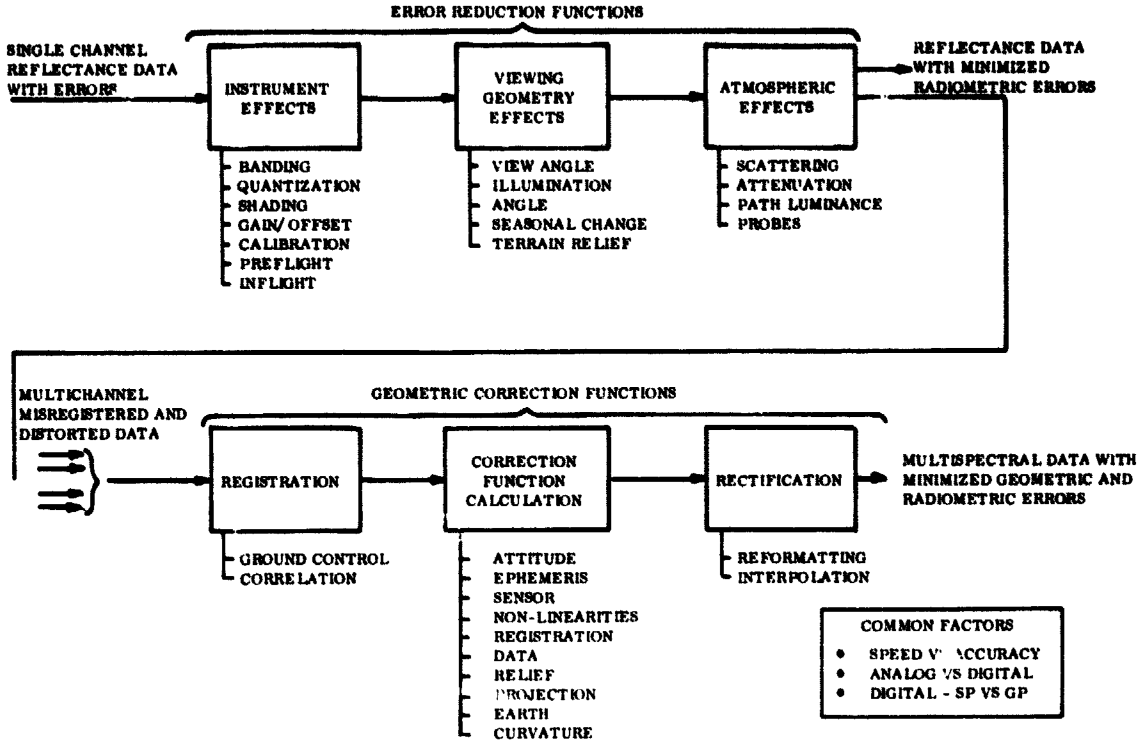


Figure 3. Preprocessing

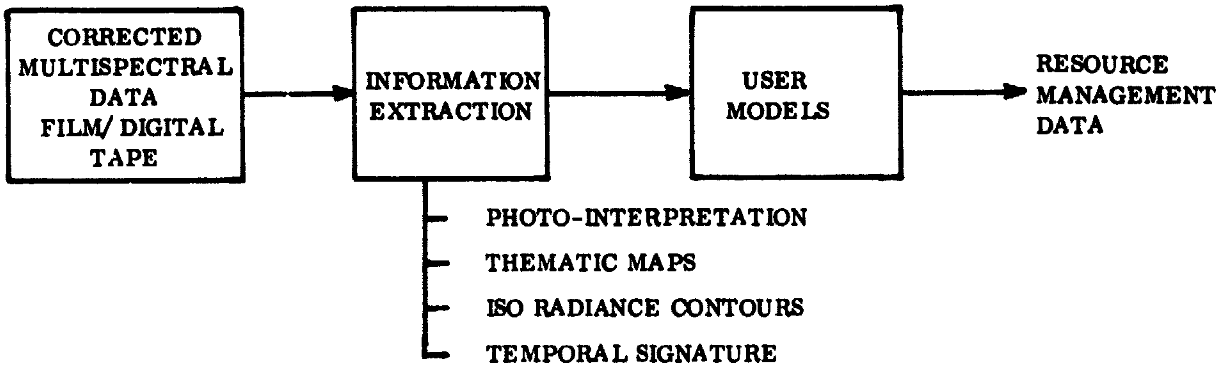


Figure 4. Extractive Processing

Technology Satellite system illustrates well the problem of data utilization from remotely sensed earth resource data. To a great extent the information that has been extracted has been from ERTS photographic images using manual photo-interpretation techniques. There are two basic limitations with this type of analysis: (1) human interpretation of multispectral data in photographic format is a slow, qualitative process; and (2) for the ERTS MSS type sensor, film cannot take advantage of the very accurate radiometric properties. For example, the spectral discrimination capabilities of ERTS 4-channel digital tapes are 2-3 orders of magnitude better than ERTS color film.

Therefore, in order to optimally utilize ERTS/EOS type data, the geometric and radiometric correction and data storage of the sensor data must be in a digital format in order to preserve the radiometric accuracy of the input data. Presently, only about 5% of the ERTS data is sent to users in a digital format, and even this small amount of data has not had geometric corrections applied. Thus, a critical problem for ERTS-B, future space missions like EOS, and other types of earth resources survey programs will be the low cost correction of all data in a digital form in such a way as to preserve the inherent radiometric accuracy. An additional advantage of digital format data is the ability to map the data to different projection systems such as UTM, Conical, Polar, etc. Another major benefit of all digital processing corrections of ERTS/EOS/Aircraft Scanner data is that temporal analysis and change detection can be effectively and in many cases automatically performed directly from the corrected magnetic image tapes.

Immeasurable benefits will be derived from significant state-of-the-art advances in these data system areas. Users of ERTS data would then be able to receive data that fulfills their specific needs (e.g., quality, quantity, format, timeliness, etc.) and would be able to apply the data quickly and effectively to problem areas.

PRESENT AND FUTURE GROUND DATA HANDLING

Currently the ERTS data processing systems at NASA Goddard Space Flight Center as well as the Brazilian and Canadian ground stations use hybrid techniques for processing corrected Image data. The scene-corrected digital tapes are made from the film product as shown in the top half of Figure 5, with a resulting loss in both radiometric accuracy and precise multichannel registration which limits the subsequent information extraction. An all digital system shown at the bottom of Figure 5 would avoid these problems, and also enable presentation in many map coordinates. Further, as will be discussed later, it can be coupled directly with spectral and temporal information extraction systems. Some of the specific data improvements are shown in Table 1.

IMAGE PROCESSING APPROACH AT GE

Figure 6 depicts the systems design approach to image processing currently under development at the General Electric Company. The integrated functional flow is centered around a minicomputer. Design flexibility, software-hardware integration and cost considerations have led to the selection of the PDP 11 series. The functional blocks in Figure 6 are so structured that any one of the "peripheral" blocks 1, 2 or 3 plus the central one 4, can be developed into a stand-alone subsystem to yield specific "products" shown to the right of the data bus.

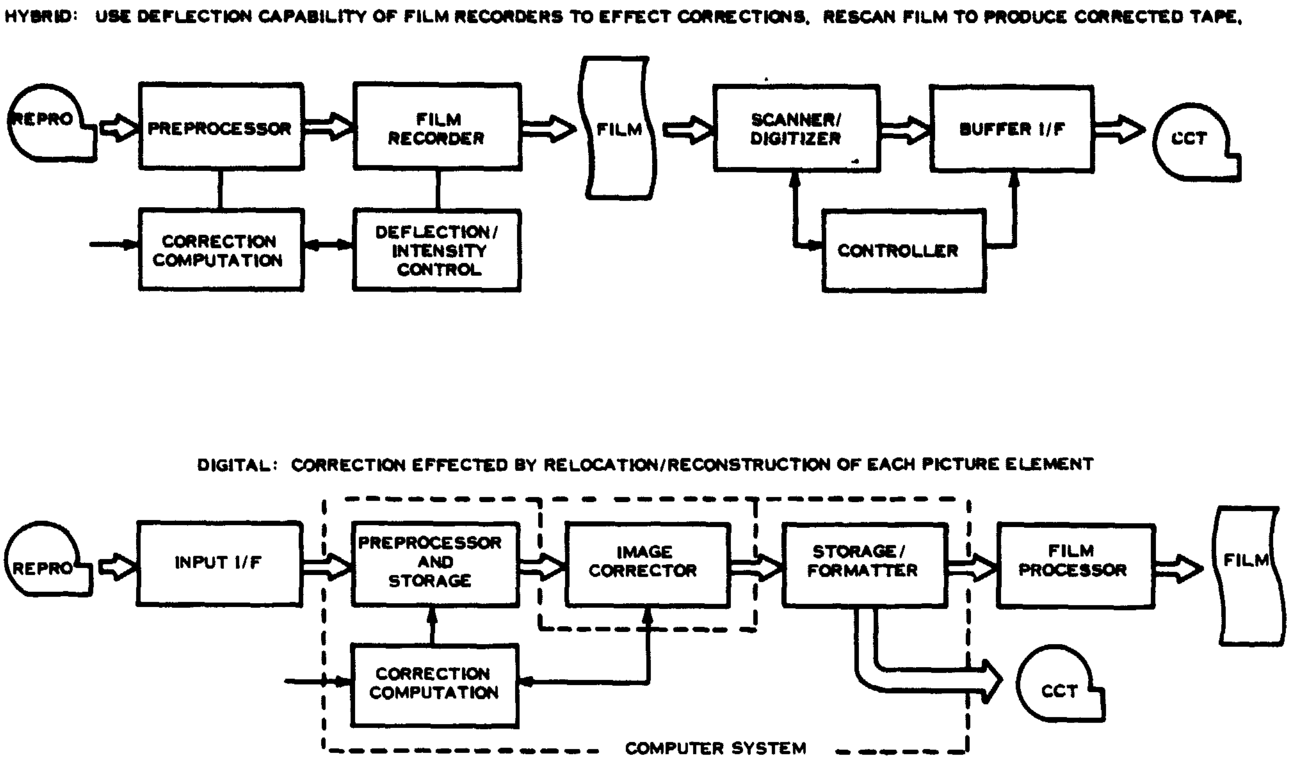


Figure 5. Image Processing Approaches

Table 1. Comparison of Digital and Hybrid Techniques for Generation of Precision Corrected Digital Tapes

Parameter	Typical Current Value for Hybrid	Achievable by Digital Ground Station
Radiometric Accuracy	5%	<1%
Geometric Accuracy	100 M	<50 M
Location	100 M	
Thru Put	5 MBPS	10 MBPS - 50 MBPS
Cost	10	1
Implementation	Analog	Digital

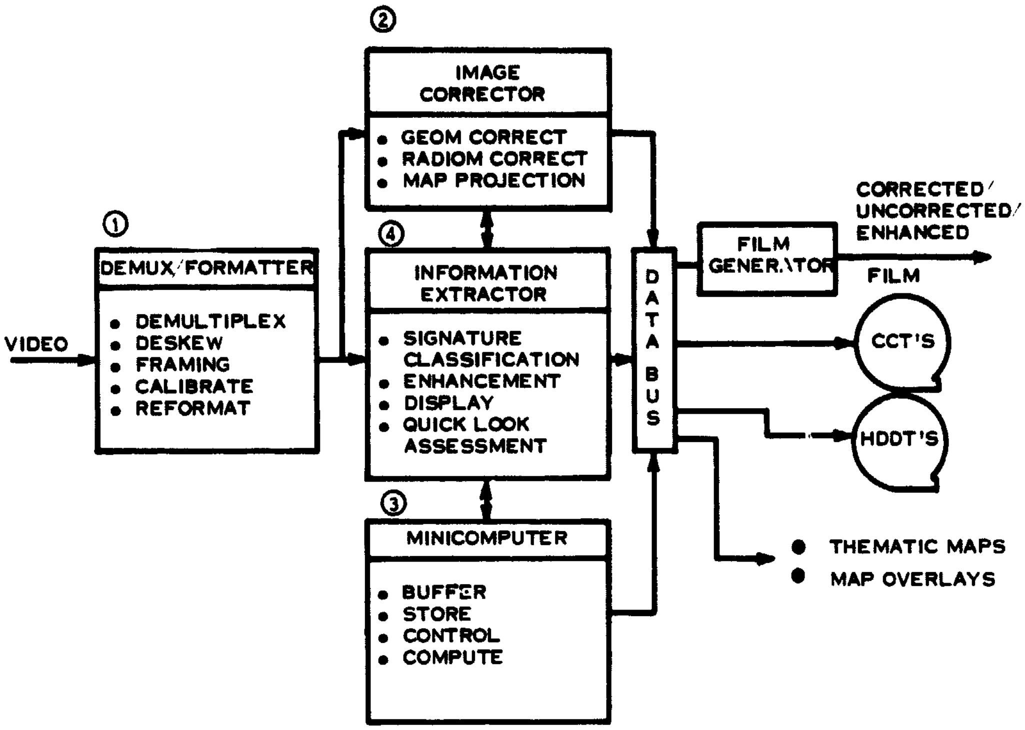


Figure 6. GE Image Processing Approach

Indeed, each of these pieces has been fully designed in this fashion and are currently in various stages of implementation:

a. The DEMUX/FORMATTER + Minicomputer can be coupled with a ground station to produce high density digital tapes and computer compatible tapes General Electric has recently been awarded a contract by NASA to build such a system.

b. The Image Corrector + Minicomputer system can be used to develop precision imagery in film and tape formats. GE has initiated fabrication of such a system at Valley Forge under its Independent Research and Development Program.

c. The Information Extractor + Minicomputer System has undergone three generations of development at General Electric's Syracuse, Valley Forge and Daytona Beach facilities over the the last six years. The latter two systems (known by their popular acronyms GEMS and IMAGE 100) have been used quite extensively in their "laboratory" versions to conduct ERTS experiments and in support of operational users. Results from several of these studies will be briefly reviewed here.

The "field" or production model of IMAGE 100 is being produced at Daytona Beach.

The first of these has been installed at the Canadian Center for Remote Sensing and the second is being installed in GE's new Image Processing and Analysis Center in Beltsville, Maryland. This system will be used to provide information extraction services to a variety of users.

IMAGE 100 SYSTEM OVERVIEW

The configuration of the IMAGE 100 Production Model is schematically portrayed in Figure 7.

Input data can be in the transparency or digital format, read in via a scanner or a magnetic tape. Multispectral black and white or color composite film is scanned by a black and white TV camera with a color-filter digitized instanteneously onto a refresh disc, and band registered. Multispectral digital data is read directly from 9-track, high density tapes onto the refresh disc within minutes.

The Processing Logic Unit is a special-purpose hardware device configured to accomplish preprocessing, multispectral analysis, and theme synthesis under interactive operator-computer control. The man-machine interaction is facilitated via two realtime display subsystems, the console TV display and the Tektronix terminal which also double as output devices. The minicomputer PDP 11/35 functions as a process control computer with multiple data disc packs for respective software systems packages.

Output products from the current configuration are slides/prints off the console TV screen, printouts and plots from a Gould printer and Gerber plotter and the Tektronix terminal. A Dicomed color printer and other output devices have been interfaced on trial basis.

Figure 8 is an example of IMAGE 100's multiple image registration capability, and shows an ERTS CCT image of Bequet Reservoir overlayed on a U2 image which was introduced via the scanner input.

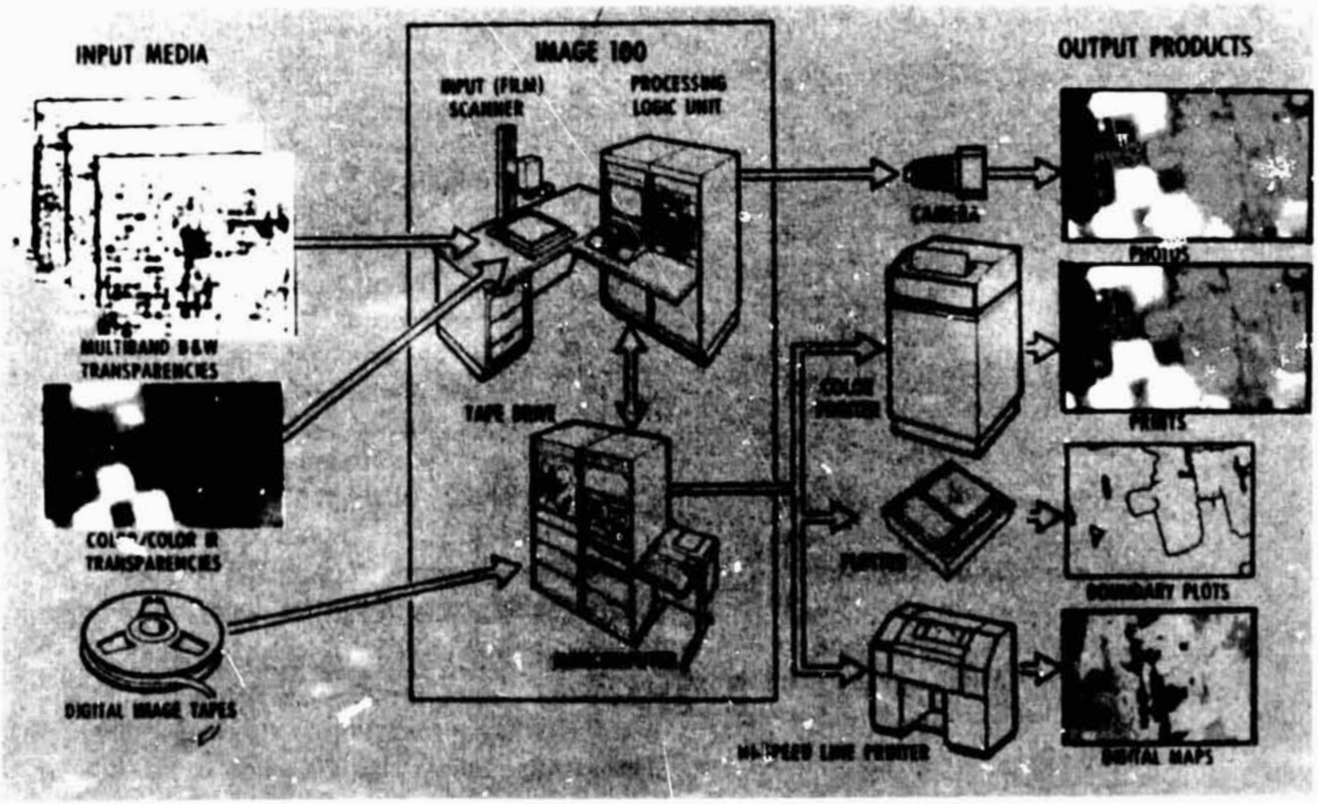


Figure 7. IMAGE 100 System Overview

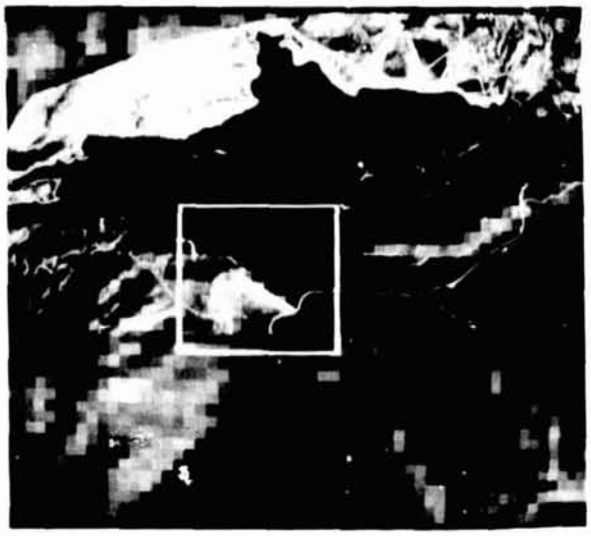


Figure 8. IMAGE 100 Multiple Image Registration

IMAGE 100 SYSTEM OPERATION AND USER ADAPTATION

The design considerations for IMAGE 100 included human factors as well as man-machine interaction for a user-oriented analysis tool.

Once an image is input to the system and stored on the refresh disc, the user has available a complete family of both pre-processing and detailed training and classification functions which are invoked at the push of a button.

PREPROCESSING

The image can be examined first in black and white, one band at a time. False color images are created instantaneously and quickly modified at the display by gain and polarity controls. Beyond this "viewing" capability, the system offers a full spectrum of "photointerpretation" modes such as ratio (of pixel spectral intensity in adjacent bands) difference-over-sum, normalization, and general purpose transformation. Spectral analysis down stream can be done in any of these modes as well as in the "raw" data mode.

Figures 9A and 9B show west central Los Angeles from ERTS CCT of March 14, 1973 in "raw" and "ratio" modes, respectively. Note the differential effects of such a transformation on the urban area, bringing out the street grid, versus the water bodies, etc. Figures 10A and 10B are split screen representation of the Wilshire Country Club as observed on two different ERTS passes. The left side of the Image shows Wilshire Country Club in March of 1973 while the right side shows it in December 1972. The lower intensities in the December Image are a result of the lower sun angle and the decrease in vigor of vegetation in the winter

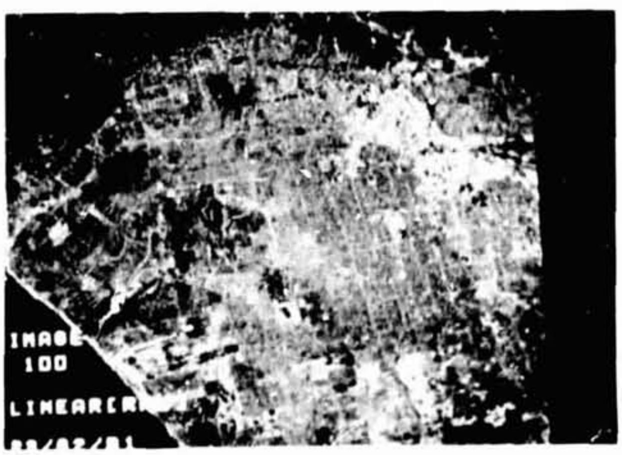


Figure 9A. ERTS CCT in "Raw" Mode

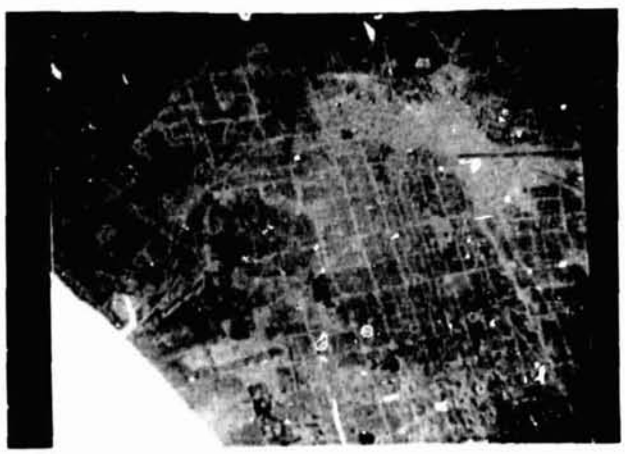


Figure 9B. ERTS CCT in "Ratio" Mode

Figures 10A

Figure 10B

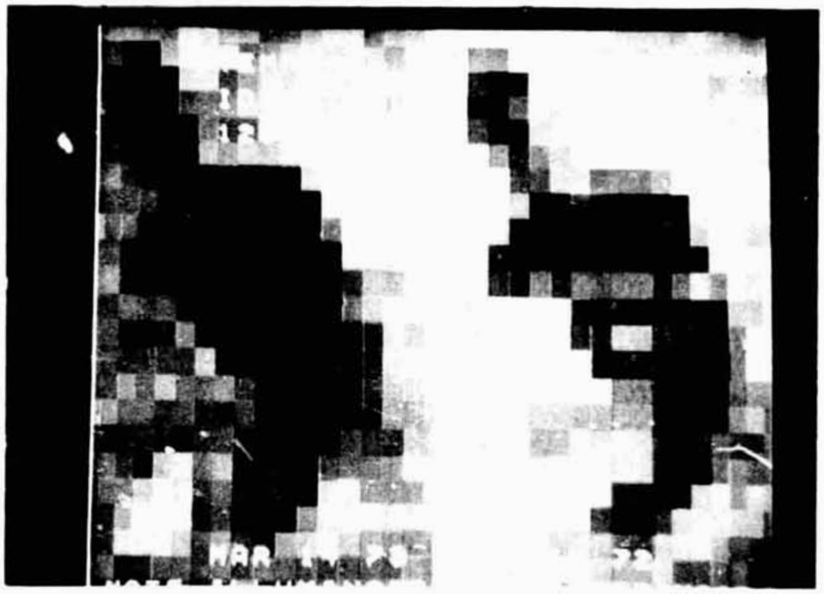


Figure 10. Split Screen Image of Wilshire Country Club (March 1973 — December 1972)

months. Figure 10B shows the same scenes after IMAGE 100 normalization (each channe divided by the sun of all channels) notice that the sun angle intensity variations have been effectively reduced. The resultant scene shows only those variations in the temporal images caused by differences in the vigor of the vegetation.

The selection of the area for "training" the IMAGE 100 on the pixels of interest, from ground truth or other considerations, is accomplished by placing the "cursor" over it. The cursor, can have one of three different formats (□, +,◇) is variable size and location, and is controlled by a "joy stick". The cursor can be used to control the corresponding segment of the field of view.

TRAINING AND CLASSIFICATION

Training and classification are critical aspects not only of IMAGE 100 but of all remotely sensed multispectral data analysis. The typical flow of this operation is depicted in Figure 11. Training and classification are defined as follows:

- Training - Multispectral analysis is predicated on the fact that like objects in a scene have similar spectral properties. To effect analysis, the user must inform the machine as to which objects or features (water, soil, vegetation, etc.) are of interest. Given object positional information, the machine extracts the four dimensional spectral properties of the selected object. This process of informing the System which object to analyze, and the System process of identifying the spectral properties of that object is called "training".

- Classification - When the spectral properties of the object are found, the IMAGE 100 System scans the total image (pixel-by-pixel) and determines if the spectral properties of each pixel correlate with those of the object of interest. This testing process is called "classification". The result of the classification process is a map in which each pixel is identified by a class type (or theme) rather than a gray level.

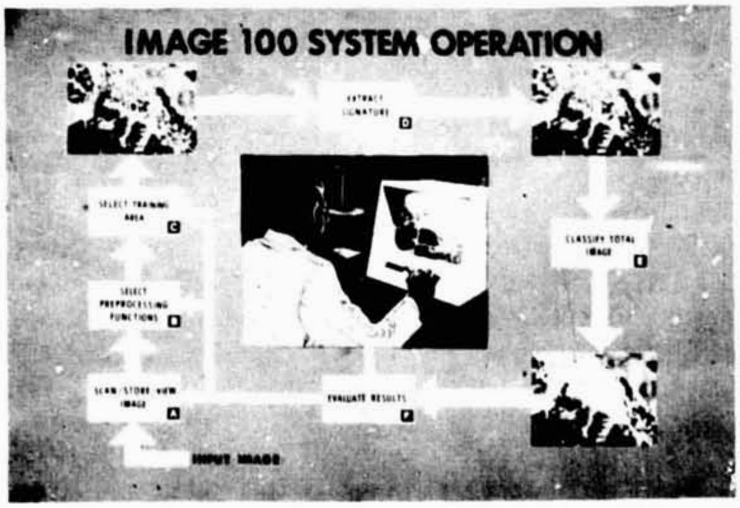
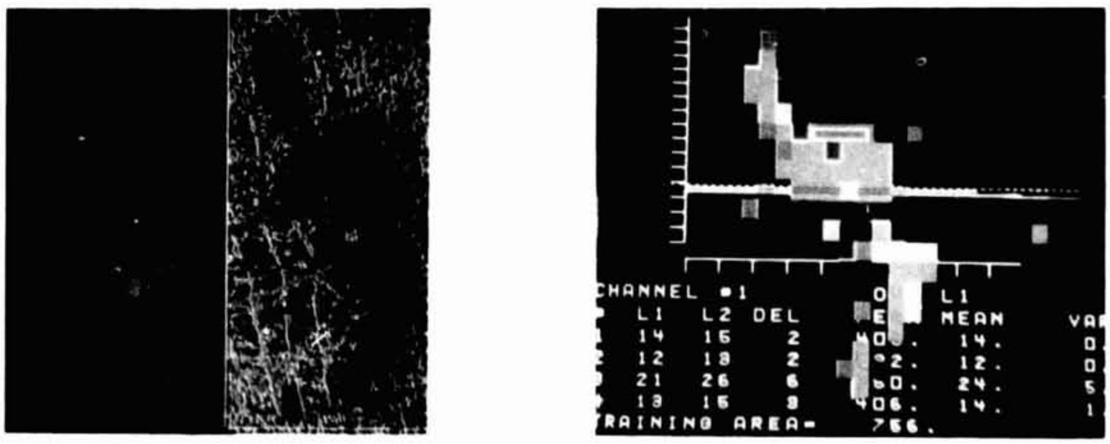


Figure 11. IMAGE 100 Operations

FINE-STRUCTURED AND GROSS IMAGE ANALYSIS

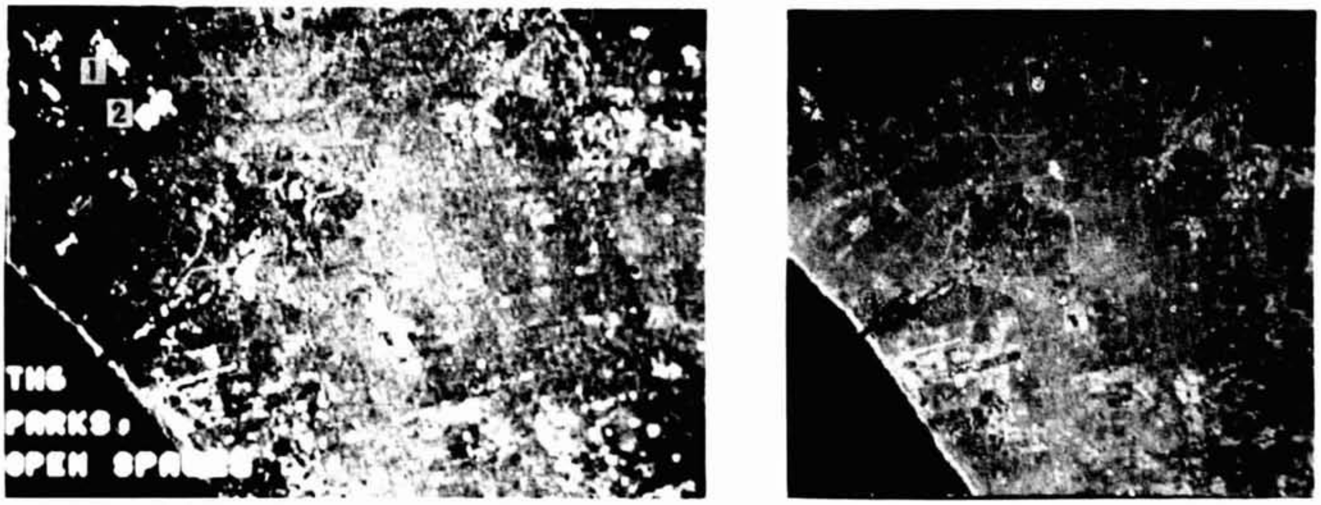
While ERTS acquires uniform data across the entire earth's surface every 18 days at a nominal resolution of 80 meters, the level of detail contained in the digital data pixel-wise that can be brought out, if necessary, by IMAGE 100 can best be appreciated by inspection of Figures 12 and 13. Figure 12A shows a portion of a U2 image of the Wilshire Country Club in the Los Angeles area. It also shows an ERTS CCT image of the same area from the IMAGE 100 TV screen. By training on an individual pixel with the 1-D histogram shown in Figure 12B, other "photomorphic" pixels were located. A series of such themes constitutes the result. Compared with a U2 image of the Wilshire Country Club (Figure 12A) the road through the club, the club house, etc., can be picked out by IMAGE 100 from ERTS CCT's. Conversely, by compositioning a gross signature, the entire club grounds are alarmed.

Using this gross signature, other grassy areas - the LA Country Club, Rancho-Hilcrest Park shown in Figure 13A, are picked up in the IMAGE 100 display shown in Figure 13B. Using the same gross signature, indeed, a rather large group of parks, cemeteries, golf courses and public open spaces are imaged from ERTS data.



(A) (B)

Figure 12. Example of Fine Structured Training



(A) (B)

Figure 13. Example of Gross Image Analysis

By extending the "open green spaces" signature to ERTS scenes spanning extensive geographic and seasonal coverage, such analyses can be made on a global scale. The speed of interactive analyses on IMAGE 100 with ERTS CCT's is such that these global studies can be conducted within an ERTS 18-day cycle.

CASE STUDIES OF IMAGE 100 ANALYSIS OF ERTS CCT/DIGITAL DATA

This section discusses both the key features of IMAGE 100 and the unique characteristics of ERTS data in the context of some specific investigations undertaken by GE scientists and engineers.

It should be mentioned that in the interest of economy of space and time, only the highlights of the results in black and white, will be included in this text. The full impact of the color transparencies from which these illustrations were made cannot be conveyed here. Nor can the dynamic realtime interactive operation of the IMAGE 100 be adequately described by anything short of a "hands on" demonstration of the system in operation.

AGRICULTURAL CROP INVENTORY AND MANAGEMENT

The General Electric Company, in conjunction with a major agricultural firm, has been investigating techniques for crop inventory and management using remote sensing.

CLASSIFICATION OVER LONC DISTANCE

The multispectral signature of cotton fields in the San Joaquin Valley, California was extracted from the ERTS digital tape data on General Electric's IMAGE 100 System, by training on a specific known cotton field. This signature was then used to classify cotton on the entire ranch, including a section 100 miles south of the training area. (Figure 14 is an insert mode representation of the IMAGE 100 display with the southern section inserted in the lower right corner of the screen.) The correct classification of cotton in both sections of the ranch (Figure 15) demonstrated that the cotton signature developed by IMAGE 100 was valid for classification of cotton in areas separated by 100 miles.

CLASSIFICATION OVER LONG INTERVALS OF TIME

In another experiment, two ERTS images of the same ranch area were taken one year apart. This data was analyzed to determine if the signature developed by IMAGE 100 for the first year could be used to accurately classify cotton at the same phase of its growing cycle one year later. Figure 16 shows a split screen representation of the same area of the ranch which was generated from the ERTS CCT's formed in 1972 and 1973. (Patterns are different due to crop rotation.) Training was accomplished on

Figure 14. IMAGE 100 Insert Mode Display

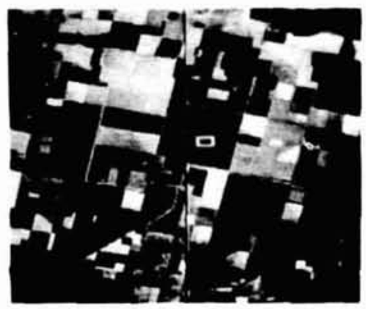


Figure 16. IMAGE 100 Classification Over Long Time Interval

Figure 15. Demonstration of a Valid Cotton Signature

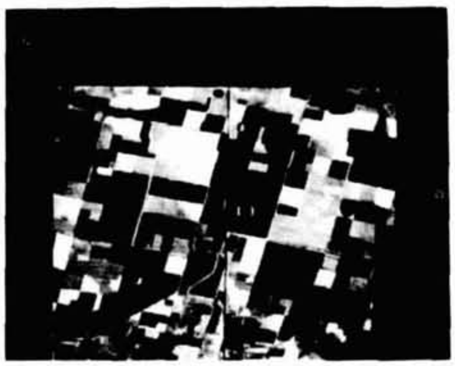


Figure 17. Classification of a Cotton Field

the field in the cursored area and the derived signature was used to classify in both ERTS images. The results of this classification are shown in Figure 17. All cotton was correctly classified and demonstrated that the signature developed by IMAGE 100 was valid for classification of cotton in the same phase of its growing cycle one year later.

CROP STATUS ASSESSMENT

IMAGE 100 is also being used to assess the effectiveness of crop rotation, fertilization, pest control, water, and other farm management programs by monitoring changes in the spectral signature of various fields throughout the growing cycle. The objective is to define and monitor indicators of the crop management programs in order to effect corrective action to avoid crop yield reduction in the affected fields. Figure 18 shows an IMAGE 100 classification of cotton in a section of the ranch. Note the variation in the spectral signature of the field on the right side of the image. The corresponding ERTS Image, Figure 19, shows that these variations, in fact, correspond to reduced infrared reflection caused by reduced vegetation vigor. Data pertaining to management practices for this field is currently being reviewed to determine the cause and formulate plans for corrective action.

In summary, there appears to be no doubt that IMAGE 100 analysis of ERTS data in digital form can provide useful information for large scale crop inventories and management of agricultural processes. The utility of this data is currently limited only by frequency of ERTS coverage and timely availability of digital data.

Figure 18. IMAGE 100 Classification of a Cotton Field

Figure 19. Variations in Spectral Signature

LAND COVER CLASSIFICATION FOR ENVIRONMENTAL IMPACT ASSESSMENT

The General Electric Company is supporting the U.S. Army Corps of Engineers in the preparation of an Environmental Impact Statement on the Mississippi River Nine-Foot Channel Navigation Project. The channel must be dredged regularly to maintain the nine-foot depth necessary to support navigation. This in turn, necessitates identifying suitable locations for disposal of the dredge spoils, and it further necessitates identifying the environmental impact of such disposal.

A principal General Electric task has been to use ERTS digital data (August 29-30, 1972) to map seven land use classes along 350 miles of the upper Mississippi River from lower Wisconsin to about 80 miles north of St. Louis, Missouri. Thirteen locks form the bounds of twelve navigation pools in this section of the river. For each of the twelve pools, General Electric has prepared seven transparent binary thematic map overlays pertaining to Woodland, Brushland, Grassland, Marshland, Open Water, Urban, and areas Devoid of Vegetation.

The themes were produced by the General Electric IMAGE 100 System from ERTS Computer Compatible Tapes. First, a highly interactive man-machine procedure is employed to develop the signatures from which the themes are generated. In this procedure an ecologist familiar with ground truth and the river environment, and a General Electric engineer, worked together to extract, check and correct the desired signatures by examining several test areas along the river. Once established, the signatures were applied with no further modifications to the ERTS digital data for a 350-mile section of the river, producing the desired themes for this section. The entire operation was completed in less than 80 hours of IMAGE 100 time of which approximately two thirds was devoted to signature development and one third to theme production.

Output is in the form of map overlays at a scale of 1:250,000. Results also are recorded digitally on magnetic tape. The figures here show results for a portion of one navigation pool in the vicinity of Muscatine, Iowa. Theme signatures used here were developed at other locations along the river. It is of interest to note that one of the areas highlighted by the "Urban" theme includes a region south of the center of Muscatine which is not indicated on the latest USGS, 1:250,000 map. However, the USGS, 7.5-minute Muscatine quadrangle map, revised in 1970 from aerial photographs, shows an extension of the Urban area specifically in this location.

Results shown here are part of an overall project for which the firm of Howard, Needles, Tammen, and Bergendoff is preparing an Impact Statement for the Corps of Engineers; the statement will be reviewed at public hearings. Because the project was conducted on a compressed time schedule, the thematic maps and data had to be produced in a short time. The near-real-time interactive capability of the IMAGE 100 very likely provided the only approach to accomplishing the thematic mapping in time to meet the schedule.

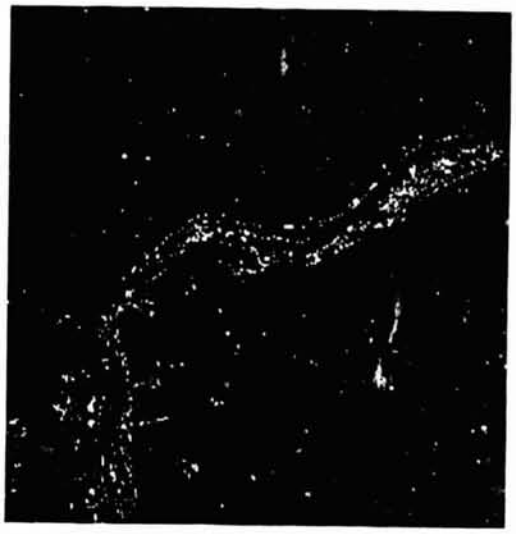
USGS Map of Region Near Muscatine Iowa. Scale 1:250,000

IMAGE 100 Display of the Scene From ERTS Digital Data

These scenes are reproductions of thematic map overlays prepared with the use of the General Electric IMAGE 100 Analyzer of an area along the Mississippi River near Muscatine, Iowa.

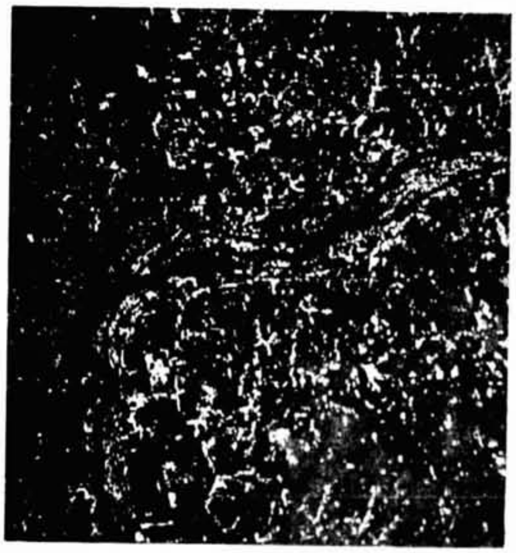
Open Water

Urban



Marshland

Grassland



Woodland

Devoid of Vegetation

THE APPLICATION OF NATURAL SCIENCE DATA TO LAND MANAGEMENT DECISION-MAKING

Donald L. Williams, Carl P. Sharpe, Peter G. Rowe

THE QUESTIONS

Many times technology transfer is presumed to focus on hardware. This presentation should indicate the potential and importance of the transfer of software technology in several fields to a developing and unrelated field. It certainly indicates the potential for the use of systems analysis, computer aided handling and remote sensing of earth science and community development data to the land management field.

This presentation could be aptly subtitled, "building the link between data and decision". Because as we have become aware that our natural environment is a scarce, precious and increasingly threatened resource, there is a developing need to integrate natural science information into land management decision-making.

The decision is, development for mankind's use at what price to the rest of his environment. More specifically: What will we build; where will we build; when will we build; what will we build; what price will we pay?

Concern about our natural environment sometimes confuses two very different issues as one. Remedial environmental clean-up and future environmental choices are two different problem sets. Granted, one can learn from the other, but the processes of solution are not similar.

Research at Rice Center[1] and this presentation concentrates on the latter problem--future environmental choices. The question we are solving is, can we accurately predict the consequences of placing various land uses in the natural environment prior to the decision to do so? If we can do so, then mankind could do the following:

1. Manage our impact on the natural environment.
2. Make informed locational choices.
3. Respond to specific hazard and resource issues.
4. Provide performance criteria for the building and operation of our communities.
5. Assign priorities to research and design and hardware production in the community development field.
6. Develop policies for land development which are consistent and fair for all over time.
7. Provide legislation which protects nature, the land owner, and the public equally.

In order to achieve this purpose, the gap between our knowledge of nature and the private and public decision-maker must be closed through action in the following areas:

1. Better understanding of the community building processes.
2. Better understanding of natural systems.
3. Development of analytical tools and procedures for predicting consequences ahead of decisions.
4. Inclusion of funds for the use of these tools and procedures in project proposals.
5. Displays the results in a form the public and their decision-makers can use.

6. Test the legality of the use of such results as the foundation for public policy in land management.

First, let us look at the procedures that are being developed and then let's examine some actual applications. We are looking at the fit between the natural environment and the social, economic and functional attributes of man's communities. It is possible to look at the fit between each of these attributes and all others; however, in this case, we are concentrating on natural environment analysis and its fit with the other attributes. We are working with the transition from nature in its present state to various forms and intensities of development.

DESCRIBING THE NATURAL SYSTEM

First Questions?

Hazard and Resources. We have found that it is extremely helpful to keep hazard issues separate from resource issues. The point being that some issues are health, safety and welfare types of questions such as ground water pollution. Others are clearly resource depletion questions like the removal of land from agricultural use. It is extremely difficult at this time to develop a hard, factual case in the resource issue arena. That is not the case witn hazard issues. Court cases can be successfully litigated based upon proof of a hazard to life and/or property. With resource depletion, we think that the ultimate choice rests with the voters of a community, be it national, state or local.

It is important to us that our work be legally defensible. Thus, an analysis procedure better recognize what can be defended and implemented and what cannot--at the outset.

Levels of Effort. It is also important to recognize that there are different levels of needs and therefore demands that will be placed upon natural environment analysis systems. The procedure that treats a locational question the same as a specific issue question is asking for problems. The same is true if you treat the location of an airport the same as the location of a 50-unit subdivision. The information required and the decisions to be made are quite different for locational and issue questions as it is for regional area and site specific questions. Thus, one of the early procedures is to define the level of decision to be made, the resources required to meet the needs of that decision and therefore the type and size of analysis required. The result is that we are developing an inventory of mutually compatible but differentiated tools.

What To Do?

The Inventory. We start with an inventory. In our work we have typically used the general natural science information classifications of geology, physiography, hydrology, climatology, soils, wildlife and vegetation and supplemented them with information on perceived natural amenities and historical and existing land uses. We must have factual natural science data that is place specific. In the end, natural scientists must be able to publicaly attest to the quality of the information, its proper interpretation and use and its accurate placement in geographic space. Without this primary input, a natural environment analysis does not exist. It is in this area that the U.S. is probably on the verge of significant technological breakthroughs. Natural science data gathered on a consistent basis, over wide geographic areas, at regular intervals and at low cost in time and dollars is essential. Remote sensing offers us such data.

At this time, however, natural science information comes to us in all sizes, shapes and colors. We are obligated to reassemble it into a form that allows comparative analysis of processes and place. This can be done with colored or digitized maps. The choice relates back to the earlier questions mentioned about the level of information available and the decisions to be made. We must in the end be able to accurately describe the natural system at work in a given piece of geography.

Cell Size. It is at this point that you decide what the geographic subdivision of the data shall be--in our case, the size or combinations of sizes of geographic cells that will be digitized.

The best way to look at this question is to ask again what kind of information will we have and what kind of decisions must it be used for. In the case of natural science, data quality and density become important questions; but, so does the question of how much searching can you do; how much time can you spend mapping it; digitizing it and integrating the results. These latter questions must be related to resources that will be expended for the decision that will be made. The more we can substitute machine functions for human functions in this part of the analysis procedure, the more likely we are to produce a cost effective procedure. At this time, a full one-third to one-half of the analysis costs are devoted to information gathering and displaying. Even worse, a mistake about the amount, kind and form of data can raise natural environment analysis costs to disasterous levels.

Problems With Integration. So we take natural science data and record it by subject area (such as soils types); amount present (percent, size, level, etc.); for a given geographic area (cell). If we took the simplest approach for each subject area, we could identify by subject areas certain cells that could be developed, certain cells that had manageable development problems, and yet others that ought not be developed. Assuming that these individual maps could be defended, there is a larger problem. The overlaying of individual subject area maps in order to get a composite development map raises several questions. Such a system of data integration presupposes that each of the mapped subjects are of equal or some determinable weighted value to each other. In other words, erodable soils issues equal ground water potential issues equal agricultural capability issues. We find no basis in fact for such a position, nor are natural scientists able to assign fully defendable weighted values to such subdivisions of information. Thus, we have been examining many disciplines, tools and techniques that would allow the integration of natural science data without the assignment of values to independent bits of data.

Cluster Analysis. One such analytical tool that we have found helpful is cluster analysis[2]. This procedure and other tools, such as dendrograms and ordination procedures, have allowed us to combine a vast array of natural science data and produce maps which indicate geographic areas of great natural similarity, and at the same time to retain all of the original data in a usable form for later land management decisions.

The procedure begins with natural science data--the variables--in whatever form, being encoded and manipulated so that digital maps can be produced for accuracy verification by natural scientists. The maps can cover a vast number of variables, such as the presence of various types of geologic formations, soils subject to erosion and natural amenities, such as views, waterfalls and recreation lakes.

The clustering procedure produces a composite map that identifies groups of cells which are similar across all of the individual variables. In addition, a profile of the clusters provides detailed information about each cluster and each variable relative to all of the clusters (such as mean and standard deviation). The result is we have gone from large amounts of unrelated natural science data to a non-weighted, integrated picture of a given piece of geography. Further, we know its individual and integrated characteristics relative to all of the rest of the geography in the same study area.

Accomplished What?

At this point, we have done nothing more than describe the natural environment of a given geographic area at a given point in time. But we have done so not only on a variable by variable basis, but, most importantly, we have done so on an integrated basis that is logically defensible.

It is appropriate to point out at this time that, with accurate remote sensing tools feeding information to data handling machines programmed with such tools, there exists the potential for producing such a description of nature automatically and at regular intervals. The limits are, of course, related to those variables that can be obtained through remote sensing techniques. Nonetheless, mankind has the potential of producing accurate descriptions of the earth's natural system unlike anything we have previously had at our disposal--and these descriptions can be dynamic rather than static.

It is also appropriate to point out that we have a data flexible procedure that allows for various qualities and densities of data; that allows new data to be added without starting at the beginning and without major costs or time delays.

DESCRIBING DEVELOPMENT

Types

At the same time a given natural system is being described, another kind of inventory is carried forward. What kind and amount of development will be proposed for the geographic area under study? A definitive list of development categories is compiled for further analysis. We try to begin to outline the general relationships between various types of development categories and development consequences upon nature. For example, different densities and types of housing created different amounts of hard surfaces and water runoff. Here the community development specialist and the natural scientist work hand in hand to begin an accurate and factual description of the cause and effect relationships between nature and manmade development.

Use Activities

This is carried forward into detailed outlines of various types of development land uses and their impact upon general natural systems. This allows a cateloging of specific use activities (such as the withdrawal of ground water) and their relationship to different types of development land uses.

At this point, all we have done is describe development land uses and their use activities in terms that relate to impacts or changes they might cause in nature.

PUTTING IT TOGETHER

If we are to predict the consequences of placing various development types on various natural systems prior to the actual act, the natural environment and development descriptions must be tied together. Needless to say, this is the step that the faint-hearted have shied from. Here is the crux of the question--the results upon which recommendations and decisions will be made. The results upon which court cases will be decided.

The tool that has been most helpful to us here is the construction of a network of key natural environmental relationships. This delineation of relationships aids the tracing of the impact of a given development type and its associated use activities through the natural system of the geographic area under consideration. Thus, not only are direct, first order impacts delineated, but so are second, third, fourth and fifth order effects described, and where possible, quantified. For example, the range of ground water withdrawal associated with a given development can be stated. If this is in an area of a particular type of fresh water aquifer, with clay layers, surface subsidence can result. If this area is near the coast, increased flooding can occur and salt water can occupy formerly fresh water marshes. In turn, the vegetation and wildlife of the area will change, altering the visual and productive characteristics of the area The question is, did we want this to happen?

By identifying the interrelationships among key natural environmental characteristics of a given geographic area and forming these into a network of interrelated phenomena, the paths by which development impacts are distributed and absorbed within the natural system are identified. The degree of a development impact thus becomes defined in terms of the extent of environmental change experienced in any portion of the network.

Taking the profile descriptions of the various clusters of the geographic area under consideration, it is now possible to predict the changes that are likely to occur in the cluster if a given development is placed thereon.

Up to this point in the natural environment analysis, we have attempted to maximize quantifiable and interrelated step-by-step--almost cook book--procedures. Subjective, value-laden procedures have been removed or minimized. This allows others to replicate the analysis for verification, and it allows those disagreeing with the Recommendations which follow to examine the source of those Recommendations, and perhaps draw different conclusions, without having to recreate the entire analysis.

RECOMMENDATIONS

We have found that several types of Recommendations can be drawn from this type of analysis.

Locational

The first type is Locational. All types of decisions related to the location of development types in space can be supported or challenged with the analysis results. Questions about alternative locations can be answered. Environmental Impact Statements have a sound non-site oriented foundation. Choices and trade-offs can be made on top of the table with the costs calculable.

Management

The second type of Recommendation is Management. The natural environment problems can be expressed and performance criteria can be written for the protection of the natural system. These criteria can be written for each cluster, for each development use activity, for each natural science subject area or for individual protection issues. By the documenting of the criteria by which the area can be protected from environmental degradation, the costs of protection can again be put on the table with other issues.

Data/Monitoring/Process

Other kinds of Recommendations that can be made and backed by the analysis are the needs for better data in a given area. Recommended monitoring procedures that should be installed during construction and operation of the proposed development. Also, Recommendations about the policies and organizational structure that will be required to use the analysis results and monitor the implementation can be prepared.

FINALLY

Thus, what has been put together is a natural environmental analysis process which allows the decision-maker to know the probable consequences of his decision prior to the act. A tool for the private and public developer and the conservationist alike. A tool that can expose the "let's develop" versus "let's protect" conflict to the light of day where the consequences and costs of trade-offs will have to be justified prior to the act and not afterward. A procedure that substitutes facts for rhetoric and emotion.

ACTUAL APPLICATIONS

The natural environment analysis process that has been described here has been developed over the past five years. The work began in Louisville, Kentucky, and has been continued at Rice Center in Houston, Texas. Its early direction was primarily locational and management criteria oriented, while recent work has been general applied research. The work is continuing this year with our Texas Gulf Coast Program/First Phase Project[3]. One product of this project will be delineation of the natural environment protection issues along the Texas Gulf Coast and their location A second product will indicate probable development scenarios for the Texas coast. The final product will indicate where the highest probability for conflict between development and protection interests exists. This will aid in the setting of priorities for continuing Rice Center work in this area as well as acting as an early warning system for private and public decision-makers.

Louisville Newcom Project

Louisville is a metropolitan region covering 6.5 million acres and having a 1970 population of approximately 1.4 million people. It is a two-state (Kentucky and Indiana) urban area. The physiography of the region changes from rolling plains,to deeply cut water courses, to hills that provide dramatic changes in elevation.

The Newcom work[4] included locational work in three arenas: natural, socio-economic and linkage (transportation, utilities, communities, etc.). The result of the locational work was the identification of five highly suitable areas capable of supporting the proposed 80,000 population new community.

Performance criteria were proposed for the planning, design and construction of Newcom. These criteria attempted to state the guidelines for use by those designing and constructing the community as well as those responsible for monitoring their performance. These criteria attempted to get at the problems of form of the community as well as the size. For example, different types and designs for housing cause different impacts on the natural environment. This means, for example, that the same 600 persons can live on the same 125 acres and cause vastly different impacts, depending on their choice of housing types.

Louisville Regional Airport Project

The type of work started in the Newcom project was carried into the Airport Natural Environment Analysis[5]. The purpose of this work was to provide the technical input to the site selection process and the foundation for the preparation of the eventual Environmental Impact Statement. The work was done in three major increments: Regional, Subregional, and Selected Sites. We began by defining the areas in the region with the "greatest development potential" and aided in the selection of 800,000 acres for detailed subregional analysis. This 800,000 acres (500,000 in Kentucky and 300,000 in Indiana) was put through an analysis procedure similar to the one described earlier. Natural science information was inventoried, digited and combined, producing cluster maps for the area. The natural impact characteristics of the proposed airport and its periferal growth were documented. From this we were able to recommend sectors of the 800,000 acres that were capable of accepting the proposed development, those areas that were not capable and write general management guidelines for design and construction.

This aided the 29 members of the public site selection committee to reduce the number of sites from 9 to 4. These 4 sites were then analyzed in detail and a preferred site chosen.

All of this work was done in a manner that was usable by the public decision-maker and citizen alike, and with the full understanding that public hearings were a part of the process and court cases were likely. It is important to also note that the material was presented in such a way that the site selection committee was able to quantify the natural environment issues along side 9 other locational issues. Thus, trade-offs were made on top of the table in full public view, and the consequences known in advance of the choice.

Corridor Analysis Projects

This is the point to note that similar work has been done elsewhere[6] on corridor locational analysis. The same types of procedures are quite applicable to the analysis of the impact of transportation and utility corridors. The trade-offs between alternative corridors can be quantified and documented prior to the final choice rather than after the choice.

Chambers County, Texas Project

Currently under way in the Houston region is a National Science Foundation funded project[7] Rice Center is responsible for one of three components of the work--the Environmental Analysis Component. The Law and Institutional Components of the project are being completed by individuals and organizations at the University of Houston. The purpose of our work on the project is to apply the natural environment analysis process to a minimally developed coastal county with a potential for growth. Chambers County, Texas, was chosen because of its current development status, its industrial expansion, its location in the Houston region and interest on the part of county government leaders.

Five objectives were set forth for our work: (1) assemble natural science data inventory; (2) investigate likely types of development; (3) assess capability of area to support development; (4) derive general management guidelines; (5) investigate monitoring techniques. The first phase of our work has been completed, and the project Technical Report[8] explains the process and the results in detail. Particular success has been achieved in the construction of the network of happenings caused by the placement of development in various geographic areas of Chambers County. The next phase of work will continue to develop this tool as well as evaluate the public and private uses of the information coming from the entire process.

WHERE ARE WE?

To date the Chambers County Project and the Louisville Airport Project represent our most comprehensive application of natural environment analysis. The Texas Gulf Coast Project will expand the procedure to applications on a large coastal region. With completion of that work, the analysis procedures will have been applied across areas and issues from a large region to 5,000 acre sites and several steps between. Evaluation of future uses by the private and public sector should be able to follow.

WHERE ARE WE GOING?

It appears that the development of tools and procedures that can accurately predict the consequences of development on nature prior to the act is within our immediate reach. The quality and sequential availability of natural science information should continue to improve. Every effort should be made to produce detailed natural systems descriptions of geographic areas in formats usable for community development questions. Our understanding of the options and alternative ways of building and operating our communities should be advanced more quickly Technological advancement of community hardware should occur in the areas of greatest long range need and cease in areas that simply will prolong existing problems. Legislative and administrative policy should make use of these new tools and we should leave the era of land use controls and enter the future with a workable system for land resource management.

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N75 17209

NATIONAL ECONOMIC MODELS OF INDUSTRIAL WATER USE AND WASTE TREATMENT

Russell G. Thompson
James A. Calloway

INTRODUCTION

In developing improved decision aids for policy makers, the importance of economics can not be overlooked. What will be produced, how it will be produced, and for whom it will be produced are always fundamental questions. In a laissez-faire structure, there is one ideal set of answers to these questions; a socialistic structure will result in another set of answers. Answers to questions of what will be produced, how, and for whom will depend both on the political structure and the policies of that structure. In a laissez-faire economy, public goods such as water and air will be free. The cost of water, since it is zero, will not affect the design of the production facilities. In a socialistic (planned) economy, limited quantities of goods are allocated to users. These limitations will imply certain values for the goods; these values will affect the design of the production facilities.

The United States has neither a laissez-faire nor a socialist economy. The government influences, but does not necessarily determine, allocations and prices of goods. Public goods such as water and air have been relatively cheap. In the past, prices of these goods have not affected the design of production facilities. However, that is true no longer.

Today, the price of water, due to government water quality policies, is rising rapidly. Very high production costs may result from a zero wastewater discharge policy. Industry managers need to know the effects of air emission and solid waste restrictions on production cost and resource use.

In making these evaluations, managers will look at many substitution possibilities in conjunction with each of the proposed waste management policies. For example, how will production costs be affected by using dry cooling rather than wet cooling? How will the discharge of wastes be affected by the use of a light feedstock rather than a heavy feedstock? How will the cost of water treatment be affected by the quality of the input water?

One of the simplest methods of making these substitution evaluations is linear programming. A linear program is developed in the following way for a design problem:

(1) an engineering flowgraph is developed for the problem;
(2) the flowgraph identifies the important decision points at which substitution possibilities may occur;

(3) for each substitution possibility, the quantity of each input and the quantity of each output, including waste, is specified (with the input-output coefficients organized in a matrix of numbers called a tableau);
(4) certain substitution possibilities are limited by resource limitations, physical laws, or public policy restrictions;
(5) given cost minimization as a goal of the decision maker, a solution to the linear program may be calculated with the use of a computer to yield the least-cost set of substitution activities and their level of operation;
(6) the effects of variations in the limitations and the coefficients on the solution may be analyzed with the use of the computer.

Results of this type of analysis will be particularly helpful to managers in evaluating how resource use, production cost, and waste discharges in different types of production may be affected by resource limiting policies of the government. The government is presently limiting wastewater discharges, air emissions, and solid waste discharges. These policies are affecting how products are produced, the types and amounts of resources used (including monies), waste discharges to the air, water, and land, and the cost of producing important final products desired by consumers.

AN APPLICATION OF ECONOMIC METHODS TO MODELING ETHYLENE AND AMMONIA PLANTS AT THE DESIGN STAGE

One important economic question is how water use and waste treatment will change in response to government wastewater effluent standards. Two types of substitution possibilities were identified in the plant modeling: (1) among classes of factors and (2) among technical variations within classes. The classes of factors affecting how water is used and waste is treated in an ethylene plant are (1) light vs. heavy feedstocks; (2) air cooling vs. water cooling; (3) electric motors vs. steam drivers; (4) high quality vs. poor quality input water and (5) a range of input water temperatures.

Within each class of factors technical variations exist which affect operation of the water use and the waste treatment system. Different flows and concentrations of wastes from the production process may be treated by varying the operating conditions of the treatment processes. These variations in operating conditions will result in different costs of production.

Ethylene

In ethylene production, propane (light) and naphtha (heavy) are possible feedstocks; the production system may be cooled with water or with air; steam may be used directly as a source of power or indirectly to produce electricity; both the hardness and the temperature of the input water will vary from one region to another.

An ethylene plant model was developed for ethane, propane, and naphtha feedstocks. The cooling system was designed for air and water cooling. The models were developed to use steam directly and indirectly (converted to electricity) as a source of power. Hard and soft input water was studied, as well as hot and cold input water temperatures. Demineralization and evaporation were used to treat inorganic wastes; oil separation, air flotation, sludge activation, and carbon adsorption were used to treat organic wastes.

Discharge policies requiring zero discharges of floating oil and suspended solids and emulsified oil increase ethylene production costs less than 1%. Zero discharges of all organic residuals (floating oil, suspended solids and emulsified oil, BOD, and phenol) and inorganic residuals (total dissolved solids) increase production costs 14%. Zero discharge of organic residuals presents a special disposal problem; this was accomplished by clarifying and demineralizing the wastewater stream from the carbon adsorption unit and using it as makeup water for the wet cooling tower. Concentrated brine streams from the demineralizers were evaporated to dryness.

The results in Figure 1 show how production costs increase with increasingly restrictive waste discharge policies for each of the important organic wastewater residuals. The results in Figure 2 show how production costs increase and how water use is changed with increasing restrictions on total dissolved solids discharges. Similar results were obtained for Trenton and Saginaw. Restrictive wastewater discharge policy may significantly affect how water is used in ethylene production; however, increases in production costs are generally relatively small for all levels of removal except those near zero discharge.

Ammonia

In ammonia production, natural gas and naphtha are alternative feedstocks; the same substitution possibilities regarding cooling, energy sources, and water quality used in ethylene production form a part of the ammonia model. A separate model represents each of four geographic regions. Demineralization and evaporation were used to treat inorganic wastes; there are no organic wastes.

Dissolved solids are the only significant discharge from the ammonia production process. Achieving zero discharge of dissolved and suspended solids causes production costs to increase by 3%. Figure 3 shows the corresponding process changes which occur as discharge standards become increasingly restrictive. Figure 4 shows how the marginal cost of removal increases with increasingly restrictive wastewater effluent standards for suspended and dissolved solids.

Figure 5 is an estimate of the consumptive demand for water as a function of water withdrawal price. If higher prices are imposed on water withdrawals to reduce water withdrawals, water recycling is employed, process water temperatures rise, and water consumption increases because of increased evaporation. Election of the air cooling option reduces water withdrawals to a minimum where withdrawals equal consumption at zero discharge.

The effects of increasingly restrictive wastewater effluent standards on increased energy use were relatively small in both ammonia and ethylene production.

EXTENSIONS

Additional plant models have been developed for caustic soda-chlorine, steam electric power generation, pulp and paper, and iron and steel. These models have been reviewed by industry and government experts and revised accordingly. Additional plant models are being developed for the following important chemical based products: polypropylene, nylon, synthetic rubber, and anhydrous ammonia.

Models of biotreater and ion exchange units have been developed and interfaced with the plant models. With adjustments in the cost estimates for plant size and with distributions of the waste loads for each industry, the effects of wastewater discharge policies on the production costs of an industry may be estimated.

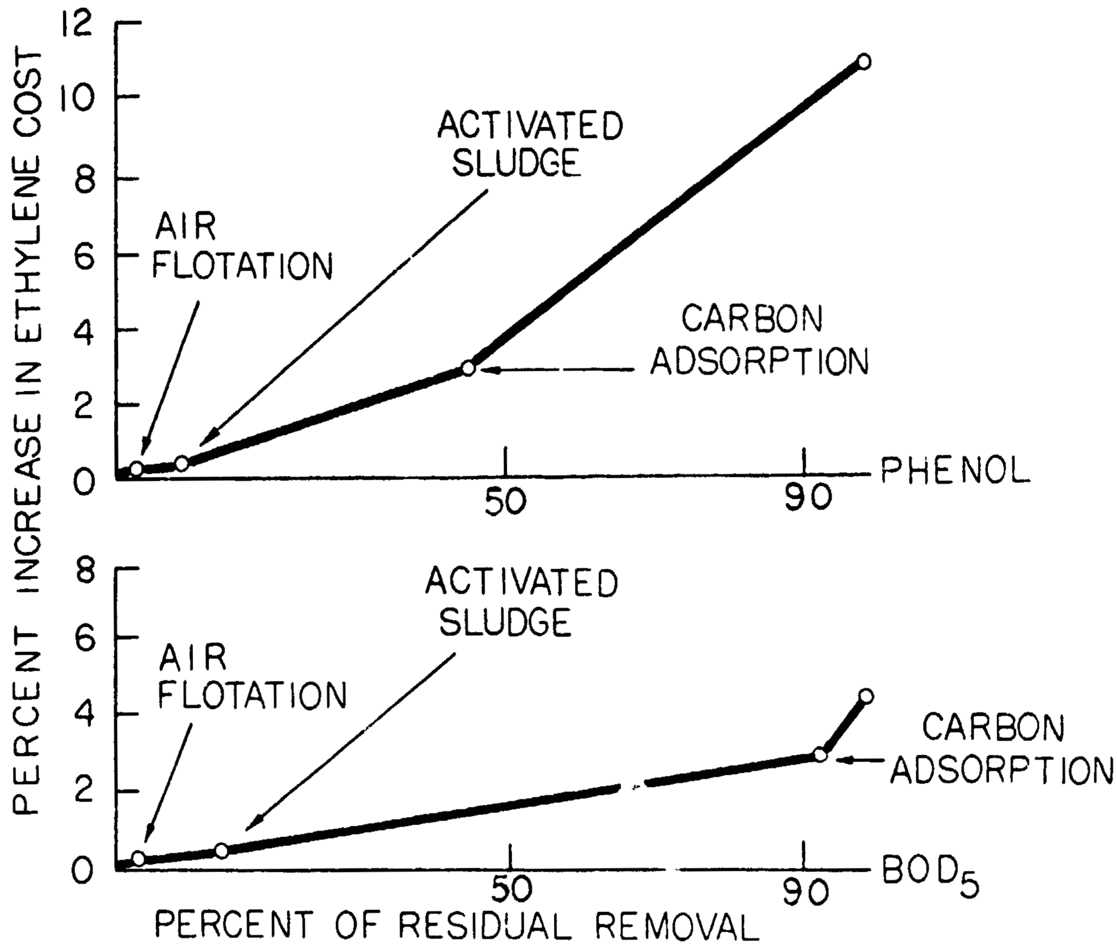

FIGURE 1: TREATMENT SUBSTITUTIONS FOR SINGLE ORGANIC EFFLUENT RESTRICTIONS IN OLEFINS PRODUCTION

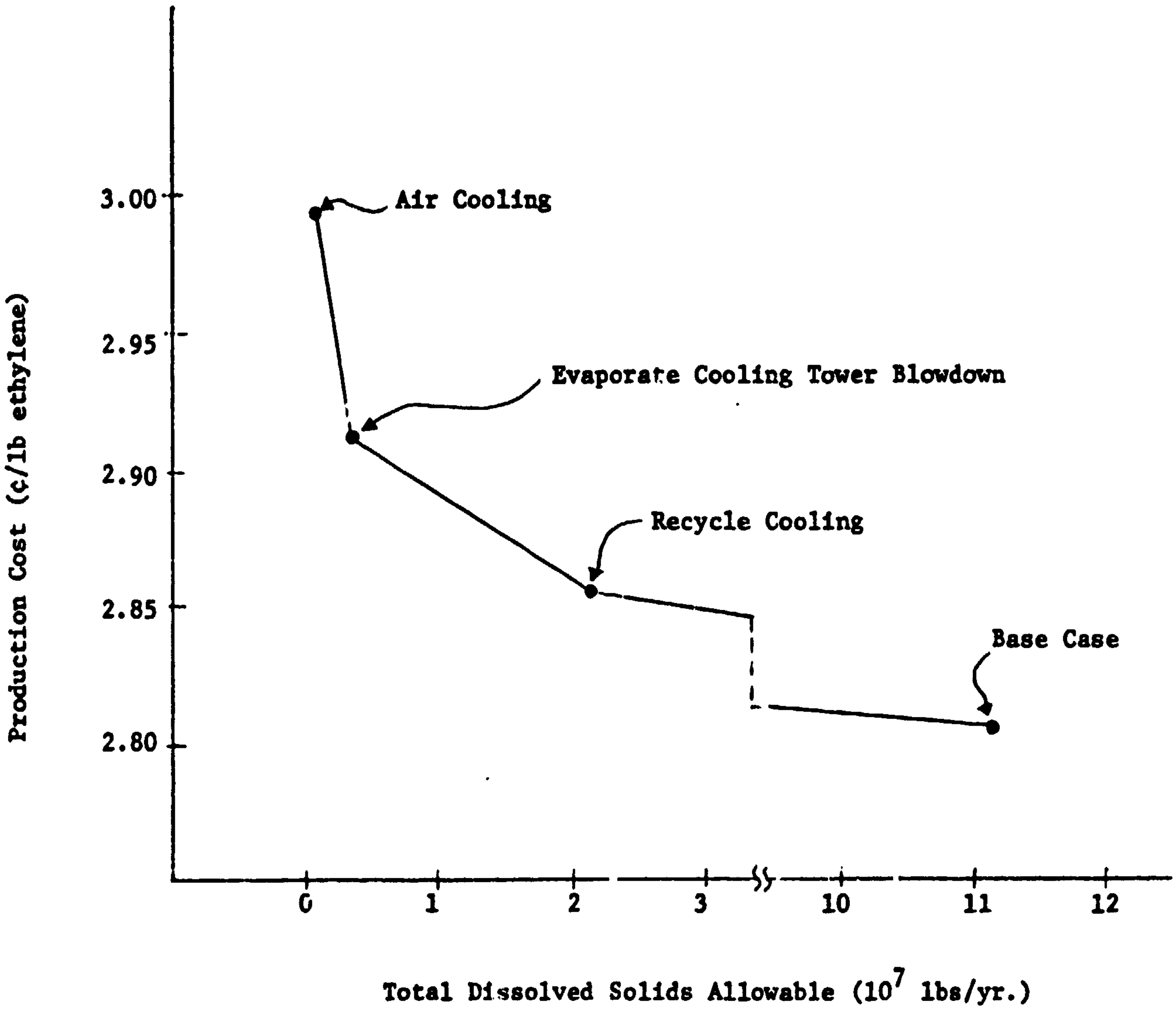

Figure 2. Production Cost Vs. Dissolved Solids for Ethylene

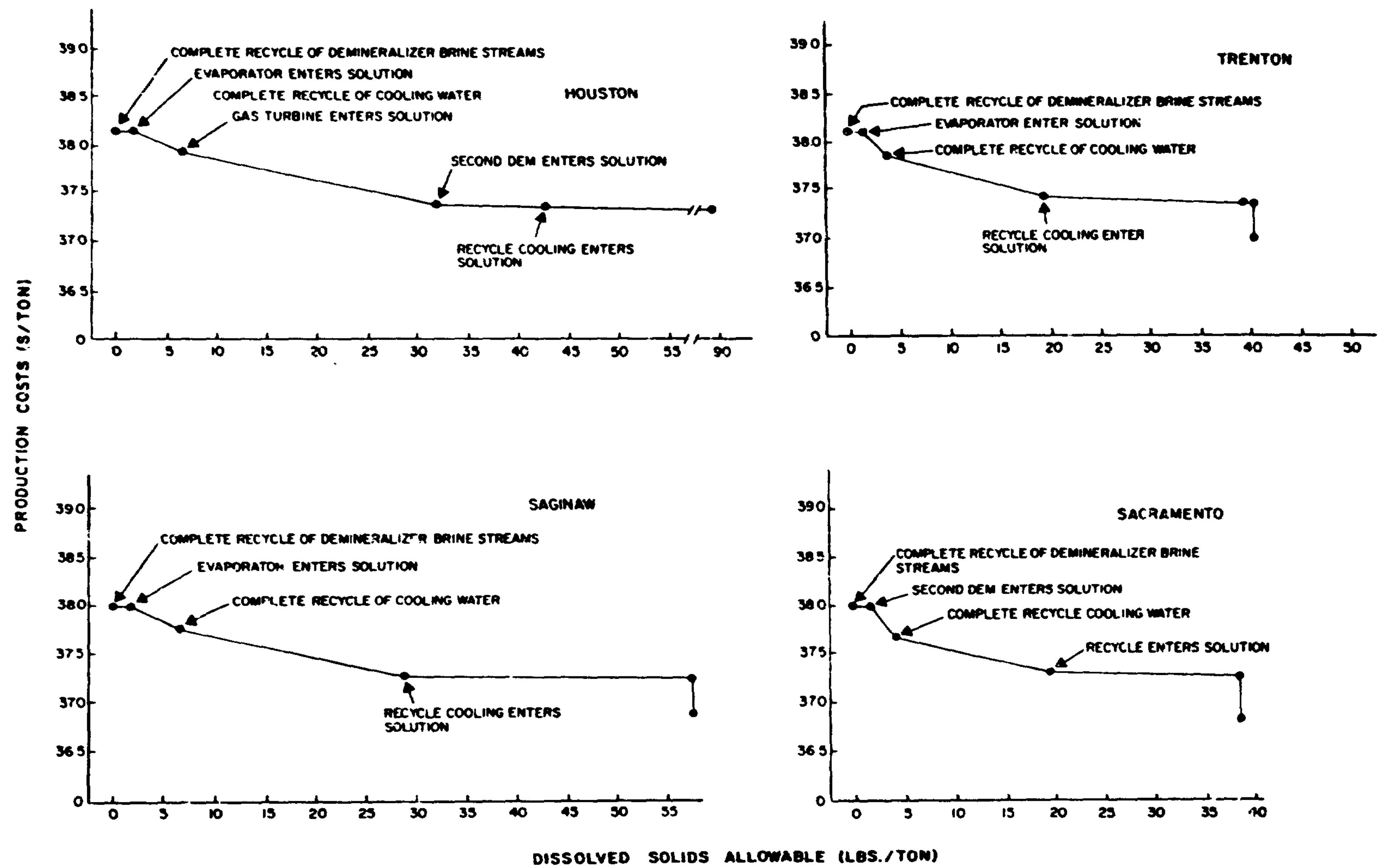

Figure 3. Production Costs Vs. Dissolved Solids

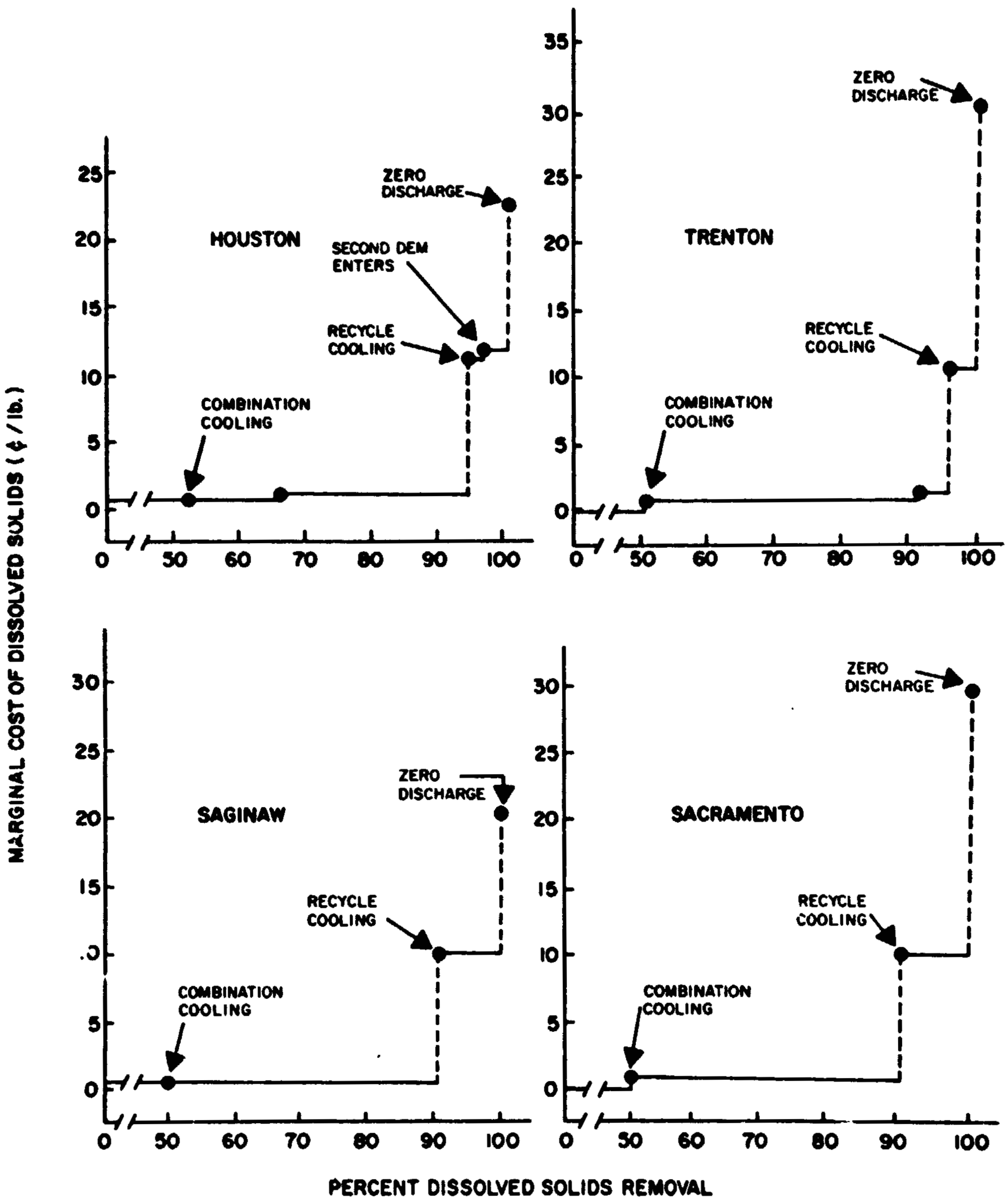

Figure 4. Cost Vs. % Removal of Dissolved Solids

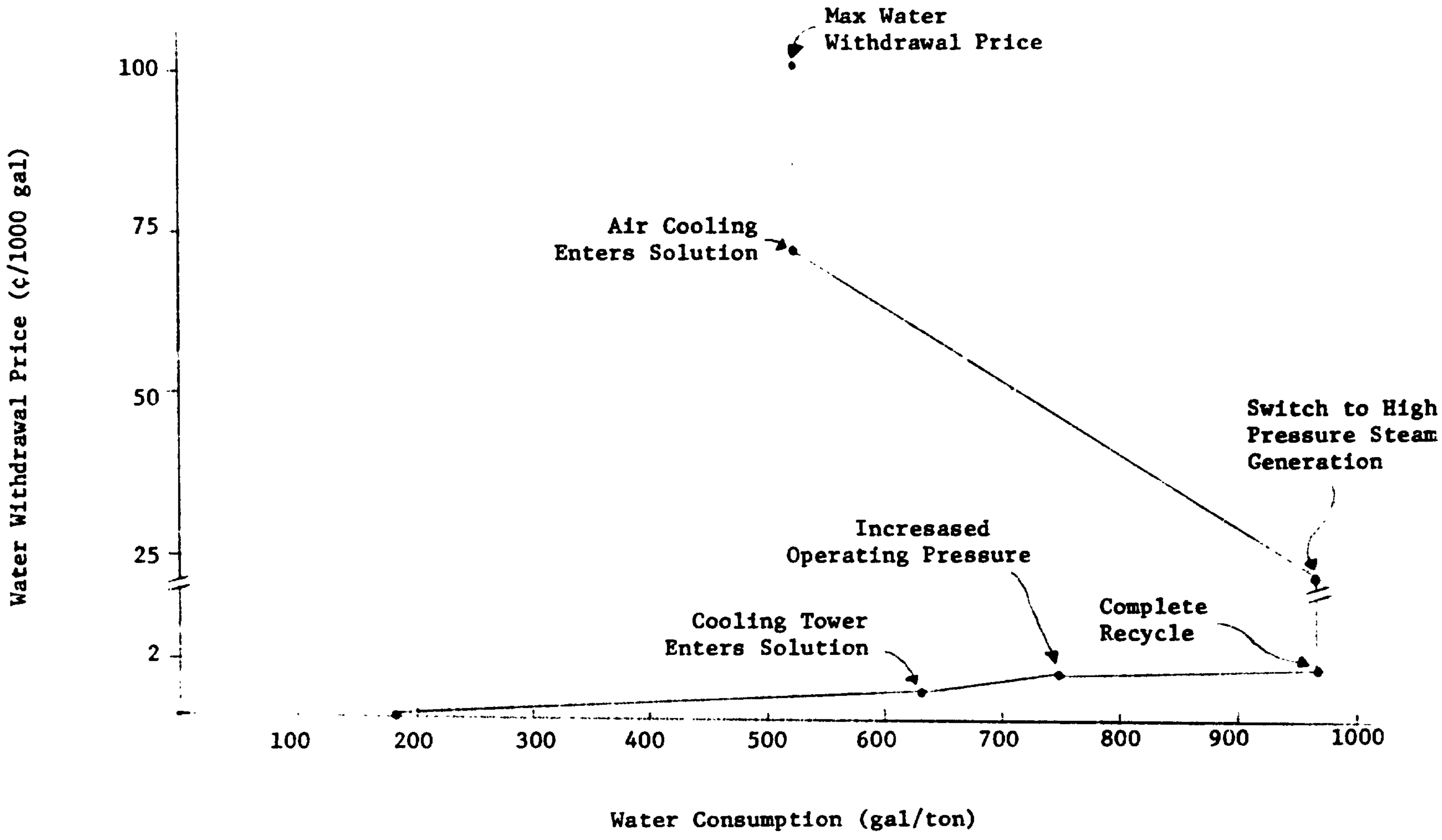

Figure 5. Water Withdrawal Price vs. Water Consumption

N75 17210

ECONOMIC MODELING AND ENERGY POLICY PLANNING

Russell G. Thompson
Andrew K. Schwartz, Jr.
Rodrigo J. Lievano
John C. Stone

INTRODUCTION

In a market economy, forecasts of energy production, use and price require estimates of the demand functions for the important uses of energy and estimates of the supply functions for crude oil, natural gas and coal. Demand functions for electricity, natural gas, and fuel oil have been estimated for household and commercial uses (Baughman & Joskow, 1974; Levy, 1973; Anderson, 1973). Demand functions for gasoline, jet fuel, and distillate fuel have been estimated for transportation uses (Houthakker and Verleger, 1973; Adams, Graham and Griffin, 1973). Demand functions for the outputs of the heavy fuel using industries have been estimated for certain important products, e.g. nylon (Ward and King, 1973). Supply functions for crude oil, natural gas, and coal are being estimated with support from NSF (RANN). However, reliable estimates of the demand functions for natural gas, crude oil, and coal in industrial uses (heating and feedstock) and in steam electric power generation are needed.

The purpose of this paper is to present a structural economic model for estimating the demand functions for natural gas and crude oil in industry and in steam electric power generation. This structural economic model was initially developed by Schwartz et.al., with the support of NSF (RANN), in the following general ways:

(1) linear economic models of production, energy use, water use, wastewater treatment, air emission control, and solid waste management were developed for petroleum refining and for production of olefins, chlorine-caustic, ammonia, sulfuric acid, aromatics (benzene, toluene, xylenes), phthalic anhydride, butadiene, styrene, cyclohexane, ethylbenzene, carbon black and styrene-butadiene rubber;

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(2) linear economic models of electric power generation for both steam and gas turbines were developed;
(3) the linear economic models in (1) and (2) were integrated into one over-all linear power process model with cascading of heat from high temperature to low temperature processes;
(4) forecasts of the national requirements for each of the important final products of the model were specified;
(5) with the objective of cost minimization, solutions to the linear program were computed for different specifications of restrictions on waste discharges and fuel availabilities.

With increased scarcity of crude oil, the model substitutes one process for another to minimize the costs of producing the forecast product requirements. The availability of crude oil is restricted until the model can no longer substitute one process for another. These process substitutions result in decreases in crude oil use and increases in production costs. This schedule of incremental values of crude oil gives the demand schedule for crude oil. Similar parametric evaluations can give the demand schedules for natural gas and waste disposal rights.

ESTIMATED DEMAND SCHEDULES FOR A NATIONAL POWER PROCESS COMPLEX

With the use of the computer, demand schedules for crude oil are being estimated for a power process complex of petroleum refining, important chemicals production, and steam electric power generation, said complex producing forecast national requirements of its products. The demand curves are being estimated for the following cases: (1) the power and process activities are fully integrated with heat from the high temperature processes cascaded to low temperature uses; biotreatment of all organic wastes is required before discharge of the wastewater stream; and cooling is supplied by wet cooling towers; (2) the power and process activities are partially integrated with restricted cascading of heat; biotreatment of all organic wastes is required before discharge of the wastewater stream; and wet cooling towers are used for cooling; (3) the power and process activities are fully integrated with heat from the high temperature processes cascaded to low temperature uses; zero discharge of all organic and inorganic wastes is required, with no liquid water leaving from the plant; and wet cooling towers are used for cooling. Zero discharge of organic residuals presents a special disposal problem; this is accomplished by clarifying and demineralizing the wastewater stream from the carbon adsorption unit and using it as makeup water for the wet cooling tower. Concentrated brine streams from the demineralizers are evaporated to dryness.

The estimated demand schedule for crude oil in Case 1 is given in Figure 1. The demand schedule basically reflects a long run curve because the model provides for new construction where necessary.

No environmental waste discharge restrictions are placed on total dissolved solids, sulfur oxides, or particulates. The breakpoints in the graph represent points at which the demand for either source of crude changes by more than 1%.

With a price increase from \$3.00 to \$10.75 per barrel, crude oil use in the complex decreases from 15.1 MMBBL/day to 11.3 MMBBL/day. With an increase in crude oil price from \$3.00 to \$5.00 per barrel the equivalent of 2.6 million barrels per day of coal is substituted for the burning of petroleum products to fire the boilers. With higher prices of crude oil, additional coal is mined and is substituted for crude oil. With price increases from \$5.00 to \$10.75, crude oil use decreases less than 1.2 million barrels per day.

The bulk of the change in crude oil use is accounted for by reductions in the use of imported crude oil; the use of domestic crude deviates little from the imposed upper limit of 3.5 billion BBL per year (9.589 MMBBL/day). As might be expected, the use of non-crude sources of energy and feedstock increase dramatically where permitted. Only external purchase of coal (at 75¢/MMBTU) is not at its upper limit in the base case. Purchases of natural gas and propane are held to 2.2 X 10^{16} BTU and 258 MMBBL (per year), respectively. Purchase of natural gasoline for gasoline blending is held to 192.9 MMBBL per year. External supplies of n-butane and isobutane feedstocks are limited to 80.68 MMBBL and 9300 MMBBL (per year), respectively.

As crude oil price increases from \$3/BBL to \$10.75/BBL, coal use increases 74.5%. Mining of coal becomes profitable at a crude price of \$4.45/BBL. Coincident with the increase in coal use, sulfur oxide emissions increase 41.74% and particulate emissions increase 60.36%. At a crude price of \$7.038/BBL, the generation of electricity in existing oil fired plants begins to decrease significantly in favor of electricity generation from new coal fired plants. As crude price increases more ethylene is made from LPG and less from naphtha and gas oil. Total consumption of ash free fuel (gas or fuels suitable for gas turbines) decreases by 4.54% over the investigated range. Consumption of heavy liquid fuels and petroleum coke decreases by 93.92%. Given the dramatic increase in coal use, however, total consumption of all fossil fuels increases by 1.76%. The currently reported results are still under refinement and further results (along with those for cases 2 and 3) will be reported at the meeting.

EXTENSIONS

The model is being extended to include linear production models for the important plastics (polypropylene, polyethylene, polyvinylchloride, and polystyrene), important synthetic fibers (nylon 66 and polyester), fertilizers (nitrogen and phosphorus), iron and steel, pulp and paper, nonferrous metals (aluminum, copper, zinc), and coal gasification/combined cycle power generation. The model, which will reflect a very large fraction of fossil fuel use in heavy industry and electric power generation, will allow us to evaluate the effects of environmental policy, energy policy, and power policy on the uses of resources, the discharges of wastes, and the cost of producing electricity, refinery products and the important outputs of the heavy fuel using industries. Economically, the model will select the least-cost manner (given different policy restrictions) to produce the nation's requirements for electricity, energy products, and the outputs of the heavy fuel using industries from the nation's limited supplies of crude oil, natural gas, coal, and water.

The microeconomic basis for policy evaluations is being interfaced with the Texas Input-Output Model and with national input-output models developed by the University of Maryland (INFORUM) and the United States Department of Commerce. These combined models will allow us to evaluate the direct and indirect effects (both within and between all industries in the economy) of policy changes on resource use, employment, production costs, investments, income, and waste discharges.

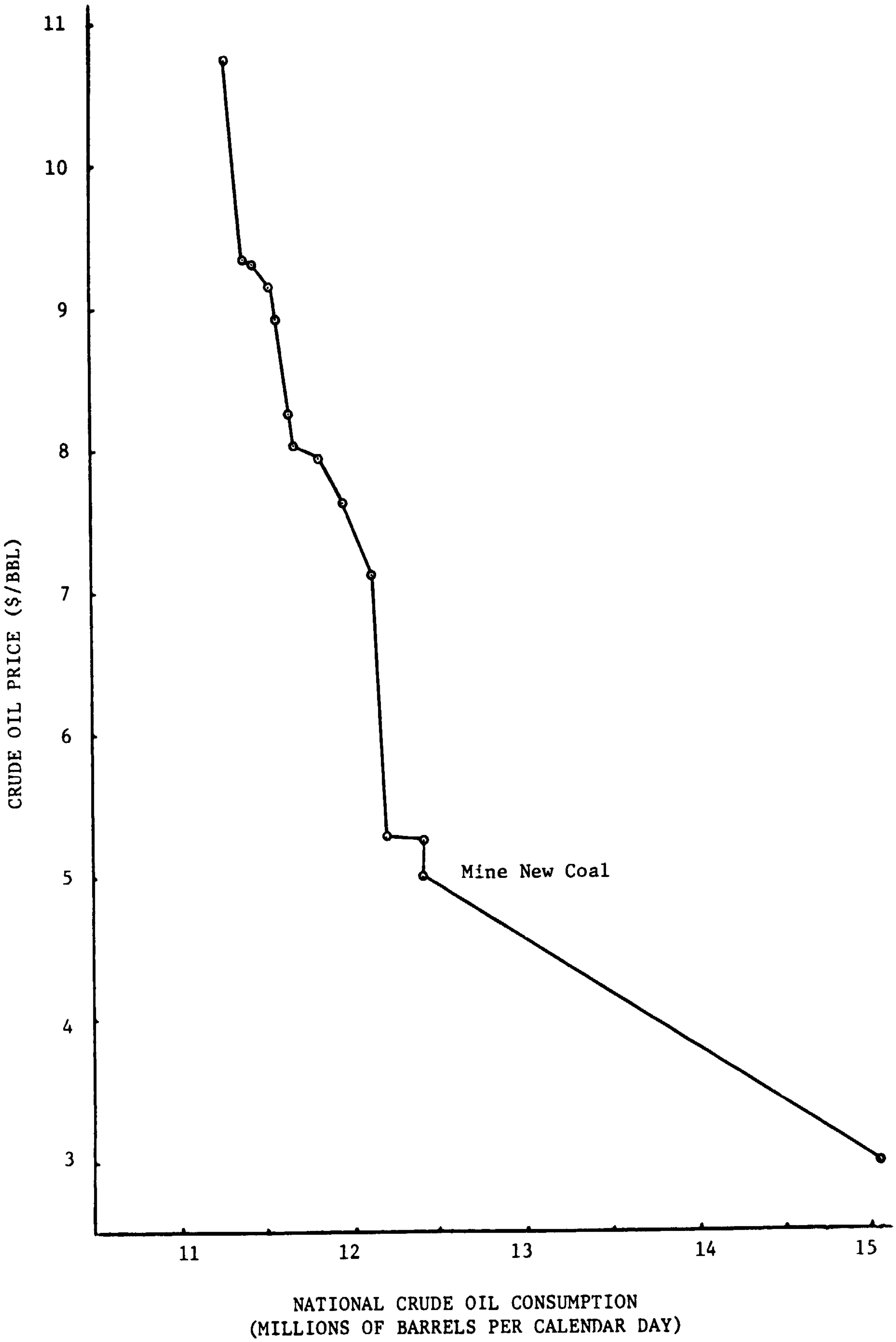

FIGURE 1: INDUSTRIAL DEMAND CURVE FOR CRUDE OIL IN UNITED STATES

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N75 17211

APPLICATION OF ADVANCED SIGNAL PROCESSING TECHNIQUES TO THE RECTIFICATION AND REGISTRATION OF SPACEBORNE IMAGERY

R.H. Caron, S.S. Rifman, K.W. Simon

I. INTRODUCTION

The volume of spaceborne imagery generated in recent years has reached staggering proportions. For example, as of March 1974 the EROS Data Center had in its holdings approximately 400,000 frames, consisting of 6000 Apollo and Gemini photographs (with nearly 2,000,000 more expected), 19,000 frames of Skylab imagery and 373,000 frames of ERTS-1 data (increasing at the rate of 12,000/month). NOAA, ATS, NIMBUS, and TIROS have also returned vast amounts of data, and the projected EOS spacecraft is expected to return data at approximately seven times the rate of ERTS. It is therefore reasonable to inquire whether the data generated thus far is being utilized effectively; and, indeed, is the spaceborne image processing technology growing at a rate commensurate with projected demands?

Although these questions are the subject of much debate (see, for example, Reference 1), one point-of-view is gaining universal acceptance, viz. that cost-effective image processing systems and techniques are sorely needed to satisfy the requirements of the wide range of users who expect to benefit from spaceborne imagery. To meet the challenge of developing systems and techniques with diverse applicability, it is first necessary to appreciate the interests reflected by the user community and the requirements they impose. Generally speaking, user requirements divide into two categories, corrective and interpretive. Cartographers and others interested in accurate mensuration work need precision geometric correction of bulk (downlinked) data; urban planners, demographers, agronomists, etc., may additionally require data for a given region to be registered spatially from pass to pass so as to facilitate change detection analysis; and those involved in the design and management of environmental systems, as well as the petroleum and mineral exploration companies, require interpretive aids such as multispectral classifiers to generate thematic maps.

This paper discusses TRW's approach to the development of an ERTS/MSS image processing system responsive to the needs of the user community. An overview of the TRW ERTS/MSS Processor is presented, followed by a more detailed discussion of certain image processing functions satisfied by the system. The particular functions chosen for discussion share the commonality of having evolved from advanced signal processing techniques rooted in the areas of communication and control. These examples show how classical aerospace technology can be transferred to solve the more contemporary problems confronting the users of spaceborne imagery.

II. OVERVIEW OF AN ERTS/MSS IMAGE PROCESSOR

The image processing functions responsive to the requirements outlined above are shown in Figure 1 in the context of an ERTS/MSS processor. The principal features of this system include: input data reformatting (and radiometric calibration, if required) onto a mass storage device; geometric rectification and/or registration; interpretive processing; and output product generation.

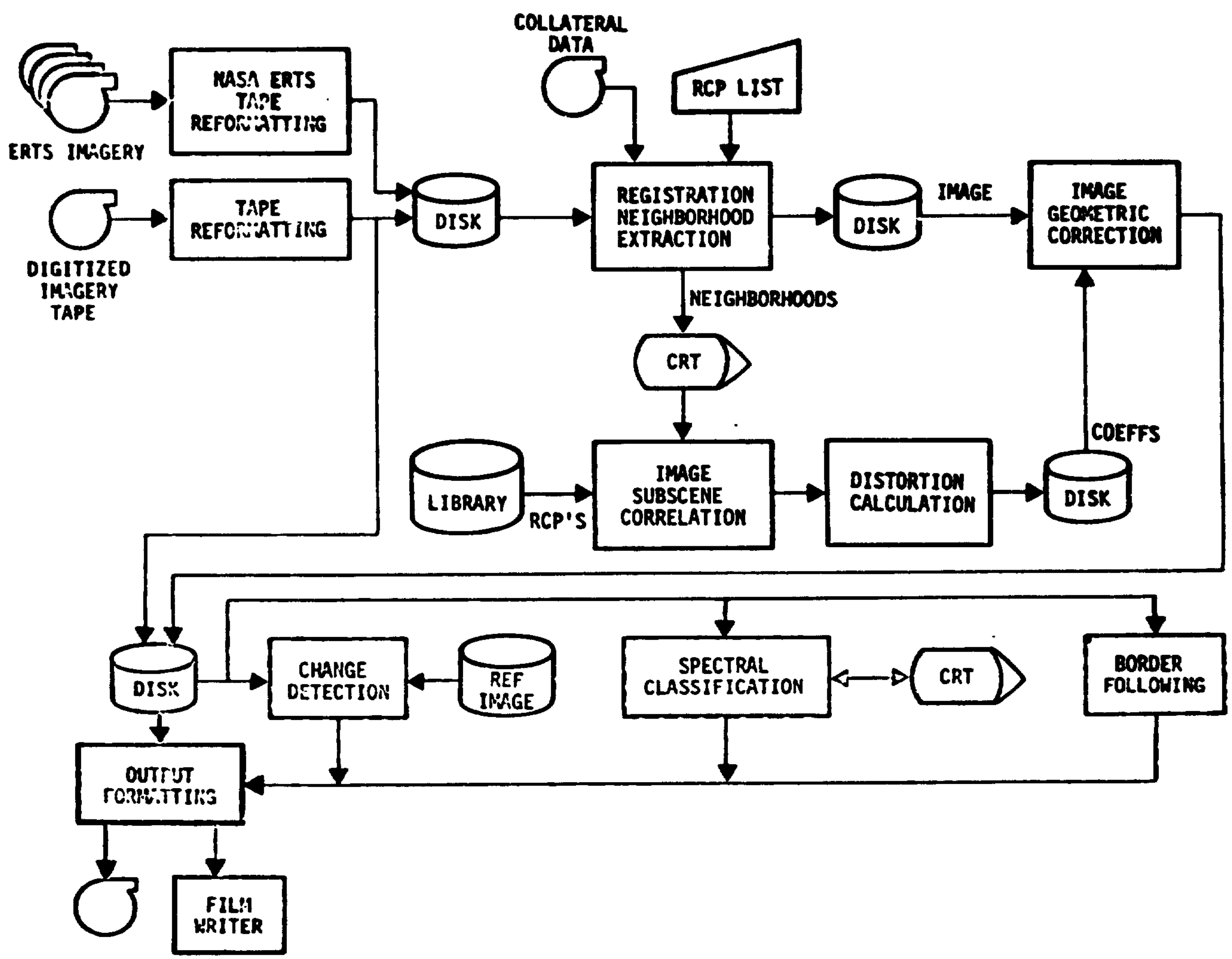

Figure 1. Image Processing System

Bulk ERTS/MSS imagery is available from the EROS Data Center on Computer Compatible Tapes (CCT's) in a digital, band-interleaved format. Each MSS image, consisting of four images (each corresponding to a particular spectral band), is divided into four swaths running the length of the imagery, each swath stored on one reel of magnetic tape. The input reformatting process in Figure 1 accepts the CCT's, converts the imagery to a band-sequential format and stores the result on a mass storage device. A separate process not shown in Figure 1 removes replicated pixels* which NASA includes to make a standard line-length. It has been found that precision change detection is not possible using pixel-replicated imagery due to the banding that results when replication occurs in different locations in different spacecraft passes.

The geometric rectification process corrects the various distortions present in the bulk MSS imagery. These distortions result from:

- o Fluctuations in spacecraft attitude and ephemeris during image scan
- o Earth rotation during image scan
- o Scan nonlinearity in the MSS mechanism
- o Sensor sampling commutation skew
- o Line length correction by means of pixel replication during CCT generation

Closely allied to the rectification process is a variation termed registration wherein the imagery resulting from one spacecraft pass is corrected to a grid so that pixels in the corrected image overlay corresponding pixels in the rectified image of another pass.

To geometrically rectify image data or bring it into spatial registration with another (reference) image it is necessary to estimate, model, and correct the image distortion. Each step must be accomplished with fractional pixel accuracy, or else the resultant "corrected" image will contain errors large enough to limit its usefulness, particularly so in the case of registration. Distortion estimation involves the use of dynamic models of the ERTS/MSS system in conjunction with a recursive estimator to solve for a mean-square-sense optimal estimate of the combined effects of attitude angles and rates and ephemeris measurement errors.[2] Distortion modelling is achieved by partitioning the bulk image into a relatively few (< 100) contiguous, rectangular blocks. Then through an iterative computational technique, a bilinear distortion model is generated for each of the partition blocks.[3] The correction process employs the distortion model to determine the pixel values at each desired pixel location in the corrected image. This latter process, termed image

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* A pixel (picture element) represents a single sample of sensor data and, in the case of the ERTS/MSS system, corresponds to a square instantaneous field-of-view of 80 meters on a side. One spectral band of bulk ERTS/MSS imagery contains more than 7 million pixels.

resampling or interpolation, inherently produces a digital output image, which can be used to generate the corrected image hardcopy.

The image processing system in Figure 1 has been designed to include a number of interpretive operations: supervised and unsupervised multispectral classification (including thematic map generation); change detection using registered imagery; and border following. In addition to these major functions, the system supports a host of auxiliary operations such as generation of image statistics, contrast enhancement, edge detection, magnification, spectral ratioing, spatial filtering and color density slicing.

It should be noted that TRW has implemented all of the processing capabilities described above using highly efficient algorithms in the context of a cost-effective, minicomputer-based hardware configuration. Much of the associated software has evolved through the application of advanced signal processing techniques to meet the challenge of stringent image processing requirements set forth in the original design. Examples of this transfer of technology are the subject of the next section.

III. TECHNIQUES APPLIED TO IMAGE RECTIFICATION AND REGISTRATION

A. Optimal Estimation

Uncertainties in satellite attitude and altitude translate into position estimation errors when one attempts to grid a spaceborne optical scanner image, i.e., establish a correspondence between points in the image and their counterparts in a planar map projection such as Universal Transverse Mercator. Investigators using the bulk image annotation data associated with certain ERTS scenes have observed position estimation errors as large as 5 kilometers.[5] MSS scene 1080-15192 of the Baltimore/Washington area and the associated Bulk Image Annotation Tape 1085-46 provide a case in point. Thus, it is apparent that an attitude time-series, for example, derived solely from attitude sampled-data on a BIAT is inadequate for projecting an optically scanned image into a map system. Clearly, some means to obtain a more refined estimate is required.

When faced with a problem in which certain parameters exhibit unacceptable uncertainties, the first step is to see if some additional information (dependent upon the parameters) can be utilized to reduce the uncertainty. The act of reducing parameter uncertainty in this fashion is called estimation and involves the use of a mathematical construct called an estimator. One type of estimator--the discrete-time, sequential estimator--is described by an equation of the form

$$\underline{\hat{x}}_{k+1} = \underline{\hat{x}}_k + A_{k+1}[\underline{y}_{k+1} - \underline{f}(\underline{\hat{x}}_k)] \ ,$$

where

$$\underline{y} = \underline{f}(\underline{x})$$

is an observation dependent upon the parameter $\underline{x}$; $\underline{y}_{k+1}$ is the (k+1)-st observation; $\underline{\hat{x}}_k$ is the k-th estimate of $\underline{x}$ (based upon the k preceding observations); and A_{k+1} is an optimal weighting matrix. The estimation equation enables one to update the current estimate of the parameter $\underline{x}$ by taking into account the error between a new observation,

$\underline{y}_{k+1}$, and the projected value of the observation, $\underline{f}(\hat{\underline{x}}_k)$, based upon the current estimate $\hat{\underline{x}}_k$.

TRW has applied the concept of discrete-time, sequential parameter estimation to the problem of reducing uncertainties in the attitude/altitude-bias time-series associated with each frame of ERTS/MSS imagery. The additional information required to update the estimator are points in the image with geodetic control, i.e., points for which the geodetic latitude, longitude, and elevation are known. Essential to the estimation process is the location of the control points in the image. Current techniques include manual designation on a CRT display using a track-ball cursor and semi-automatic designation via an optimized sequential similarity detection algorithm (SSDA).[6] Considering that one pixel accuracy is attainable by either of these methods, it follows that position estimation error on the order of 80 meters can be achieved with precision geodetic control points.

Position estimation performance using the TRW attitude/altitude-bias time-series estimator is summarized in Figure 2. The plots shown were obtained by running the estimator with k=1,2,.. ,10 observations. After the k-th observation, the resultant estimate x_k was used to compute the position estimation error for each of the 10 control points. From this sample of size 10, a mean and standard deviation were computed. This process was repeated for k=1,2,.. , 10 to obtain the plots of Figure 2. Notice that the error after three control points approaches the 80 meters resolutional capability of an ERTS/MSS detector. The standard deviation curve of Figure 2 is asymptotic to 30 meters, a value determined by the uncertainty ascribable to each of the precision control points.

B. <u>Signal Reconstruction</u>

Once optimal estimates for parameters exhibiting high a priori uncertainties are obtained, a distortion (warp) function can be generated. This function is essentially a bijective mapping between the bulk (uncorrected) image and the corrected image. To utilize the distortion function to reconstruct an ERTS scene, it becomes necessary to generate image data at pixel locations other than the sampling locations of the bulk image.* There are two ways to accomplish this:

1) Move the sampled pixels around, (e.g., EBR beam position modulation);
2) Interpolate the desired pixel values from the bulk image pixel locations.

TRW has employed the latter process, which in contrast to the former produces a digital data stream as the output product. The input to the resampling process consists of a set of distortion

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* Remember that the bulk image is a digitized version of the analog image seen by the MSS detectors.

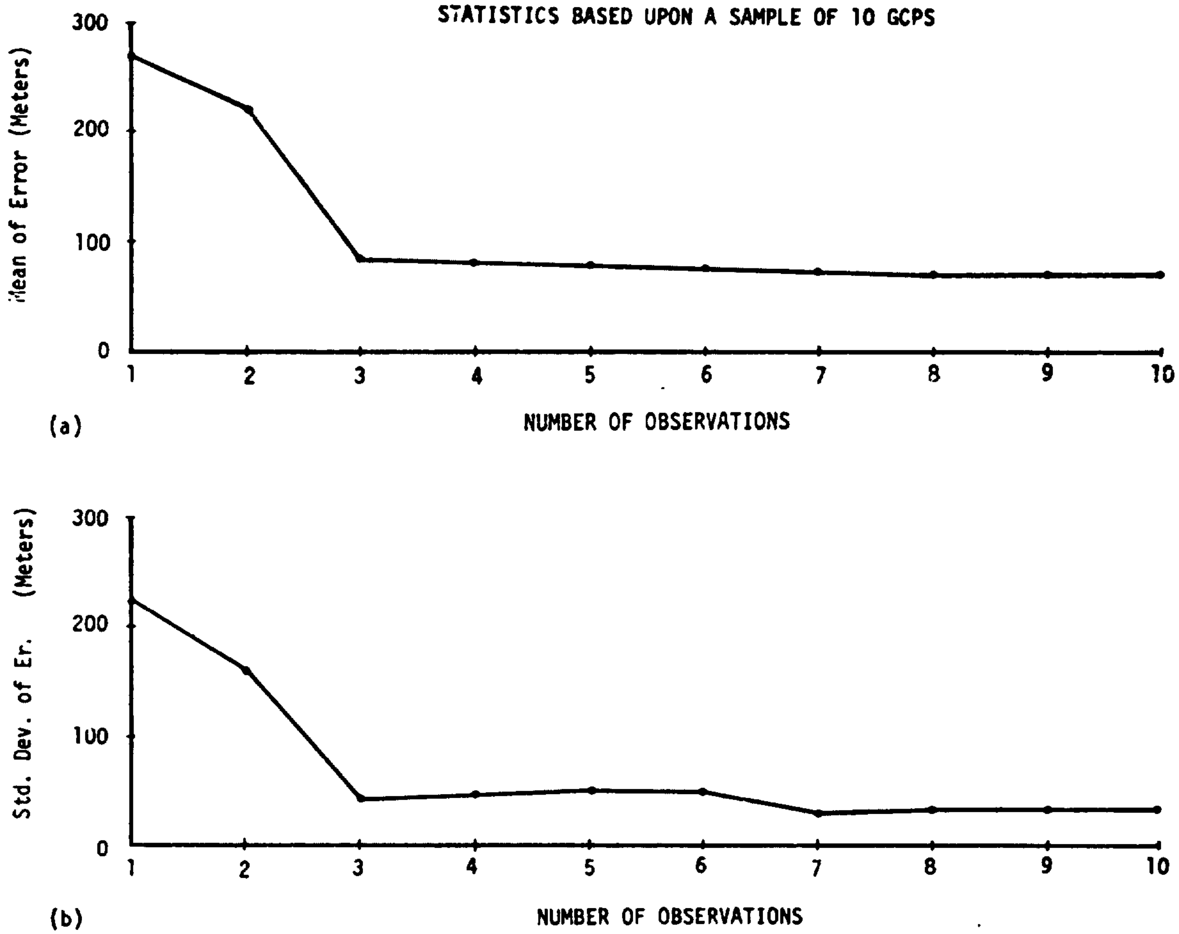

Figure 2. Position Estimation Error Profiles

coefficients for each of the image partition blocks and the reformatted bulk image data. Conceptually, the process consists of reconstructing in its entirety the corrected (rectified) image and then resampling its intensity values at predesignated positions within the bulk image. The power of the resampling method becomes clear when it is realized that complete flexibility is afforded in the matter of pixel spacings and line spacings, thus making possible the custom tailoring of the corrected image to any application and/or hardware constraints.

The reconstruction process is implemented by appeal to a generalization of Shannon's sampling theorem.[7] In 1949, C.E. Shannon showed that a function whose Fourier transform is zero above some frequency ω_c can be reconstructed from a countably infinite number of equally distant samples providing that the space between samples does not exceed π/ω_c. This concept of signal reconstruction generalizes to two-dimensional, single-valued functions (e.g., images) whose Fourier transform is null outside some bounded region of the transform domain. More particularly, if the function $f(x,y)$ has a Fourier transform which is null outside a rectangle with sides 2a and 2b, then

$$f(x,y) = \sum_{n=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} cdf(nc,md)k_b(x-nc,\ y-md),$$

where

$$k_b(x,y) = \frac{1}{4\pi^2} \iint_B e^{j(ux+vy)}\, dudv\,,$$

and B is a region in the transform domain encompassed by the rectangle and encompassing the support of the transform of f.

In the context of image reconstruction, the sampled data $f(nc,md)$ consists of the pixel intensities in one spectral band of the bulk MSS imagery. In practice, it is impossible to consider an infinite number of samples so the infinite summations above are approximated by finite summations. Furthermore, to minimize processing time it is necessary to utilize an approximation to the optimal resampling kernel, k_B. Three kernels corresponding to nearest-neighbor interpolation, bilinear interpolation and TRW's Cubic Convolution Process are shown in Figure 3 for one dimension. In the ideal band-limited case f(x) is of the form sinx/x, which TRW has approximated by the cubic spline function of Figure 3C. Examples of imagery produced by the three processes are shown in Figure 4: the bulk image in the upper left, and the processed image using nearest-neighbor interpolation (upper right), bilinear interpolation (lower right), and TRW's Cubic Convolution Process (lower left).* Note the many one-pixel discontinuities characteristic of nearest-neighbor interpolation, particularly evident for the road intersection in the upper

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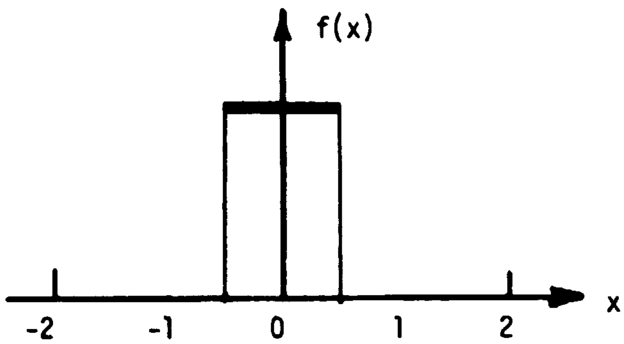
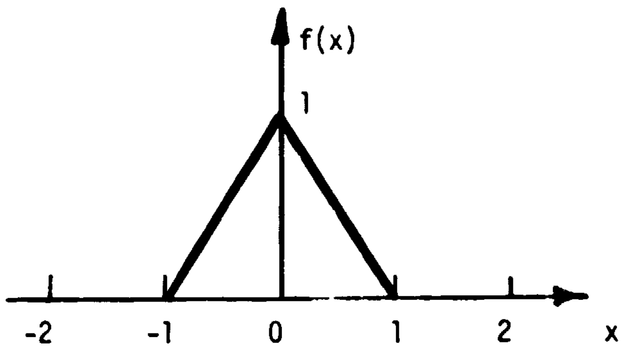
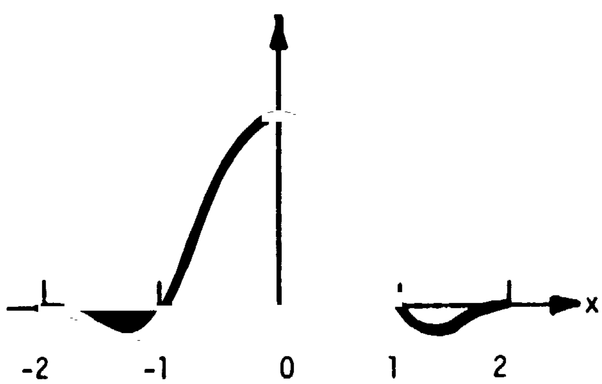
* This figure was produced from electrostatic line printer output. Each pixel is represented by a 3x3 dot matrix; thus, ten gray levels are possible.



a. Nearest-Neighbor



b. Bilinear



c. Cubic Convolution

Figure 3. Interpolation Kernels in One Dimension

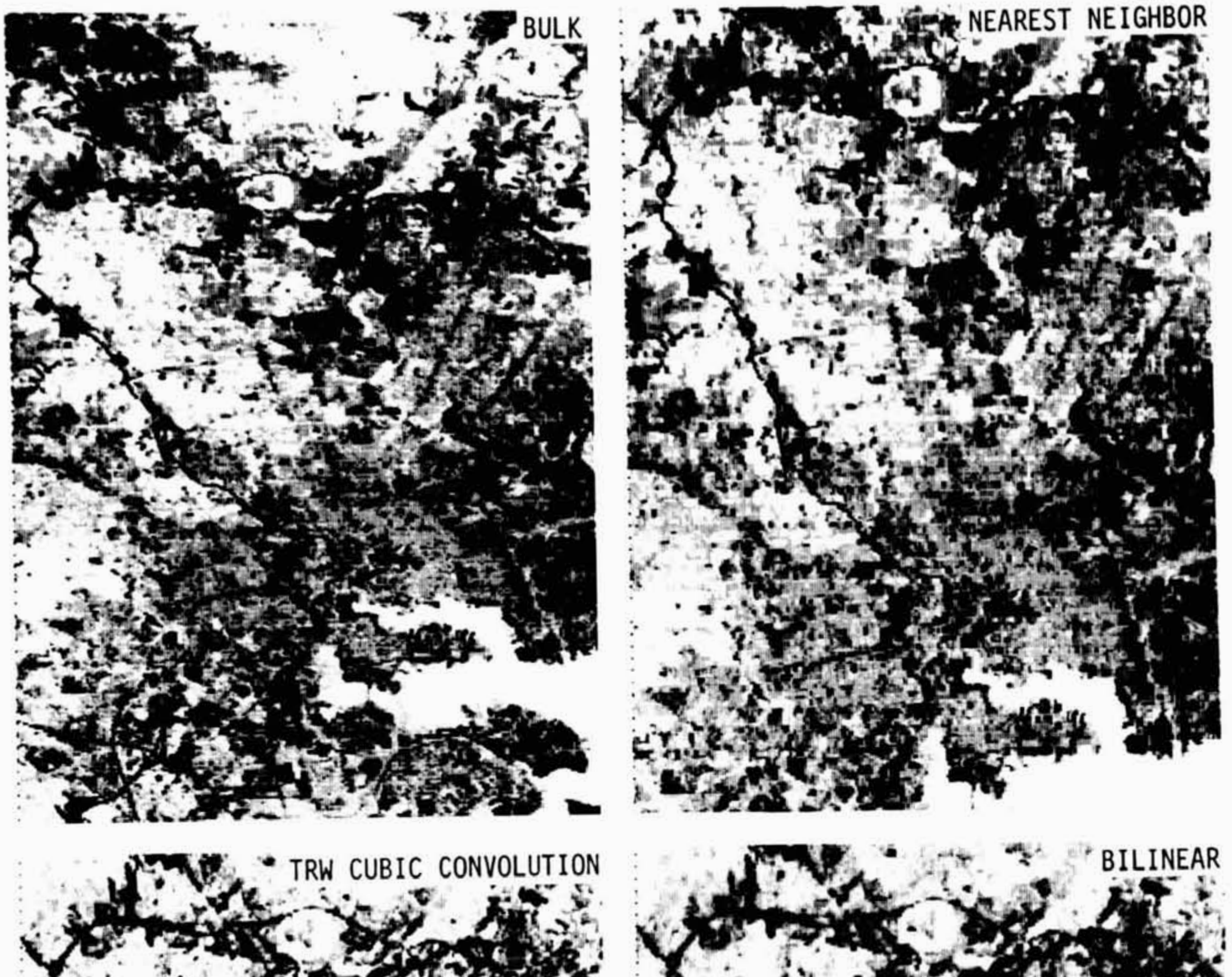


Figure 4. Rectified Image Detail for Three Interpolation Kernels

left corner of the processed image. Bilinear interpolation, on the other hand, eliminates these discontinuities, at the expense of image resolution. Finally, the image processed by the Cubic Convolution Process shows none of the nearest-neighbor image discontinuities, and no loss of resolution.

C. Signal Correlation

For the purpose of geometric correction, it is sufficient to maintain geodetic control to the accuracy of one pixel. As mentioned above, this requirement is attainable using geodetic control points (GCP's) whose geodetic positions are known with 30 meter uncertainty and whose image locations are specifiable to $\pm$ 1/2 pixel. On the other hand, registration applications require CP position uncertainty below 10 meters and the ability to locate a CP in the image with $\pm$ 1/8 pixel uncertainty. These more stringent requirements are achieved within the context of the image processing system in Figure 1 by making use of the registration control point (RCP) concept and the processing technique known as RCP correlation.

The location of GCP's are determined by reference to maps and are specified in earth-centered rotating coordinates or their equivalent. GCP location accuracy is limited by knowledge of their exact coordinates, inadequate specification of the exact point to which the coordinates apply, and the accuracy of correlating the image representation of the point with its map representation. On the other hand, the locations of RCP's are specified by projecting their image designations into an appropriate geocentric coordinate system using the optimal attitude/altitude-bias estimates obtained during rectification of the image. Simultaneously, image segments containing the RCP's are extracted and saved in a library for correlation with corresponding image segments in later spacecraft passes. RCP designation uncertainty in imagery of a subsequent pass is dictated exclusively by the correlation process used, since the RCP position in the reference scene is precisely specified.

Two methods of RCP correlation have been employed by TRW with great success: (1) the manual flicker mode; and (2) the semi-automatic SSDA mode. Both methods use the Cubic Convolution Process to zoom RCP image segments to a size suitable to the accuracy desired. The flicker mode allows an operator to translate the zoomed comparison image over the zoomed reference image until both align. Alignment is discerned by flickering between the two channels of a CRT display in which the images are stored. The SSDA mode makes use of an automatic translational technique which chooses the "best alignment" as that in which the sum of absolute pixel intensity differences between comparison and reference images is a minimum. Work is currently underway to develop a fully automatic RCP correlation algorithm which does not require operator intervention.

IV. CONCLUSION

Critically important to the utility of spaceborne image data is the need for precision correction and spatial registration, on the one hand, complemented by a repertoire of interpretation techniques on the other. It has been shown how signal processing techniques which originally evolved in the disciplines of communication and control have been applied to satisfy the image correction requirements of a diverse user community. In the same sense, interpretive processing stands to benefit from a similar transfer of technology. The interpretation of spectral signatures as fuzzy sets and the application of the Karhunen-Loeve transformation for the purpose of image enhancement and data compression are but two examples, not addressed in this paper, which exemplify this concept.

ACKNOWLEDGEMENTS

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"THE CHALLENGES OF TECHNOLOGY TRANS~~~R"

John N. Hazelwood

I am happy to have the opportunity to talk to you today on the subject of Technology Transfer. Although as a patent attorney I am particularly interested in the proprietary aspects of technology, my comments here will be primarily directed to observations from my own experience in aerospace and in industry, which may point to some of the challenges in accomplishing technology transfer. And I am thinking in particular of the position of industry seeking technology through the media of technology searches.

Most of us have heard of the NIH or not-invented-here syndrome. People are frequently reluctant to use the work of others. This reluctance seems to increase, the further removed a new concept is from the originator and the particular problem solved by him. This applies too where technology envisions new horizons and the prospective users must open their perspective to see the market possibilities through the eyes of others. Yesterday Tim Murphy aptly mentioned the fresh outlook provided by aerospace technology. This is desirable and good. But it's tough to sell. Those fellows on the firing line like the familiar and proven. The mere fact that technology is new, or indeed that it is patented, is no per se assurance that it will be successfully utilized. The records are full of excellent technology and inventions which have for one reason or another not taken hold. It may be a matter of cost, non-availability of start-up capital, market timing, poor business judgment or other reason. But the picture may change. Technology has moving targets. For instance, the energy situation has put a new perspective upon extraction and use of our energy resources. A number of speakers have illustrated this and the part technology can play. John Hiltabiddle interfacing a "Variflux" steam generator with a 1917 steam turbine installation. Paul Purser in petroleum operations. Butch Voris and Bill Shinnick with respect to Alyeska. Tim Murphy also brought the message down to earth and close to home in candidly pointing up Grumman's program of energy conservation and use. Look at coal. It has gone from fairly recent lows aroung \$5 - \$6/Ton to the vicinity of \$10 and over \$20 in the energy crunch. Latent art may now be attractive. But mere availability in the literature is not the key.

We've got to penetrate that literature. An engineer in general industry faced with a technical problem wishes to quickly and efficiently locate, analyze and apply technology to solve his problem. Research, marketing and sales people too, want to translate technology and the vision of others to the enhancement and creation of markets and better satisfaction of customer requirements. And, management of the cost conscious potential user wants to accomplish this analytical route quickly and efficiently without unnecessary doubling up. All are faced with the problem of translating from the environment which generated the original technology to their own particular situation, which may differ considerably from that of the originator. The potential users may, and often do, lack a specialized engineering staff, laboratory and test facilities, production machinery and tooling, or other important implementation tools. They don't have a person from aerospace familiar with the technology working at their elbow, instructing and selling its merits.

I'd like to look at this gap between origin and industry use. Let's focus upon the nature of the environment which typically spawns the bulk of new technology; it's generally aerospace-oriented or at least characterized by a very high engineering content, with performance rather than cost frequently the major governing criteria. Systems are fail safe and redundant. Not that cost isn't considered. We're aware of value engineering, zero defects, suggestion programs and the like which, in addition to program monitoring, review and planning, are devoted to keeping program costs in line. However, resultant technology is often far removed from the cost constraints of commercial and industrial markets where return on investment and profitability are key criteria.

The large aerospace manufacturer will frequently employ many engineers on a major project. Hundreds of sheets of drawings, specifications, test reports, and all sorts of related documents and reports will flow from such a project, reflecting the most sophisticated of space age techniques and support capabilities. Whether it's airframe or life support or other system, the project frequently is day-to-day pushing the art to its utmost and is staffed by specialists in numerous disciplines. Orchestration is frequently provided by ASPR, NASA or other regs in great detail. CPFF contracts are a major tool since the project is shooting for targets not assuredly within reach.

I would like to contrast this with a small manufacturer with whom I once worked in private practice. He manufactured and sold equipment for harvesting a wide variety of agricultural crops. Once I was preparing a patent application on one of his units which had gone from customer requirement to field use in less than six months. I asked one of the engineers for drawings which I could use in assisting our patent draftsmen and myself in making up a suitable patent application. He took me to a corner of the shop and pointed to some chalk marks on the floor showing sprocket and chain layouts and a few other details and indicated that was it! With them you'd better bring your camera! If they needed additional chassis strength they would put in another I-beam. The costs would be greater than that of the added structure were they to thoroughly analyze alternatives. And test facilities and sophisticated design and test techniques weren't available to them anyhow! This is in stark contrast with the aerospace manufacturer who will analyze structural and equipment changes in his aircraft with the utmost precision, wringing the last bit of performance and fail-safe reliability out of each change. Admittedly these two organizations are at opposite ends of the spectrum of potential technology users or originators. Obviously that small manufacturer could not stand the heavy cost burden of the aerospace manufacturer if he's to market his product. He'd probably never even heard of ASPR. Similarly, the put-in-another-I-beam approach would see the aerospace manufacturer in early difficulty. Certainly industry is frequently better equipped and staffed than the small manufacturer which I mention. But the point is there. The companies are poles apart in their technological capabilities and their production techniques. Each company is doing an effective job in its own way in meeting the demands of its particular market. Incidentally, that small manufacturer has now grown to become the division of a major corporation and now produces ground equipment which services the wide-bodied commercial jets of a leading aerospace company. No doubt they're much more concerned with drawings, releases, tests, and a multitude of other requirements than they were in those early days. And, I'm sure their production capabilities have progressed apace.

We have to bridge this big gap and provide the visibility and vision to translate technology to meeting today's problems across the entire spectrum of industry if possible. This calls for people familiar, not only with the particular technology involved, but truly aware of the needs of industry and the substantial differences there existing, at the particular operating or implementing level. This is the challenge to the technology disseminator in government. Here I'd like to reference the EPA program discussed by Ken Suter. EPA has been able by virtue of its charter to home in on the target audience and their problems. It's important that we do the same in the big picture to the extent possible in giving searches real, present value at the operating level--always looking at the practical side. We must give real life to those computer readouts and reduce to usable dimension what may otherwise constitute numerous impracticable solutions to the user's current problems or his potential market horizons. But the technology disseminator can't know all the potential user's limitations either. The user must have at hand motivated people who are aware of the technology resource, its strengths and limitations, and must closely work with the disseminator in bringing the most pertinent information to bear upon his engineering or marketing needs. He's got to know what he can realistically expect from technology.

If possible, the user and the disseminator should narrow the field of search to produce results compatible with the user's capabilities. This isn't easy and will require a good deal of close coordination and understanding at both ends. Unfortunately, the potential for generation of unproductive paperwork is nevertheless with us. It is inevitable that a good deal of technology documentation will be turned up which will be reviewed and discarded by the user. Obviously he wants options and a chance for a fresh look, so he wants some of this. But it is essential that the search results not produce so much paper as to discourage him from analyzing and pursuing the solutions turned up by the search. This appears to be the bottleneck to real technology utilization at the operating level: Getting the engineers and others to really dig into search art. Of course, the user's management not only wishes to cut through to the core as quickly as possible and utilize the technology, but insofar as possible wishes to extend it to solve like problems elsewhere in the organization. They don't want to traverse the same search and analysis path twice if they have once reached a satisfactory result.

If the potential technology solution involves esoteric high cost materials, processes, or tools not available to the potential user, the feasibility of substitute means must be considered, versus resort to more conventional alternatives not stemming from the technology search. Personal rapport between disseminator and user can assist here. In fact, this person-to-person contact appears to be a real key, particularly where there is relatively limited time available to reach a problem solution. Jim Meechan mentioned that Rockwell International's technology transfer program moves skilled specialists into areas of need. In fact, he cites people transfer as essential to their program. We can, then, see the problem if person-to-person contact, devoid of people transfer, must be accomplished at long range, as is generally the case in working with regional Industrial Applications Centers.

It seems evident that the problem of the user must be significant or the market potential substantial to merit extensive abstract review and screening, which, of course, just starts a process which hopefully sees the potential user ordering and reviewing papers disclosing the abstracted content in detail. I think it is evident that at least in the problem-solving aspect of technology use there will be a cutoff point of prospective utility and the organizational level where technology searches will have value. Delivery commitments and turnaround time will often be critical and impose severe restraints. But, I think we can enlarge this scope of potential use through educational programs as mentioned by Butch Voris. We've got to let the engineers know how to effectively use the system. And close the loop to let NASA and others know how it can be improved.

So we recognize that technology transfer presents challenges. Certainly this is nothing new to NASA. When faced with a goal of placing man on the moon, it met that challenge, pushing to the forefront in advancing many arts. Already we have seen encouraging results which demonstrate the potential of NASA's technology, the heart pacemaker, non-ferrous metal recovery, and application of fuel cell technology to electric utility power production. Jeffrey Hamilton in his presentation yesterday mentioned these and others. The work of the Lewis and Ames labs has been touched upon by Lyman. Both can be real sources of assistance to industry. Lewis from the days of NASA has continued to push the art of compressor and turbine design and many of the engines and APU's flying today can be traced to their work or people coming out of that lab. Ames has figured in solving some sticky aerodynamic supersonic flow problems. The area rule of Whitcomb has been used in key fashion in the F-102, the CV 990 and today accounts for the 747 fuselage shape just aft of the upper deck. For a good overview of the technology transfer program and results to date, I suggest you read Neil Ruzic's article: <u>You Can Buy Research Dollars for Pennies</u>, which appears in the August issue of Industrial Research and which was mentioned yesterday by Lyman.

At Dresser we're optimistic concerning the potential for Technology transfer in our various product and service lines. We're a large organization with over 40,000 people worldwide, serving the energy and industrial markets through some 1,200 products and services. We're devoted to research and development which will provide us with pluses over our competition. We have a challenge in calling upon this technology resource to assist us in such diverse lines as well logging services and oilfield products, manufacture of refractory brick and pipeline compressors. We have already made use of such technology in the petroleum and minerals area, stress analysis and materials makeup. We have established technology lines of communication and focal points for obtaining and analyzing technology for its dissemination to other interested segments of our organization. Emphasis is upon building familiarity with the technology resource and effectively communicating the potential to our technical and market-oriented people to make the best use of it. We carry this technology to the applications engineering level to accurately pulse customer requirements.

A word about the role of patents in technology. Patents provide the proprietary leg-up which is frequently essential to get a project off the ground, particularly where considerable development work is envisioned and the results or market are speculative. To be of significant value a patent must be enforceable, and its claims must cover the product or service which you intend to market. Any license perforce must include these considerations. NASA has pursued a policy of patenting items which it feels have significant commercial potential. There are now understood to be over 3,000 patents available for licensing. If considerable risk is envisioned in a development relying upon Technology as a base, the exclusive license may be a desirable avenue. Certainly if the results of one's research and development are to be made freely available to his competitors without their taking commensurate risk, investment in such research will be considerably impeded. It's clear that making inventions or technology freely available to all is no guarantee of use and, indeed, frequently accomplishes the exact opposite. We have a real challenge in realizing the full potential of technology. I think it's evident that people-to-people communication lies at the heart of our problem. Many in industry do not have people to shift from aerospace disciplines into industry, often no easy task in itself. We have numerous potential solutions, often obscured from visibility by a great deal of documentation which is of little practicability in meeting industry's immediate needs. Industry will be convinced by demonstrated results. With management commitment and education of key company personnel, flow down to the implementing level can be accomplished. If industry, government agencies and others having technology to disseminate or use, can mutually understand the technology tools and translate to one another's capabilities, we should all be able to profit from this national resource.

(CONCURRENT)

MEDICAL AND LIFE SCIENCES, AND

TRANSPORTATION AND MATERIALS

F O U R T H   S E S S I O N

THE PROCESSING AND TRANSMISSION OF EEG DATA

A. E. Schulze

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PROCESSING EEG DATA - THE SLEEP ANALYZER

Introduction

Interest in sleep research has been stimulated by the discovery of a number of physiological changes that occur during sleep and by the observed effects of sleep on physical and mental performance and status. The use of the relatively new methods of EEG measurement, transmission, and automatic scoring makes sleep analysis and categorization feasible. Sleep research involving the use of the EEG as a fundamental input has the potential of answering many unanswered questions involving physical and mental behaviour, drug effects, circadian rhythm, anesthesia, etc.

In addition, a small system which is specifically programmed for analysis of the EEG and the classification of the depth of sleep was used on Project Skylab and has many applications of potential interest to the clinician. These applications include the analysis of parameters influencing insomnia, the development of prognoses in the case of the patient who is comatose due to any number of reasons, the monitoring of total anesthesia, and the evaluation of the effects of drugs and drug dosage on sleep patterns.

Sleep Analysis Techniques and Method

Although a number of physiological changes are known to occur during sleep, only the electroencephalogram (EEG) has thus far proven to be specific enough to allow objective measurements of sleep to be made. More easily recorded variables; such as, heart rate, respiration, respiration rate, and blood pressure in combinations, have been shown to correlate well with sleep stages as defined by EEG criteria. Methods involving the use of these variables, however, have usually been limited to studies of normal subjects under controlled laboratory conditions. Under uncontrolled conditions, interpretation of the results would be extremely difficult because of the possibility that recorded changes might be due to factors unrelated to sleep. Heart rate and/or respiratory rate, for example, normally depressed during sleep, could be elevated if the subject developed a minor illness, consumed extreme amounts of food or alcoholic beverages, or entered adverse environmental conditions (e.g., extremes of heat or cold, increased CO_2 level). Also, without the use of an electro-occulogram (EOG) signal, it is difficult to distinguish between Rapid Eye Movement (REM) and other stages of sleep.

Several techniques for the automatic processing of the EEG for depth of sleep have been attempted. These techniques have included frequency analysis, period analysis, amplitude analysis, frequency/voltage ratio analysis and combined frequency and amplitude analysis (pattern recognition). These techniques have not yielded classification in exact agreement with visual record scoring. Techniques which simulate the approach of the electroencephalographer to scoring have been developed and their correlation with visual scoring has proven accurate, but they require the use of large computing systems.

The sleep analysis device developed by Dr. James D. Frost, Jr. of Baylor College of Medicine and Methodist Hospital in Houston utilizes the continuous decrease in average frequency of the EEG with the transistion from the waking state to Stage 4, and the accompanying progressive increase of the average amplitude. Thus, the technique is similar to that used by the electroencephalographer in the visual scoring of sleep stages. The self-contained sleep analyzer unit is extremely small and portable such that real-time sleep analysis can be performed outside of the research laboratory. It was chosen by NASA for use on Project Skylab, and was used successfully on all three missions.

A commercial version of the sleep analyzer was developed using commercial parts and industrial quality standards; and, in this case, NASA technology was applied in the public and private sector in advance of its use in the space program. Sleep Analyzers are currently in use in several research laboratories throughout the United States. The product is being manufactured using NASA patents under a royalty-free licensing agreement with NASA.

In operation, the electroencephalographic and electro-occulographic signals are amplified and passed through bandpass filters. These filters are selected such that only the data pertinent to the factors related to sleep are amplified. The filtered signals are sensed for amplitude and pulses are generated and utilized to form an analog voltage proportional to sleep. Comparators and digital logic are utilized to divide this analog of sleep into the various stages of sleep. If the subject is in either Stage 1 or 2 and a rapid eye movement occurs, the instrument will indicate stage REM for 30 seconds unless the subject is awakened.

Outputs from the respective stage indicators are summed in an amplifier and the resultant output is an analog voltage which steps in amplitude according to the indicated stage. A chart recording of this voltage provides a record of the levels versus time.

Although the sleep analyzers are still exclusively research tools, Telecare sees many possible future uses for the device in medical clinics. Medical researchers have been interested in using the device in treating insomniacs and other patients experiencing "sleep neuroses." Doctors associated with several government agencies are considering studying the sleep patterns of personnel engaged in unusually stressful duty. It can be used by the researcher in the laboratory, clinic, or patient's home.

TRANSMISSION OF EEG DATA - THE EIGHT-CHANNEL TELEPHONE TELEMETRY SYSTEM

Introduction

Trained personnel capable of analyzing and diagnosing EEG records are in short supply. Such personnel are usually found only at the larger medical facilities. Hence, in a suburb or rural area one normally expects a relatively long "turn around time" and inconvenience associated with either of the following:

1. Taking the record at a facility with EEG equipment but without personnel to interpret the record and then sending the record to another facility for analysis

or

2. Requiring the patient to go to another facility for the service.

Hence, it is felt that technology derived from aerospace data handling experience could be applied to help alleviate this problem and also provide for data transfer from one research laboratory to another under NASA's program. Dr. J.D. Frost and Dr. M. DeLucchi provided ideas and technical supervision for the program.

As such, this system, developed under contract NAS 9-12947, is a portable, irdirectly-coupled, telephone telemetry system which will transmit to a central receiving site (by common voice-grade telephone line) eight channels of EEG data of sufficient fidelity for screening and/or limited diagnostic use. The system:

1. Requires no electrical connection to the telephone at the transmitter or at the receiver (uses magnetic coupling)
2. Is compatible with common EEG recording practice for real-time recording
3. Will accept 8 input channels simultaneously with one telephone transmitter and one telephone receiver
4. Operates from standard power sources.

Telephone Telemetry Techniques and Methods

Numerous modulation techniques were examined for application in this project. Both acoustic and magnetic couplings were also examined. Frequency modulation was selected and each of the eight channels were placed in the upper octave of the voice band (1300 Hz to 2330 Hz). Solid-state voltage-controlled oscillators (VCO's) were selected with adequate stability for transmission of the data. Magnetic coupling was used at the transmitter, and the transmitter was built as simple as possible in order to minimize cost.

Crystal filters, frequency translation, and phase-locked loops are used at the receiver to separate the channels. The frequency response of the system extends from 0.5 Hz to slightly over 30 Hz per channel while maintaining a Signal-to-Noise ratio of 30 dB. Pre-emphasis and de-emphasis are provided as appropriate. Access to controls on the receiver are provided to optimize operation from fixed locations.

Preliminary clinical testing was performed in the Neurophysiology Department of Methodist Hospital. Various "dial-up" telephone links were accomplished and the noise and cross-talk between channels were shown to be very acceptable.

Extensive tests of the system are continuing and several features have been added to the system. A "call-back" feature was added which allows the user on either end of the system to alert the person at the other end to pick up the handset. A switch is being provided which will convert a single channel of data to a wide-bandwidth channel for diagnostic scrutiny.

Thus, it will soon be possible to equip remote rural hospitals or medical offices with the capability of obtaining real-time consultation with EEG experts by the use of any dial-up telephone and a telephone telemetry transmitter. This could improve and speed medical care in these areas while requiring only a modest investment in equipment.

Other applications of this multiplexer are foreseen wherever eight channels of data with a 30-Hz bandwidth are required at a remote point. The basic transmitter and receiver can be extended in frequency to dc or very low frequencies, if required. The technique can also be used over any audio link, including single-channel tape recorders and two-way radio.

CONCLUSION

Space technology has been accrued for processing and transmitting the EEG. This technology has been applied to the development of products which would improve the level of medical research and health care delivery.

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MEDICAL BENEFITS FROM THE NASA BIOMEDICAL APPLICATIONS PROGRAM

John L. Sigmon

INTRODUCTION

Since its creation by the Space Act of 1958 the National Aeronautics and Space Administration has been a major contributor in the advancement of technology. This technology which has advanced the state of the art in a variety of disciplines has made possible the accomplishment of feats such as manned exploration of the moon, mapping of other planets in our solar system, and earth orbiting medical laboratories, which a few decades ago were considered to be science fiction and the impossible. Increasingly, the same technology which made these feats possible is being focused down to earth on major medical problems facing mankind.

Research and development programs associated with the NASA space program have created a tremendous amount of technology in virtually every scientific field. The stockpile of technology consists of more than nine hundred thousand documents and increases by approximately seventy-five thousand entries each year. Much of the new technology from the space program is directly applicable to non-aerospace uses and diffuses into the public community through the non-aerospace divisions of aerospace contractors. Other new technology does not spread as easily. For this reason the NASA Technology Utilization Office in Washington, DC initiated an active program to assure "the widest and most applicable and appropriate dissemination of information concerning its activities and results thereof." The specific objectives of this program are:

1. To increase the return of the national investment in aerospace research and development by encouraging additional uses of the knowledge gained in those programs;

2. To shorten the time span between the discovery of new knowledge and its effective use in the marketplace;

3. To aid the movement of new knowledge across industrial, disciplinary, and regional boundaries; and,

4. To contribute to the knowledge of better means of transferring new knowledge from its point of origin to its points of potential use.

Under this program, Applications Teams were established under contract to NASA to interface between the aerospace technology availabilities and specific public problems. There are Applications Teams established throughout the nation concentrating in such fields as air and water pollution control, transportation, mine safety, and law enforcement. The Biomedical Applications Teams (BATeams) are also established to concentrate on those technological problems facing the biomedical community. One such BATeam has offices at the Lyndon B. Johnson Space Center here in Houston. Each team is familiar with active areas of aerospace research, the NASA computerized collection of aerospace technology documentation, and methods of data retrieval from the information bank. The BATeams are, in effect, human connections between the NASA technology bank and the biomedical researchers and practitioners at work in medical schools, hospitals, clinics, rehabilitation centers, and industrial centers throughout the nation.

THE NASA BIOMEDICAL APPLICATIONS PROGRAM

To achieve its goals the NASA Biomedical Applications Program performs four basic tasks:

1. Identification of major medical problems which lend themselves to solution by relevant aerospace technology;

2. Identification of relevant aerospace technology which can be applied to those problems;

3. Application of that technology to demonstrate the feasibility as real solutions to the identified problems; and,

4. Motivation of the industrial community to manufacture and market the identified solution to maximize the utilization of aerospace solutions to the biomedical community.

In identifying and obtaining these major technological problems, the BATeam actively pursues direct contact with medical researchers and practitioners in medical schools, hospitals, clinics, rehabilitation centers, and industrial centers. The identification and definition of the medical problems are then followed by an information search for applicable aerospace technology.

Request acquisition is one of the most important activities of the BATeam. These requests may come to the BATeam unsolicited or on other occasions, the BATeam actively solicits requests with the institutions which might have a need for NASA technology.

Request definition is performed through the joint efforts of the technology requestor and a selected BATeam member who is familiar with the request background. The objective of this step is to define precisely and concisely the request and the required technology to answer the request. In many cases, after proper definition it is found that the request should be rejected for any number of reasons including existence of commercially available hardware or information which satisfies the requirements of the request, or the request is so complex as to be beyond the state of the art of aerospace technology.

Relevant aerospace technology which may offer an answer the request is identified through three methods. The first is . computer search of the NASA data bank utilizing the NASA Scientific and Technical Information Facility in College Park, Maryland. The information available to the NASA data bank consists of more than nine hundred thousand documents, articles, and translations that have been abstracted in the Scientific and Technical Aerospace Reports (STAR) and the International Aerospace Abstracts (IAA). A search is also performed through MEDLINS, a computer index of medical articles. At the same time, the BATeam contacts directly scientists and engineers at the NASA field centers.

All potentially applicable technology is evaluated by the BATeam. That technology which the BATeam considers pertinent to the request is forwarded to the requestor along with a compilation of literature retrieved from the information search. In some cases the BATeam arranges meetings between key NASA personnel and the technology requestor.

The requestor must then evaluate the technology. His decision to pursue a proposed solution depends upon several factors: his evaluation of the validity of the proposed solution, its cost-effectivity, and his capability to implement the solution.

In an increasing number of requests received by the BATeam the technology requestor does not have resources available to implement the solution. NASA has developed an Applications Engineering Program to facilitate the implementation of selected technology applications identified by the Biomedical Applications Program. This assistance, usually funded by NASA, provides for the design and development of hardware prototypes which are then loaned to the requestor for an evaluation period. Complete documentation is prepared following this evaluation for distribution to interested parties.

Benefits of the Biomedical Applications Program

There have been many successful technology applications over the last few years. Among these were:

1. Computer techniques for removing irrelevant details from x-rays;
2. Wireless respiratory monitors for infants;
3. Cardiac catheter pressure transducers;
4. Implantable rechargeable cardiac pacemakers;
5. Biological isolation garments for leukemia patients;
6. Computer analysis of infrared photos of skin burns;
7. Environmental control systems for quadriplegics;
8. Lightweight prosthetics materials;
9. Investigations into the development of an automobile driving control for quadriplegics;
10. Lightweight long-duration breathing apparatus developed for firefighters;
11. Paper money identifiers for blind persons; and,
12. Economical vital signs monitors for use in nursing homes.

Recent technological advancements which hold great potential as future technology applications include the following examples.

Biological Isolation Garment. A special garment originally designed to provide a portable sterile environment for returning Apollo astronauts to earth from the moon has been adapted for the National Cancer Institute and is being modified for the Baylor College of Medicine to protect leukemia patients with severe immunodeficiencies.

Leukemia patients have had available the use of laminar flow rooms to provide sterile environments, with some children confined to sterile plastic bubbles from birth. However, a portable sterile environment is needed to permit patients to move from the sterile chambers to other places of treatment. The need is especially important for children who are less tolerant of confinement in single rooms. The isolation garment allows them to leave the laminar flow room for treatment and recreation and for visits with families.

The original NASA biological isolation garment designed for the relatively short time between the astronaut's leaving the spacecraft and entering the portable quarantine facility aboard the recovery vessel posed problems of weight, heat, and claustrophobia for medical patients, especially children. The suit was modified to allow the addition of a positive-pressure portable air supply system to overcome the heat problem by providing ventilation. Since many contaminants affecting the patients derive from their own skin surface, the air flow is directed downward from the top of the head to reduce the danger of self-contamination.

Infant Respiratory Assist Device. The treatment of hyaline membrane disease (respiratory distress syndrome) by medical researchers at the University of Miami School of Medicine is being aided by Skylab technology. A respiratory assist device has been patterned after the lower body negative pressure system developed for cardiovascular studies in Skylab's zero-gravity environment.

Respiratory distress syndrome, a condition in which the lungs of a newborn infant are collapsed, is one of the major causes of infant mortality. More than twenty thousand infants in the United States are estimated to succumb to this condition each year. Respiratory distress syndrome is believed to be caused by the absence of an alveolar substance that decreases the surface tension and permits the lungs to re-expand after each expiration.

Researchers at several medical centers in the United States and Canada have recently reported encouraging results with the use of continuous positive airway pressure and continuous negative pressure therapeutic techniques. The positive-pressure method uses a tube in the throat that continuously forces oxygen-rich air into the lungs, while the negative-pressure method keeps the infant's lungs expanded by subjecting the chest to continuous negative pressure to maintain the proper residual volume of air. If life can be sustained for four days by either method, the missing alveolar substance will then be present in a sufficient quantity for normal, unassisted breathing to occur.

Specialists at the University of Miami School of Medicine were among the first to use the negative-pressure technique. A commercially available respirator that was modified to produce a constant negative pressure has saved the lives of several infants. To refine this improvised system, the University of Miami medical team desired to fabricate a negative-pressure chamber that would cover only the infant's thorax, arms, and upper abdomen. Such a system would offer advantages over the use of continuous positive-pressure in the airways primarily because it would avoid intubation and would leave the face free for nursing care, such as removal of mucus from the throat.

The NASA engineers who developed the Skylab LBNP device assisted the University of Miami medical team in designing the air seals in the respiratory assist device. The seals in the infant's chamber are similar to the seals used in the Skylab negative-pressure device in that they are adjustable and can accomodate infants of various sizes.

Mobile Automatic Metabolic Analyzer. Information on the workloads encountered by severely disabled patients in rehabilitation programs is being provided by instrumentation and techniques originally developed to monitor the metabolic activity of the Skylab crewmen. Information provided by this system will be valuable in improving the design of patient-assist devices and for assessing the effectivieness of various treatment procedures. The NASA instrumentation provides accurate measurement of the metabolic activity of both normal and severely disabled subjects during actual "walking" conditions and can also be used to follow the progress of severely disabled persons through the many phases of their rehabilitation programs. In a cooperative effort between a Department of Health, Education, and Welfare Social Rehabilitation Services training center and NASA, a special motorized cart and an instrumentation system (provided by NASA) enable physical therapists to gather accurate workload information. The instrumentation consists primarily of a portable mass spectrometer to analyze respiratory gas exchange, an electrocardiographic recording system, and devices for measuring patient velocity. The motorized cart is used to control the patient's velocity accurately. The mass spectrometer provides a continuous record of the amount of oxygen consumed and the carbon dioxide produced by the patient. Pulse rates and electrocardiogram (EKG) tracings are also recorded.

Accurate velocity measurements are essential to meaningful workload data. Together with accurate physiological data, velocity data will allow medical personnel to measure the actual work performed by a patient. This information will aid in designing various prosthetic devices and therapeutic techniques that will minimize the stress on patients.

The instrumentation has been installed at the Spain Rehabilitation Center in Huntsville, Alabama. Studies of amputees will include both semistationary and ambulatory activities involving the use of parallel bars, walkerettes, crutches, and lower-extremity prostheses or braces. Further studies will include conditions such as cardiovascular disease, cerebral hemorrhage, spinal cord injury, diabetes, hypertension, neurological diseases, and severe pulmonary diseases such as emphysema and asthma.

In-Flight Medical Support System Training Document. The IMSS document was developed to illustrate to the Skylab crewmen the use of all the onboard medical equipment and to provide them with procedures for basic in-flight medical care. The document supplemented the 80 hours of crew medical training. The unique feature of the document is the systematic approach and step-by-step procedure used to portray complex material. This innovative method of presentation was developed during earlier space flight programs to assist engineers in the operation and analysis of complex spacecraft systems.

With the demand for improved health services, from more ambulances in the cities to more physicians' assistants in remote areas, the demand for improved educational and instructional material has increased. Thus, NASA sent the IMSS training document to several emergency medical units in Texas for review. The instruction manual was received enthusiasticly and NASA has cooperated with the Indian Health Service and the Houston Fire Department of Ambulance Service to develop similar manuals for training medical personnel.

Emergency Ambulance Cardiac Care System. Skylab technology has been applied to the development of an ambulance-carried compact medical unit that contains essential equipment designed to meet the diagnostic needs of heart patients at the scene of an emergency. This portable ambulance module incorporates all the basic components required to meet medical emergencies. For the first time, these components have been combined in a single package the size of a suitcase and weighs approximately 40 pounds. The components include a two-way voice radio, and EKG display and telemetry system, which can relay cardiac data to the receiving hospital and the physicians who will provide later treatment to the patient, a defibrillator for external heart stimulation, a semiautomatic indirect blood pressure measurement system using a special microphone positioned under a hand-inflated cuff (similar to the blood pressure device developed for the Skylab program), and a basic pharmaceutical package. Optional equipment available includes an electroencephalograph, derived from the Skylab sleep analyzer, that can provide remote observation of brain-wave action.

The emergency ambulance cardiac care system has been tested extensively and is being used by the city of Houston. Technicians are being trained to use the 28 municipal medical resuce vehicles that have been equipped with the portable ambulance modules. Many other cities are currently evaluating the new unit.

Remote Health Care. During the early definition stage of the Skylab Program, NASA attempted to design an integrated medical system that could be used effectivley to administer health care to crewmen in an orbiting space station. A system incorporating the major systems of that design and some of the technology resulting

Skylab Program is now being set up for evaluation in Arizona.

With the increasing commitment to provide quality medical care to all citizens located in both rural or inner-city areas, the widespread use of space-age technology will become an important means of supporting facilities isolated from major medical institutions. In cooperation with the Indian Health Service of the Department of Health, Education, and Welfare, NASA is developing a system (Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC)) for this purpose on the Papago Indian Reservation in Arizona.

The STARPAHC system is being built and assembled under a NASA contract, with the target date for operation being January 1975. With STARPAHC, modern medical skills and equipment are made available to remotely located and widely dispersed patients. Through a remote health clinic and mobile unit, physician's assistants, paramedics, and nurses work under the supervision of a physician. These remote personnel communicate with physicians in near by hospitals with a very high frequency radio and microwave television and computer communications network.

<u>Collection and Quantitative Determination of Organic Volatiles in the Skylab Cabin Atmosphere</u>. The purpose of this project during the third manned Skylab mission was to collect and analyze postflight the volatile components in the cabin atmosphere. An important aspect of the project was the assessment of the impact of the temporary overheating of the spacecraft on its general habitability and the determination of possible toxic products from the spacecraft materials. This project demonstrates a new and innovative gas-phase analytical technique for providing an greater understanding of trace volatile organic compounds. Further studies in this area are presently being conducted by the University of Houston under contract to NASA. The studies use high-resolution gas chromatography/mass spectrometry for the analysis of the organic volatiles present in the sample fluids or gases.

NASA has filed for patents on this new technology, and the following industries have expressed interest:

1. Air and water pollution research (detection of air and water pollutants and new methods of sampling)
2. Manufacturers of analytical equipment (development of field-type sampling and analytical devices)
3. Tobacco industry (development of cigarette smoke profiles)
4. Medical community (early detection of diseases studies based on analysis of body fluids (blood, breath, urine))
5. Food industry (sampling and definition of flavors and aromas)
6. Petroleum industry (sampling of volatiles of crude oil and core samples for determining constituents)
7. Pharmaceutical industry (methods of detecting metabolic changes due to drug therapy)

CONCLUSION

Medical benefits from the NASA Technology Utilization Program and the associated Biomedical Applications Program have been many. However, with the successful completion of the Apollo and Skylab Programs, more attention within NASA is being directed towards applications and increasing the return of the national investment in aerospace research and development programs. We invite the medical and industrial communities to participate in the technology transfer process with the NASA Biomedical Applications Program.

HYPOBARIC CHAMBER FOR THE STUDY OF ORAL HEALTH PROBLEMS IN A SIMULATED SPACECRAFT ENVIRONMENT

Lee R. Brown, Ph.D.

INTRODUCTION

In 1968 The University of Texas Dental Branch and Dental Science Institute at Houston received a contract (Contract No. NAS-9-11118) from the Manned Spacecraft Center, Houston. Texas for a Study to Define and Verify the Personal Oral Hygiene Requirements of Extended Manned Space Flight. It was believed that all possible health hazards should be eliminated to insure the unqualified success of extended space ventures; specifically, the projected Skylab missions. The oral tissues are particularly vulnerable to stress and systemic disease. The mouth serves as a portal of entry for pathogenic agents, acts as a reservoir for infectious microorganisms, and plays a prominent role in cross contamination and disease transmission. Changes in oral microorganisms usually precede the clinical manifestations of acute and chronic infectious oral pathoses. Clinical examination of the oral tissues can identify changes in tissue integrity caused by local and systemic impairments of microbial and nonmicrobial origin leading to mucositis, dental caries and periodontal disease. Such impairments to oral health would be extremely detrimental to the performance of personnel confined to space capsules.

To gain some insight into the effects of a simulated spacecraft environment on mouth bacteria, studies were first made using nonhuman primates (marmosets) before engaging in land-based, spacecraft-simulated studies with humans. Marmosets were selected because they are the smallest of the primates and the easiest to handle and maintain. Their mouth structures and oral disease symptoms simulate those of man.

A hypobaric chamber was constructed to house two marmosets simultaneously in a space-simulated environment for periods of 14, 28 and 56 days which coincided with the anticipated Skylab missions. This report details the fabrication, operation, and performance of the chamber and very briefly reviews the scientific data from nine chamber trials involving 18 animals. The possible application of this model system to studies unrelated to oral health or space missions is discussed.

MATERIALS AND METHODS

Two plastic isolators (18 inch diameter and 36 inches long) were fabricated[1] to house two marmosets each. The cylinder portion of the isolators was made from 3/8" acrylic plastic and the endpieces from 1" acrylic plastic. The endpieces were held in place by six 3/16" diameter joining brass rods. The rods were threaded to permit tightening of the endpieces by wing nuts. A rubber gasket was recessed in each endpiece to effect a seal.

The chamber cage racks were constructed from 1/4" acrylic plastic. They were designed to allow caging of two marmosets in separate compartments. The ends and center dividers of the cage racks were perforated with numerous 1/2" holes for circulation of gases. The base was formed of plastic strips for passage of animal waste. Wastes were collected on a removable 1/8" thick plastic plate (11" wide, 35" long) bent to direct urine flow toward the center and containing wood shavings and Tel-Tale Silica Gel[2] to remove moisture, boric acid to inhibit bacterial degradation, and Purafil granules[3] to absorb organic compounds.

Food boxes, watering troughs, and environmental boxes were made from 1/8" plastic and attached to the cage racks by bolts and wing nuts.

An acrylic plastic external unit was fabricated to recirculate chamber atmosphere at 2 CFM to enhance removal of CO_2, water vapor, and organic contaminants. A magnetically driven squirrel cage blower circulated the chamber gases sequentially through canisters of chemical scrubbers, over an electrode for monitoring the partial pressure of oxygen, and back into the chamber. Various by-pass and shut-off valves were included in the recirculation system to control the flow through specific canisters, and to by-pass certain parts of the unit. This permitted recharging and calibrating of the oxygen electrode in the oxygen gland assembly and replacement of the purification canisters.

The oxygen level was continuously monitored by a Beckman Model 778 Process Oxygen Analyzer[4] containing a polargraphic oxygen sensor. This sensor was placed in a gland assembly of the recirculation system. The concentration of ammonia, hydrogen sulfide and carbon dioxide in the chamber was checked periodically with a Unico Model 400 Precision Gas Detector[5].

Pure oxygen or a mixture of 70 per cent oxygen - 30 per cent nitrogen was supplied to the chamber from size 1A cylinders of compressed gas provided with two-stage regulators.

Oxygen was supplied automatically to the chamber, as needed, to maintain a 70 per cent - 30 per cent oxygen-nitrogen ratio at a chamber pressure of 5 PSI. Chamber pressure was used to control the amount of oxygen supplied since the chamber and the recirculation unit were built as a hermetically sealed system. Any change in pressure such as that caused by the uptake of oxygen during respiration (the carbon dioxide produced was removed by Baralyme[6]) could be utilized as an oxygen controller. A device was designed to provide oxygen to the animal chamber when the negative pressure increased by 0.1" Hg. The device consisted of a "V"-shaped mercury manometer (3/16" bore) formed within a four-inch square block of acrylic plastic, a 6 to 8 volt auto light bulb activated at 5 volts from a 1 volt filament transformer of standard design, a 10 X microscope eyepiece to concentrate light, a Raytheon CK122 Photocell[7], a small transistorized amplifier[8], and a E4F1000S SPDT relay[7].

During evaluation of the chamber to 5 PSI, both ends of the manometer were left open. Thus the column of Hg prevented the passage of light through the translucent manometer. Then the connection tube from one end of the manometer was clamped shut to allow the column of Hg to move with an increase in negative pressure. When negative pressure increased, as with CO_2 removal, the column of Hg moved to allow light to pass through a 1/8" diameter recess in the manometer. The light energized the photocell and the impulse was amplified and passed to a relay which activated the Dormeyer Commercial solenoid (type 4X241). The solenoid then opened a tubing clamp[8] which functioned as an oxygen valve.

To establish a hermetically sealed system, air from the complete hypobaric assembly was evacuated by an oilless, greaseless vacuum pump (Gast[9]). A 24 hour maintenance of a negative pressure of 28.5 inches of Hg was considered evidence of seal. The chamber then was repressurized and opened to receive the test animals.

The chamber was evacuated in a progressive manner with additions of pure oxygen to hyperventilate the animals and overcome their sensitivity to oxygen depletion before obtaining the final chamber atmosphere of 70 per cent oxygen and 30 per cent nitrogen (177 mm Hg oxygen and 76 mm Hg nitrogen at 5 PSI).

The animals were sampled microbiologically at two day intervals to obtain four baseline (prechamber) counts prior to each of the chamber trials. During the fourth sampling period, the animals were examined, weighed and placed in the chamber which was adjusted to the designated atmospheric conditions. After each week of confinement, the animals were removed, examined, weighed, sampled, and placed back into a clean chamber. At the end of each chamber trial the animals were removed, and after three days of readjustment, resampled microbiologically on four occasions at 2 day intervals to obtain post chamber recovery values. Oral tissues were also examined for dental plaque and calculus accumulations and for the presence of inflammation and mucositis.

RESULTS

The chamber functioned with minimum attention and without insurmountable problems. The oxygen controlling mechanism operated efficiently and required only a slight pressure adjustment every two to three days. The chamber atmosphere was sampled at regular intervals during operation. Readings with the Unico Gas Detector after two hours of operation were identical to those of the laboratory atmosphere: 0.17% CO_2 and no detectable hydrogen sulfide or ammonia. Seven day readings averaged 0.48% CO_2 with no detectable H_2S or NH_3.

The marmosets reacted to the pressure changes during the initial adjustment to 5 PSI by head shaking and scratching or pulling their ears. Some marmosets regurgitated each time the chamber was evacuated. In the first trial both marmosets developed ophthalmic complications during the first three days of isolation. Initially they rubbed or scratched their eyes, and blinked excessively. Later their eyes appeared glazed and dry and by the third day both marmosets displayed periorbital swelling, which subsided during the fourth day and disappeared by the fifth day. These symptoms were not observed on subsequent chamber isolations after eliminating one of the desiccating agents ($CaCl_2$).

The animals adapted to the chamber rather easily and were maintained in the simulated spacecraft environment with few problems except for weight loss and diarrhea. The weight losses occurred in 16 of the 18 animals and were independent of the diarrhea. Usually only one of the two marmosets developed diarrhea which always followed the initial weight loss. The specific cause(s) of diarrhea, which is exceedingly common in captive marmosets irrespective of environment or diet, was not delineated in this study. Assessments of the stool microflora in animals with diarrhea revealed no qualitative or quantitative differences from animals with normal stools.

Dental calculus and plaque accumulations during each chamber isolation were found comparable in amount to the accumulations at ambient conditions of equal duration.

Numerical changes of microorganisms were observed in many marmosets during chamber isolations, but the changes varied with microbial categories, sample time, and animal tested.

DISCUSSION

A relatively inexpensive, light weight, hypobaric pressure chamber was fabricated which was suitable for studying the effects of space-simulated environments on the oral health of small primates. Chamber atmosphere could be controlled rather simply and with minimum attention.

The marmosets readily adapted to a simulated spacecraft environment for as long as 56 days without pernicious effects. Although persistent weight loss and diarrhea were observed, no other health impairments were apparent. There was no evidence of deleterious changes in the oral tissues and no indication of disease transmission between chamber occupants by oral exchange of microorganisms or by symptom complex.

The specific causes of weight loss and diarrhea were not elucidated. The most pronounced weight losses were observed in the first 14 day chamber trials concurrent with an excessive, intermittent noise level produced by an oxygen valve. The valve was later modified to suppress the noise which conceivably could have created undue stress in the normally high spirited marmosets. This attempt to prevent weight loss was followed by pre-isolation conditioning of the animals to the chamber. Neither noise suppression nor conditioning seemed to have any effect on weight responses during subsequent chamber trials. Comparisons of the amount of food and water intake of animals inside and outside of the chamber environment did not account for the weight losses. Furthermore problem could not be related to the diarrhea since the w losses always preceded diarrhea and frequently occurred in the absence of diarrhea.

There were no noteworthy qualitative changes in the oral microflora attributable to the chamber environment. Conversely, there were some chamber-associated, quantitative, microbial differences. These, however, appeared to be animal-related rather than group-related. Most of the statistically significant differences in microbial counts during chamber trials resulted from microbial increases in only a few animals within the group and/or from transient or cycling behavior rather than from an overall count trend. Increased counts were widely distributed among organism type, sample type, and chamber trial. On the basis of this study, there are no predictable health hazards which might originate from the oral cavity during prolonged space flights.

Although the chamber described was designed and used specifically to study the effects of a simulated spacecraft environment on the oral health of small primates, it could be used to study problems unrelated to oral health and space missions. The chamber could readily be used to study numerous problems related to pollution and other environmental factors;

i.e., the effect of various gases and related pollutants on respiratory, optical, skin and other tissue responses. Controlled studies could also be carried out on the effects of gaseous pollutants and/or chemical aerosols on food and water contamination, and the growth and reproduction of plant life. The effects of confinement, overcrowding, noise, silence, temperature, humidity, etc. on physical and mental responses could be investigated under controlled conditions.

CONCLUSIONS

A hypobaric chamber was fabricated and tested for maintaining marmosets in an atmosphere of 70% O_2 to 30% N_2 at 5 PSI. Marmosets adjusted to a space-simulated environment rather easily and were maintained in the environment for periods up to 56 days with no problems except for weight loss and diarrhea.

There were no apparent environment-associated changes in the oral tissues and no noteworthy qualitative alterations in the oral microflora. There were, however, environment-associated quantitative microbial changes which were animal-related rather than group-related. These changes primarily involved widely distributed increases in certain resident and transient oral microorganisms. There was no direct evidence of oral transmission of the microorganisms between pairs of chamber-housed animals.

It is believed that this chamber could readily be used to study numerous problems related to pollution and other environmental factors.

FOOTNOTES

1. Plastic Fabrication, Inc., Houston, Texas.
2. Davidson Chemical Co., Baltimore, Maryland.
3. Marbon Chemical, Division of Borg-Warner Corp., Washington, W. Va.
4. Beckman Instruments Inc., Fullerton, California.
5. Union Industrial Equipment Corp., Fall River, Mass.
6. National Cylinder Gas Co., Chicago, Ill.
7. Sterling Electronics, Houston, Texas.
8. Fabricated at The University of Texas Dental Science Institute at Houston.
9. Gast Manufacturing Corp., Benton Harbor, Michigan.

IMAGE PROCESSING OF ANGIOGRAMS: A PILOT STUDY

L.E. Larsen, M.D.; R.A. Evans, M.D.; J.O. Roehm, Jr., M.D.

PREFACE

Image processing has its highest public visibility in the context of NASA activities. Two of the most widely known applications were the processing of lunar imagery from the Surveyor spacecraft and earth resources imagery from the Earth Resources Technology Satellite (ERTS).

Since NASA is the world's largest consumer of image processing, the Johnson Space Center provided a unique opportunity to explore the application of specialized image-processing hardware to radiology. We are indebted not only to Johnson Space Center and the Health Applications Office of the Earth Observation Division, but also to the IBM Houston Scientific Center for allowing us the use of their image-conversion facilities.

INTRODUCTION

The technology transfer application this report describes is the result of a pilot study of image-processing methods applied to the image enhancement, coding, and analysis of arteriograms. Angiography is a subspecialty of radiology that employs the introduction of media with high x-ray absorption into arteries in order to study vessel pathology as well as to infer disease of the organs supplied by the vessel in question.

The specific angiograms were of the abdominal aorta and a lateral view of the right internal carotid artery. Since the objectives and pathologies were different in these two instances, a brief description of the disease states may be useful. The abdominal aorta is the major arterial vessel in the abdomen. It is a frequent site of atherosclerotic involvement that may progress to an aneurysm that will require surgical treatment. Less-severe stages of the disease result in saccular deformation of the arterial wall. These changes, observed over time, can help to quantify the rate of disease progression as well as aid the surgeon's decision of when to intervene. Therefore, the relevant part of the angiogram is the shape of the walls of the abdominal aorta, and other features of the x-ray are immaterial.

In the case of the cerebral angiogram, the problem is quite different. In the particular case under study, the patient was found to suffer what may be described as a small stroke. The angiogram demonstrated multiple vessel occlusion due to emboli or small particles plugging the artery as the vessel size decreased. In this instance, the objective was to enhance these abnormally abrupt terminations of the blood vessels in order to determine the extent of involvement.

The overall aim of the pilot study was to explore the possible application of image analysis and coding to the abdominal-aorta problem and the utility of image-enhancement methods for the cerebral angiogram. The basic requirements in terms of hardware and software for the application of these methods in clinical practice needed to be defined from practical experience, and we hoped to extract some feeling for the benefits such an approach could offer.

METHODS

In both the aortogram and cerebral angiogram, the basic data consisted of x-ray film images of the target (abdomen and head, respectively) before and after introduction of the contrast medium. The first step was to convert these images into a computer-compatible form. This was accomplished by scanning either prints or transparencies by an electromechanical device that positions a photometer (measures reflectance or transmission) over the surface of the image in a series of vertical lines, with each line containing a number of positions for photometric measurements. In our case, the x-ray films were printed, then the prints were scanned with a 10-mil aperture in 10-mil steps across the image in a raster format. At each measurement position, the reflectance was quantified by a 6-bit number to give 64 levels from full reflectance (white) to full absorption (black). The data was arranged on the tape with implicit positional information, such that the first logical record contained the first 700 sample points from top to bottom of the picture. Subsequent records contained a total of 700 scan lines, to give a total of roughly 500,000 data points per x-ray, with 8 bits per data point for 4 million bits per picture.

The initial conversion of the aortograms was accomplished differently. Since the objective was only to retain vessel shape, the outline of the vessel walls was traced with a cross-hair X-Y digitizer in a film where all background was subtracted from the angiogram. That is, a cross-hair is located in two-dimensional Cartesian coordinates, and its position on the X and Y axes is accurately measured to 100 parts per inch; then the cross-hair is manually positioned over the vessel wall, and its position is recorded as it is moved along the vessel-wall outline. Any branching vessels are removed by linearly interpolating across their points of departure from the aorta. In this way, one normal and one moderately diseased aortogram were converted to an order series of paired coordinate values in a plane; then the image was converted to binary form (black or white) by calling a point in the plane between the two walls one (black) and all other points in the plane zero (white). Thus, all gray tone was removed, and only edge information remained.

Once the x-rays had been converted to this computer-compatible form, the processing stage could begin. The cerebral angiograms were processed to enhance the abnormally abrupt vessel terminations. The first step was to manually register the images from before and after introduction of the contrast medium. Thus, the before-image was a plain skull film, and the after-image was an early arterial-phase angiogram. Image registration was accomplished by aligning major skull landmarks from the two images. The image values that represented the skull film were then numerically subtracted from the angiogram at identical coordinate points.[1] The result was to enhance the vessels, since the skull background had been removed. Thus, the vessel terminations were made more evident. Further processing to enhance these vessel terminations took the form of contrast enhancement in the differenced angiogram. The objective was to further highlight the abrupt change in contrast at the vessel termination by a non-linear digital filter. This filter was designed to be used interactively, with different parameters to be used for different parts of the picture. Contrast enhancement was accomplished by transforming a small range of density values into the full range of available values.[2] Thus, a fraction of the original range is stretched across the entire dynamic range, with the result that small, even imperceptible, density differences are contrast-magnified. This operation is then repeated across several ranges of the original densities or reflectances.

The effect is to enhance small-vessel terminations with one parameter choice and to enhance contrast changes within larger vessels by another parameter choice. The latter, while not a primary objective, would be useful for detection of atherosclerotic vessel disease in the upper neck, where surgical intervention is possible.

Lastly, the densitometry approach was further developed by pseudocoloring.[3] For this approach, the values between 1 and 64, which represent the picture at one particular 10-mil sample-point in space, are represented as a set of colors and displayed on a color TV monitor. The actual procedure covered the range of reflectances in 16 rather than 64 steps; then, 16 unique colors were interactively assigned to the 16 reflectance values. When the original image is in analog form, the edge-enhanced version of the angiogram is available with or without background overlay. The perceptual effect may be compared to a plot of the original reflectance values for one scan line through the before and after films. Clearly, isoreflectance contours are markedly enhanced by pseudocoloring.

The use of graphed reflectance value proved to be especially enlightening, because it exposed a misregistration of 60 thousandths of an inch. The plots also confirmed an earlier supposition that the original prints were not identically processed photographically prior to conversion. Thus, some errors in subtraction were explained.

The aortogram-processing followed an entirely different course. The conversion process itself accomplished an edge enhancement, with the remaining problem being one of quantifying the degree of atherosclerotic involvement; that is, the problem was now one of image analysis and coding rather than image enhancement. The approach we chose for the analysis problem was to express the defined edges of the vessel walls as discrete Fourier transforms.[4] This is basically a method that models the edge as a spatial series, composed of sine and cosine basis functions. The edge path is then coded by the coefficients that weight the various sinusoidal components. Since the atherosclerotic changes are in the form of low spatial-frequency sacculations, the edge can be coded with only three or four low-order coefficients and thereby accomplish a data reduction from about 500 original data points down to less than 10 transform coefficients. The result of this analysis is shown for both a normal and a moderately diseased abdominal aorta.

Once the digital processing is accomplished, the last step is to produce a pictorial output from the digital tape. This is accomplished in essentially reverse procedure from the conversion process. In the case of the cerebral angiogram, the same rotating drum scanner/plotter was used. The first record or tape contained data for the first scan line, the second record for the second scan line, etc. The individual data values were converted to an exposure-intensity value for a light source projected through a 10-mil aperture onto film. Thus, roughly 500, 000 data points were "plotted" on the film in this way, and the processed image was thereby reconstructed. In the case of the abdominal aortogram, the X-Y coordinate information stepped the location of a plotter head over the plotter table until the walls of the vessel were drawn.

CONCLUSIONS

The pilot study served to illustrate only a small proportion of the versatility and power of image-processing methods. Many additional approaches to the angiograms under study were possible. Some may have been better than the ones we chose. However, the intent was to explore the methodology with trial problems rather than to launch a definitive project. Within this concept, we discovered and ameliorated many practical difficulties in the conversion, digital storage, and regeneration of images, as well as defining the effect of common methods of photographic processing. Similarly, we made some progress toward developing the computer-program library, necessary for routine image processing. The most important of these practical lessons was the absolute necessity for efficient algorithms (due to the enormous volume of data) and interactive processing, whereby the results of a given digital operation could be judged quickly by means of a digital image display. The end product of any enhancement effort must be useful and informative to the observer. Since parameter adjustment can make the effect of any digital operation widely different in different parts of the same picture or between different pictures, the informed use of any digital operator requires man/machine interaction by means of rapid display of the digital images. A theoretical picture is insufficient.

As for the specific angiograms studied, it became abundantly clear that digital subtraction and contrast enhancement were useful methods that provided perceptual extensions that were simply not possible with the unaided eye. Likewise, we demonstrated that aortograms could be economically analyzed and coded for atherosclerotic disease. Of course, no general conclusions could be drawn from this pilot-level study; but we did acquire much of the knowledge necessary to initiate plans for a clinically useful image-processing system.

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2. Harry C. Andrews, Digital Image Restoration: A Survey, Computer, 7: 36, 1974.

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INTERDISCIPLINARY STUDIES ON THE DEVELOPMENT OF NUCLEAR-FUELED CIRCULATORY SUPPORT SYSTEMS: COLLABORATION OF INDUSTRY AND ACADEME

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The purpose of this report is to acquaint the Houston community with specific areas of available technology, both public and private, to demonstrate to industry how this technology may be acquired and put to use to provide new and useful services for man. Because as many of the participants are from mid and upper-level management as from research and development, we have been asked to avoid excessive technical details and to include the processes by which we acquired and either transferred or utilized advanced technology.

Much of the technology utilized in the development of nuclear-fueled circulatory support systems in our laboratories has evolved from industry, NASA, and AEC; our projects involve radiation biology, thermodynamics, energy transfers, hemodynamics, hematology, pathology, and surgery. From the perspective of what existed in this area ten years ago, much has been accomplished. Much remains to be done and further collaborations are needed.*

INTRODUCTION (ANTIQUITIES)

Artificial organs, both as assist and replacement devices, have a history almost as ancient as that recorded of man. Before western civilization began its ascendancy with Socrates and Hippocrates, devices were being fashioned to replace portions of the body in Asia, India, and the Middle East. The available records do not suggest that these modalities of treatment were considered to be different in any way from others then available. Acceptability and utilization have increased with the passage of time. Today, nonetheless, there is a certain mystique regarding the possibility of implanting fissionable materials in man to power artificial internal organs. For nearly a decade now, our laboratories have been involved in these possibilities and their physiologic, engineering, economic and social implications. The underlying theme of these investigations has been to determine the feasibility of implanting nuclear-fueled energy sources to power totally implantable circulatory support and/or heart replacement devices.

THE CONCEPT:

The heart is essentially a pump. The notion of building an artificial heart should then not be new. Nearly four decades ago, John Gibbon initiated studies to bring this idea to reality by beginning to work on an artificial pump oxygenator. His technology transfer involved a successful and productive collaboration with IBM in Boston and Philadelphia. This temporary method of bypassing the heart and lungs not only proved to be successful in animals, but also in the first human patient to undergo successful cardiopulmonary bypass in 1953. By the late 1950's, use of cardiopulmonary bypass to support patients during intracardiac surgery was widespread.** By 1960, workable cardiac valves and blood vessel prostheses were developed. These prostheses supported the thesis that small mechanical pumps might be designed, again involving technology transfers, for implantation within the chest (or abdomen) as a temporary supportive mechanism or substitute for the reversibly or irreparably damaged heart. From the beginning, the concept of technology transfers between germane disciplines was adopted and promulgated.

THE MANDATE:

When nationally coordinated investigations on implantable circulatory support or replacement devices began, there was ample reason to doubt that workable devices could be developed. At present, the idea is no longer far-fetched and families of systems have been evolved. Pneumatically driven implantable left ventricular assist devices have undergone two recent federal reviews. Federal criteria for validation of this family of devices prior to use in man are being developed. Our laboratory's participation in these policies has been intimate. Nuclear systems (vide infra) have been developed and implanted in animals to demonstrate feasibility. This change in outlook over a period of ten years is largely a consequence of programs supported by the National Heart and Lung Institute, and, more recently, the Atomic Energy Commission. From the outset they have involved multiple technology transfers to and from industry, medicine, cardiology, biomedical engineering and surgery. More specifically, in 1963 the National Advisory Heart Council decided to give priority to the development of an artificial heart, as did the West German and Russian Ministries of Health in 1970-72. In 1964, after clarifying the needs with respect to materials, driving mechanisms and control systems, coordinated investigations in the areas of implantable circulatory assist and replacement systems were initiated. In 1966, a systems analysis approach was adopted to direct and coordinate the programs in order to make feasible the optimal utilization of resources and technology transfers from medicine, the basic sciences, engineering, industry and systems management to implement and give impetus to these endeavors.

Until 1969, the programs focussed on the separate development of each component of circulatory support or replacement devices. That year, the direction shifted somewhat in that efforts were initiated to integrate devices and techniques, developed and developing, necessary to evolve a complete, fully implantable, nuclear-fueled left ventricular assist device in order to create experimental models and a data base for the development of subsequent, more advanced prototypes.

In anticipation and subsequent support of this mandate, our efforts, with our engineering colleagues, have been focussed on four major areas: 1) the evaluation of the biologic effects of chronic intracorporeal heat and radiation; 2) the development of efficient and reliable implantable nuclear engines; 3) in-vivo evaluations in experimental animals of the biocompatibility of the various system components; and 4) investigations of the hemodynamic effectiveness of nuclear-fueled circulatory support systems in experimental animals.

Three systems are currently under investigation; each has undergone a series of modifications to improve overall thermal-mechanical efficiencies and to decrease physiologic alterations resulting from system size, intracorporeal heat and the physiologic interactions between the prostheses and the experimental animals.

ENGINEERING SPECIFICS (THERMAL ENGINES)

Thermocompressor Engine (AeroJet Liquid Rocket Corporation, Sacramento, California)

The current thermocompressor engine utilizes a modified Stirling cycle. Alternating thermal expansion and contraction of helium gas drives a piston against a mechanical spring at a rate of 16-20 Hz. The system pressure varies between 185 and 215 psia during each cycle. An internal gas regenerator allows heat stored during depressurization to be used during the next pressurization stroke. A portion of the helium volume of each high pressure stroke is delivered to a high pressure accumulator. Gas is replaced from a low pressure accumulator. The stored high pressure helium is released on signal to be applied via a pneumatic actuator to the blood pump. Modifications in the engine and the pump actuator controller have increased the engine efficiencies. The current efficiency is 16.2%. Component reliabilities have also been improved. Successive major design alterations of in-vivo tested engines are listed in Table I. Engine power output is approximately 8 watts. The engine module weighs 3.7 kg and displaces 1.5 liters.

Modified Stirling Cycle Engine (Donald W. Douglas Laboratories, Richland, Washington)

This modified Stirling cycle engine uses a thermodynamic cycle similar to the thermocompressor engine. Alternating thermal expansion and contraction of helium drives a piston against a crank and flywheel. This engine operates at 20-25 Hz. at pressures of 200 to 240 psia. Pressure is stored in a hydraulic pressure accumulator. This pressure is released on signal and transferred to a hydraulic actuator on the blood pump. The specific design modifications are presented in Table II. The engine module weighs 4.7 kg and displaces 3.0 liters. The engine power output is 5 watts.

Tidal Regenerator Engine (Thermo-Electron Research and Development Center, Waltham, Massachusetts)

The tidal regenerator engine converts thermal energy to power by alternating vaporization and condensation of water. A small electric torque motor displaces 0.2 ml of water into a boiler and superheater. Vaporization of approximately 0.016 ml of water produces a pressure of 130 psi within the 3.5 ml displacement of the engine. This pressure is transferred through hydraulic lines to the blood pump. The advantages of this engine include operation at biologic heart rates and absence of valves, sliding seals and pressure accumulators. Electric power for the displacer torque motor and control logic is derived from an integrated thermoelectric module. Since the first in-vivo test of this system, various design modifications have been made resulting in higher engine efficiencies of 9.5%. These modifications are enumerated in Table III. The current engine module weighs 4.1 kg and displaces 1.75 liters. The engine power output is 2.75 watts or 0.0037 hp.

THE BLOOD PUMP

The left ventricular assist pump is a pusher-plate actuated rolling diaphragm type pump. Blood is accepted from the apex of the left ventricle and ejected into the descending thoracic aorta. The blood contacting surfaces are flocked with a layer of polyester filaments 10 mils long and 1 mil in diameter, applied with a density of 150 filaments per mm^2. This flocked interface promotes a rapid deposition of red blood cells, platelets, and fibrin which provides a stable, blood-compatible neointima, resistant to mechanical and thermal stresses. The pump incorporates a Hall-effect sensor, a linear volume displacement transducer or a strain transducer for position sensing and a blood-cooled heat exchanger for dissipation of reject heat. Modifications have been made in the current pusher-plate pump to improve hemodynamic efficiency and to reduce size. Previously utilized silastic disc valves have been replaced by valves which incorporate a hingeless tilting pyrolytic carbon disc in a titanium body. These valves have a central flow configuration with low gradients and low profiles. The pump compliance bag, which prevents air-spring effects within the thoracic cavity, is currently filled with distilled water rather than air to minimize leakage.

IMPLANTATION TECHNIQUES

Calves weighing between 95 and 120 kg are anesthetized with halothane-nitrous oxide-oxygen using a high flow, non-rebreathing system and intubated with an oro-tracheal tube. Ventilation is maintained with a volume cycled Ohio 560 respirator. Anesthesia is continued in the lightest possible plane with intermittent halothane supplemented by gallamine triethiodide for muscle relaxation. Arterial and venous cutdowns and tracheostomy are performed. A left thoracotomy and left transverse celiotomy are made. A six-centimeter length of 20 mm Dacron tube graft is anastomosed end-to-side to the descending thoracic aorta. A double row of stay sutures is placed in the central tendon of the left hemidiaphragm, avoiding the phrenic nerve. An incision is then made in the diaphragm between these sutures. Through the abdominal incision, two 2 cm wide nylon velour strips are passed around the left twelfth rib cephalad and tendon of the iliopsoas muscle caudad.

The circulatory support system is fueled with a 50-watt plutonium-238 fuel capsule† with observation of strict radiation safety procedures. The pusher-plate pump is passed into the abdominal incision, through the diaphragm and into the chest. The engine module, connected to the pump by its drive lines, is placed into the abdomen and secured with the previously placed nylon strips. Before manipulation of the heart, 200 mg of lidocaine are given intravenously and an infusion of lidocaine 1 mg/minute is begun. During cardiac manipulation, aortic systolic pressure is maintained above 140 mmHg by a slow intravenous infusion of metaraminol.

A Dacron felt sewing ring is sutured to the apex of the left ventricle. A small apical incision is made and a Foley catheter is passed into the left ventricular cavity utilizing a central stylet. The Foley balloon is inflated with saline and a circular core of apical myocardium is excised, using a cylindrical knife. Hemostasis is secured by gentle withdrawal pressure on the Foley catheter balloon. The pusher-plate pump is connected to the outflow tube graft and primed with saline. Under a CO_2 atmosphere, as the Foley balloon is deflated and withdrawn, the pump inflow tube is rapidly passed into the left ventricular cavity and secured with a purse-string suture around the silastic flange of the felt sewing ring and the engine is started. The pump is sutured to the diaphragm and the diaphragmatic incision is closed around the drive lines.

POST-IMPLANTATION MONITORING

Central aortic and right atrial pressures are monitored with fluid-filled catheters attached to Hewlett-Packard 267BC transducers. The left ventricular pressure is obtained with a Konigsburg P10-D transducer introduced into the ventricular cavity by direct puncture. Left ventricular dP/dt is determined by continuous electronic differentiation. Pump filling and ejection is recorded from a position sensor incorporated on the pusher-plate. Permanent recording is obtained with a Hewlett-Packard 7700 eight-channel strip recorder and a Hewlett-Packard seven-channel magnetic tape recorder. Continuous hemodynamic analyses are performed with an on-line Hewlett-Packard 5690B cardiac catheterization computer interfaced with the eight-channel recorder. Engine temperatures are monitored during tidal regenerator experiments with chromel-alumel thermocouples placed on the boiler, isolation cylinder oil and the hottest portion of the thermoelectric module. Cold-junction reference temperatures are obtained with a thermistor placed on the thermocouple terminal strip. In Stirling cycle engine experiments, thermocouples are placed on the hot end near the fuel capsule, the valve head and the working fluid. Thermistors are placed at intervals on the surface of the engine module. In all experiments, rectal temperatures are monitored from a thermistor probe with a Yellow Springs Instruments Telethermometer.

RESULTS

Hemodynamics

Hemodynamic function of a nuclear-fueled cardiac assist device during representative in-vivo experiments (H122N and H186N) is illustrated in Figures 1, 2, 3 and 4. Peak aortic pressure is phase-shifted into diastole and increased. Left ventricular peak pressure is decreased, 37% (Figures 1 and 2). Left ventricular end-diastolic pressure is decreased, 62% (Figure 3). Left ventricular dP/dt is decreased, 49% (Figure 4). During this experiment the pump stroke volume averaged 96 ± 6 ml. The average pump rate was 62 ± 4 beats/min. This left ventricular assist system maintained an average minute output of 5.96 ± 0.33 liters. In order to evaluate the effectiveness of this nuclear-fueled cardiac assist device in meeting varying physiologic demands, a vasopressor agent (metaraminol) was given by intra-venous infusion. The pusher-plate pump was able to maintain systemic perfusion against increased peripheral resistance. Systemic blood pressure increased from 118 mmHg systolic to 190 mmHg systolic while left ventricular peak pressure increased from 65 to 80 mmHg (Figure 5). Left ventricular end-diastolic pressures remained well below control levels (Figure 6). Significantly, left dP/dt, which had been markedly reduced by the assist pump, did not increase in the presence of alpha and beta-adrenergic stimulation (Figure 7).

The effects of myocardial ischemia on left ventricular assist device function have also been evaluated. At the time of sacrifice of H-186N, branches of the left anterior descending coronary artery were serially ligated until a significant increase in left ventricular end-diastolic pressure was obtained. In the absence of cardiotonic drugs, the nuclear-fueled cardiac assist system was able to elevate the depressed systemic blood pressure to near normal levels while reducing left ventricular peak pressure, 59% (Figure 8). The elevated left ventricular end-diastolic pressure was decreased, 86% (Figure 9). Left ventricular dP/dt was reduced 60% (Figure 10).

Biochemistry, Hematology and Coagulation

Hematologic values have remained within limits established as normal for this species with the exception of platelet counts which showed an immediate rise, returning to normal within twenty-four hours. Prothrombin and partial thromboplastin times were mildly prolonged throughout the experiments. Renal function, as reflected by blood urea nitrogen and serum creatinine levels was not impaired. Serum alkaline phosphatase, lactate dehydrogenase and glutamic-oxaloacetic transaminase levels were markedly elevated throughout the experiments. Bilirubin levels showed a slight progressive rise. In examining these trends, low sample numbers and terminal variations must be considered. No consistent trends were seen in serial plasma hemoglobin levels. Several factors influence hemolysis rates. These include turbulence in the pump (beat rate, stroke volume), type of prosthetic valves used, temperature of the heat exchanger and the amount of blood transfused during and after surgery.

Temperature

Engine and animal core temperatures obtained during a representative experiment (H197N) are presented in Table IV. The rectal temperature did not exceed 102° F.

SUMMARY

Nuclear-fueled circulatory support systems have been implanted in 15 calves with survival up to 175 hours. These experiments are summarized in Table V. Mechanical modifications have been made to improve system efficiency and reduce heat losses to the surrounding tissues. Engine efficiencies have been increased primarily by two methods: reduction of static heat losses and improvement of thermal regenerators. The next generation of engines have predicted efficiencies in excess of 15 percent.

These developments of totally implantable nuclear-fueled circulatory support systems could be of considerable value in the management of certain patients with severe myocardial disease. Such endeavors are prime examples of mission-oriented research which present a series of complex multidisciplinary problems. Each must be solved simultaneously within severe weight and volume constraints. Each requires the development of new technologies and multiple technology transfers. Each involves a multiplicity of parallel approaches, some rewarding and some unrewarding. The integration of biologic and physical disciplines which traditionally have not been interfaced is a sine qua non. A further prerequisite is continuing cooperation and interaction between federal, university and industrial interests. Very early it became apparent that the problems presented by such anticipated goals were [and are] of such magnitude that they could not be solved by a single agency, industry or laboratory. In addition, the usual step-by-step time-sequence approach for the development of such systems is essentially untenable. As a result of these considerations, we have employed a modified systems analysis and development approach in which all subsystems are considered concurrently. Conceptual design, development and in-vivo testing are achieved by the coordinated efforts of many individuals, disciplines and investigators. If the momentum that has been developed over the past decade can be maintained, and if we can solve in similar fashion problems which we thought were insoluble six,

seven and eight years ago in the manner which we have thus far achieved, it is quite possible that nuclear-fueled circulatory support systems could become clinical realities by the end of this decade; it may well be the end of the following decade. We welcome you to visit our laboratories to discuss and perhaps participate in these collaborative technology transfer and investigative efforts.

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FOOTNOTES

*The results of these efforts, thus far, are available through the Medical Devices Applications Program, National Heart and Lung Institute, Cardiovascular Devices Branch, Division of Heart and Vascular Diseases, National Institutes of Health, Bethesda, Maryland, 20014. Reports TE 66-67, 25-68, 199-68, 107-69, 12-70, 130-70, 5-71, 158-71, and 122-71 are of interest. Proposals 21-70 and 33-70 are relatively comprehensive. Reports 97-69, 106-69, 117-70, 118-71, 67-71, 150-71, 3-70, 6-72 and 26-72 are current. Specification 70-71 is of particular interest. Reports TH 43-68-1455-3, 4 and 5 are most recent. In all more than 70 individual documents from our laboratories and those of our engineering colleagues in Waltham, Massachusetts, Sacramento, California, and Richland, Washington, are available through the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22151. These reports describe in detail a continuing series of investigations that have been undertaken to focus on specific relevant problems and to evolve workable solutions. In brief, these include 1) the development of a compact, totally implantable blood pump which propels the blood efficiently without thrombosis or damage; 2) the development of implantable nuclear engines compatible with the pump; 3) the development of methods to dissipate excess heat from the engines; 4) the development of methods to couple efficiently the engine and the pump; 5) development of an anticipated long-term (10 year) data base regarding the in-vivo effects of prolonged intracorporeal irradiation; 6) the development of nuclear handling technology; 7) the start-up of procedures of prototype nuclear-fueled circulatory support systems with the necessary implantation technics, and 8) initial in-vivo testing.

**This year, more than 50,000 patients will undergo the relatively new coronary artery bypass procedures involving use of the heart-lung machine.

†Donald W. Douglas Laboratories, Richland, Washington. The 50-watt Pu-238 fuel capsule is 1.28 inches in diameter, 2.0 inches in length and has a mass of 472 grams. The capsule temperature is approximately 1000^{0} F. The 124 grams of substoichiometric ($PuO_{1.8}$) plutonium oxide fuel is pressed and sintered to 77 percent of theoretical density. A low neutron emission rate of 2.9×10^{5} neutron/sec (corresponding to 2720 neutrons/sec-gm Pu) is achieved by enriching the plutonium with Oxygen-16. The fuel pellet is triply encapsulated in tantalum, T-111 and Platinum-20% Rhodium. This heat source is designed to survive a maximum credible accident (2400^{0} F temperature) within five years after encapsulation.

Capsule qualification tests included: 1) internal pressure (up to 6000 psi at 2300^{0} F), 2) external pressure (3000 psi for 15 min.), 3) crush (20,000 lb. for 1 hour), 4) impact (120 ft-lb), 5) puncture (44 fps onto 1/8 inch diameter pin) and 6) shear (10,000 lb. for 1 hour), as well as 7) fire/corrosion, 8) thermal shock, 9) free drop, 10) water immersion, and 11) thermal exposure.

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TABLE I

Thermocompressor Design Evolution

MK V B/PAC 4 Implanted 3-1-73	Mk V B/PAC 4 Implanted 4-16-73	Mk VI/PAC 4A Implanted 12-4-73	Mk VI/PAC 4 Implanted 12-8-73
Heat dissipation primarily to abdominal cavity	Heat exchanger added to cold flange for external cooling	Heat exchanger added to cold flange for external cooling	Heat exchanger added to cold flange for external cooling
		Heat pipe cooling	Internal water pump/ heat exchanger at blood pump base
No insulation and PAC	Insulation added to PAC	Insulation added to PAC	Insulation added to PAC
No valve head cooling	No valve head cooling	Radial gas cooler added on valve head	Radial gas cooler added on valve head
Deformable blood pump inlet tube	Non-collapsible blood pump inlet tube	Non-collapsible blood pump inlet tube	Non-collapsible blood pump inlet tube
Gas filled compliance bag	Gas filled compliance bag	Liquid filled compliance bag	Liquid filled compliance bag
Short gas regenerator	Short gas regenerator	Longer gas regenerator	Longer gas regenerator
Higher stressed PAC bellows	Higher stressed PAC bellows	Lower stressed PAC bellows	Higher stressed PAC bellows
		Improved bearing life	Improved bearing life
Engine efficiency: 14.1%	Engine efficiency: 14.1%	Engine efficiency: 16.2%	Engine efficiency: 16.2%

TABLE II

MODIFIED STIRLING CYCLE ENGINE DESIGN EVOLUTION

Implanted 3-17-72	Implanted 5-31-72	Implanted 2-21-73	Implanted 4-30-73	Implanted 2-6-74
soft (Teflon) overflow valve seat	soft (Teflon) overflow valve seat	hard (steel) overflow valve seat	hard (steel) overflow valve seat	hard (steel) overflow valve seat
no hydraulic fluid filter	hydraulic fluid filter	hydraulic fluid filter	hydraulic fluid filter	hydraulic fluid filter
radial clearance between displacer and cylinder wall 0.0095 in.	radial clearance between displacer and cylinder wall 0.0095 in.	reduced radial clearance between displacer and cylinder wall 0.0074 in.	reduced radial clearance between displacer and cylinder wall 0.0074 in.	reduced radial clearance between displacer and cylinder wall 0.0074 in.
rubber diaphragm between gas and hydraulic fluid	rubber diaphragm between gas and hydraulic fluid	rubber diaphragm between gas and hydraulic fluid	nickel coated rubber diaphragm between gas and hydraulic fluid	corrugated metal diaphragm between gas and hydraulic fluid
hydraulic fluid pressure reference accumulator at atmospheric pressure	hydraulic fluid pressure reference accumulator at atmospheric pressure	hydraulic fluid pressure reference accumulator at atmospheric pressure	reference accumulator pressurized to 5 psi	reference accumulator pressurized to 5 psi
prototype bearings	prototype bearings	prototype bearings	prototype bearings	enlarged bearings longer life
aluminum cold plate with epoxy gas plug	aluminum cold plate with epoxy gas plug	aluminum cold plate with epoxy gas plug	aluminum cold plate with epoxy gas plug	brass cold plate with brazed gas fittings
engine efficiency 6%	engine efficiency 6%	engine efficiency 10%	engine efficiency 10%	engine efficiency: 10%

TABLE III

Tidal Regenerator Engine Design Evolution

Model 1 Implanted 2-14-72 Pump output in vitro* 3.0 l/min.	Model 1A Implanted 3-7-73 Pump output in vitro 4.5 l/min.	Model 2 Implanted 3-20-74 Pump output in vitro 6.5 l/min.
Basic TRE-no regeneration High static heat losses (30 watts) Low control electric power (200 mw) No boiler temperature control Effective steam temperature: 550° F Bellofram pump seal No provision for externally supplied cooling	Basic TRE-no regeneration Moderate static heat losses (18 watts) Low control electric power (200 mw) Electrical boiler temperature control Effective steam temperature: 550° F Bellows pump seal No provision for externally supplied cooling	TRE with regeneration Moderate static heat losses (18 watts) Adequate control electric power (325 mw) Thermostatic boiler temperature control Effective steam temperature: 650° F Improved Bellows pump seal Heat exchanger added for external cooling
Engine efficiency: 6%	Engine efficiency: 6%	Engine efficiency: 9.5%
*@120 mmHg. Ao. Syst. and 75 BPM		

TABLE IV

Engine and Animal Core Temperatures
Range Over 72 Hours In Vivo

POSITION	TEMPERATURE °F
Engine	
Hottest portion near thermoelectric module	820 - 840
Isolation cylinder oil	600 - 605
Boiler	350 - 360
Cold frame reference	120 - 121
Animal (Rectal)	99 - 102

TABLE V

NHLI NUCLEAR-FUELED CIRCULATORY ASSIST SYSTEM IMPLANTATIONS*

IMPLANT DATE	CALF	CONTRACTOR	IMPLANT PERIOD (HOURS)	SYSTEM FAILURE	ANIMAL CONDITION
14 Feb 72	28	Thermo Electron	8	Kinked inflow tube	Good
17 Mar 72	30	McDonnell Douglas	1	Overflow valve	Good
17 May 72	3	Thermo Electron	7	Thermal instability	Good
31 May 72	31	McDonnell Douglas	7	Overflow valve	Good
21 Feb 73	H-117	McDonnell Douglas	12	Entrained gas in hydraulic system	Good
1 Mar 73	H-118	Aerojet	9	Thermal management induced fibrillation	Thermal Injury
7 Mar 73	H-122	Thermo Electron	112	Pump drive bellows leak	Good
16 Apr 73	H-125	Aerojet	73*	Foil insulation vacuum seal broken	Good
30 Apr 73	H-119	McDonnell Douglas	29	Animal Sacrificed	Pneumonitis
4 May 73	H-128	McDonnell Douglas	5	Animal Failure	Tachycardia
4 Dec 73	H-186	Aerojet	74**	Actuator bellows leak	Good
11 Dec 73	H-185	Aerojet	175**	Actuator bellows leak	Pulmonary edema
6 Feb 74	H-187	McDonnell Douglas	22	External gas line broken	Good
11 Feb 74	H-191	McDonnell Douglas	54	Thermal Management	Thermal Injury
20 Mar 74	H-197	Therm Electron	73	Animal Sacrificed	Pulmonary edema

*Cardiovascular Surgical Research Laboratories, THI
**Externally cooled

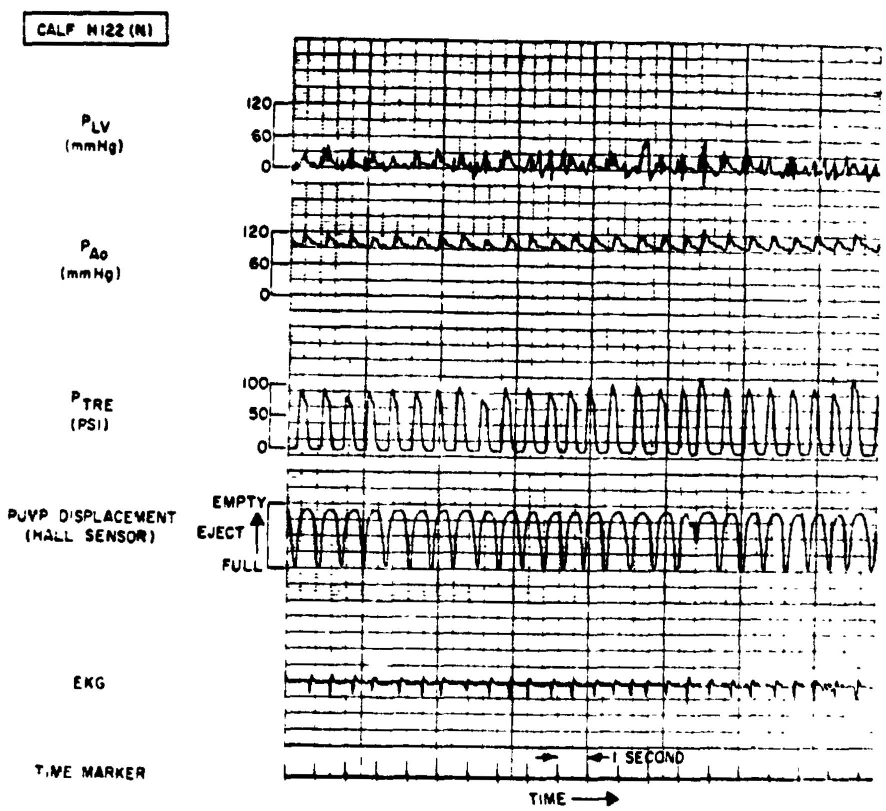

Figure 1. Representative physiologic tracing from in-vivo nuclear fueled circulatory support system experiment. Note that while left ventricular peak pressure is markedly reduced, systemic blood pressure is maintained.

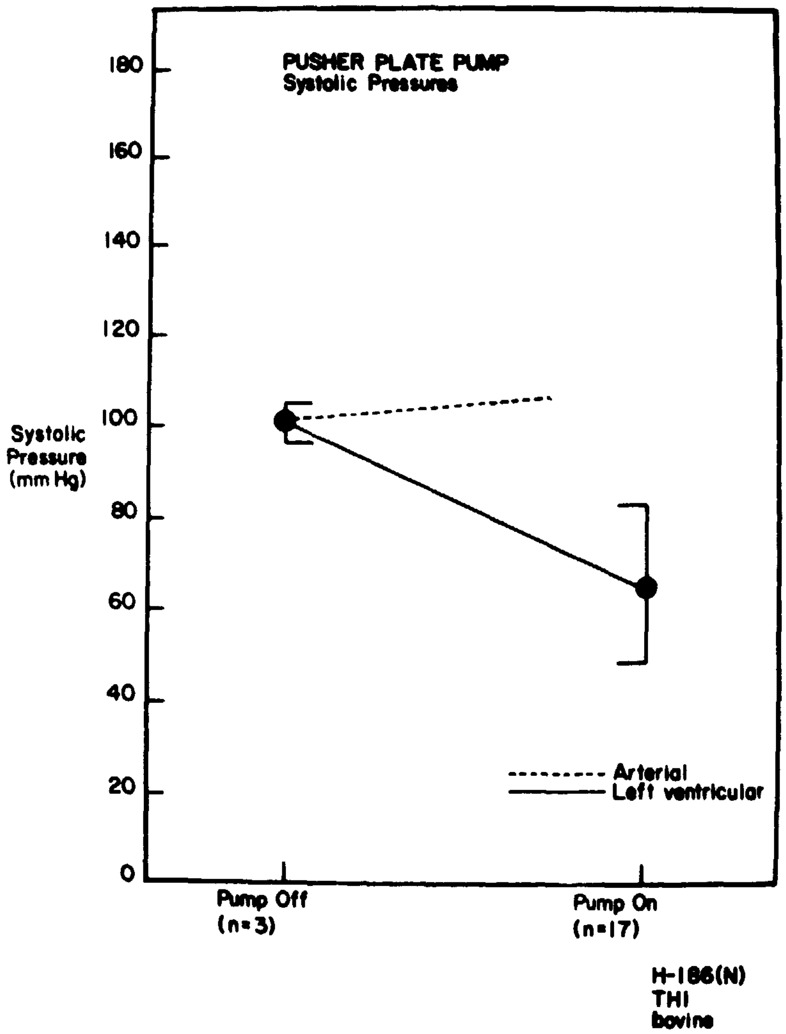

Figure 2. Effect of nuclear powered pusher-platc pump on arterial and left ventricular systolic pressures. LV peak pressure is decreased 37%.

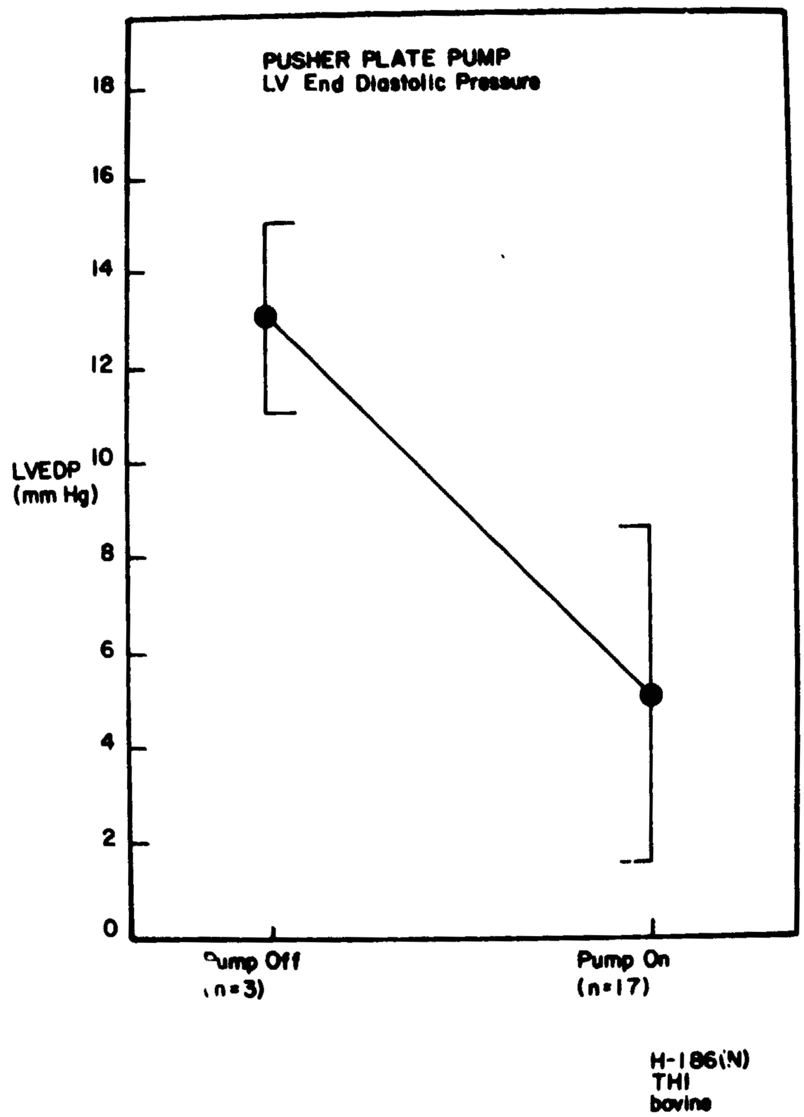

Figure 3. Effects of pusher plate pump on left ventricular end-diastolic pressure. LVEDP is decreased 62%.

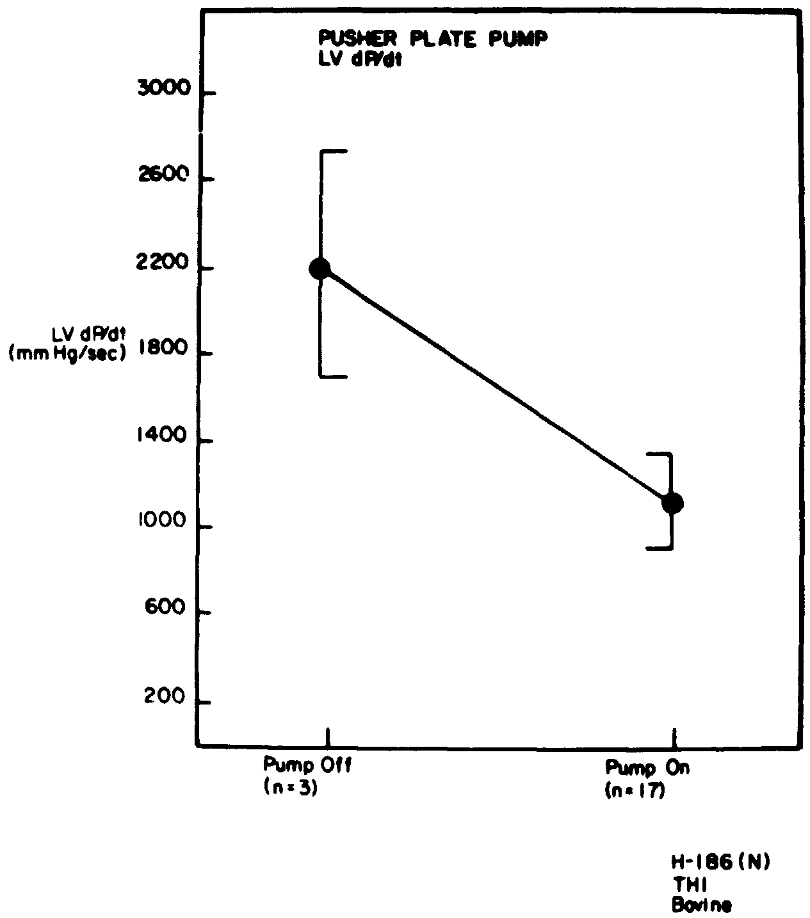

Figure 4. Effect of cardiac assist system on left ventricular dP/dt. LV dP/dt is reduced 49%.

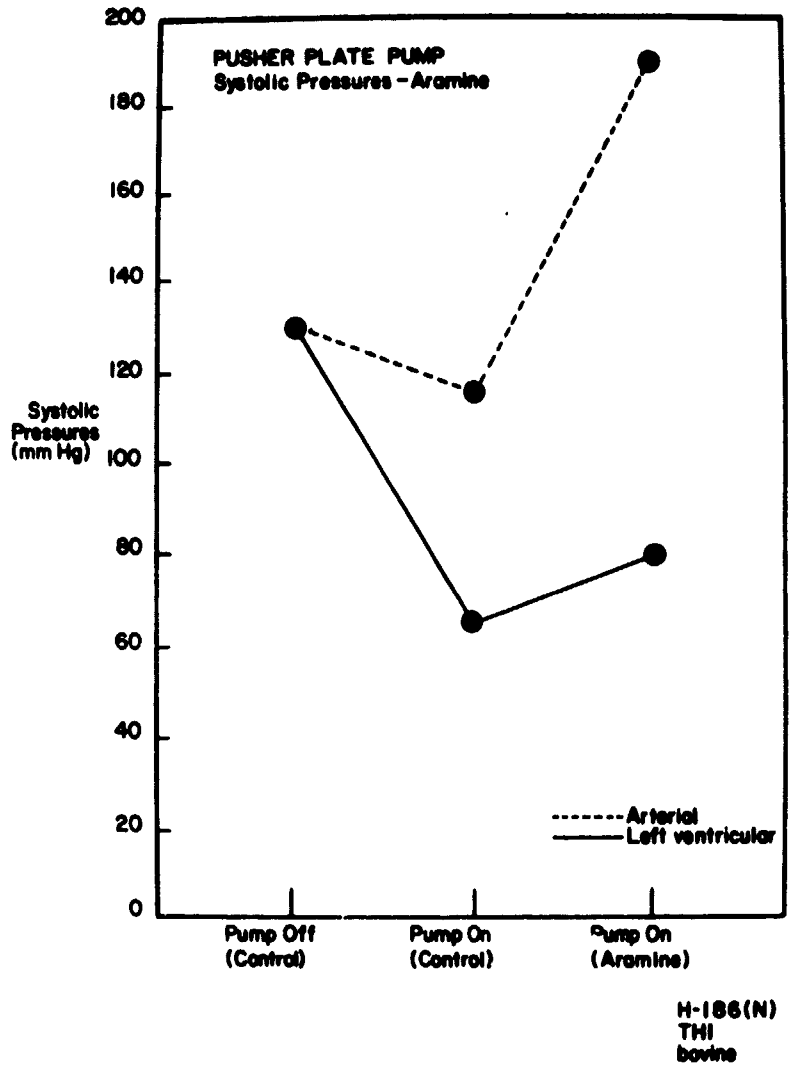

Figure 5. Effects of nuclear powered circulatory support system on arterial and LV systolic pressures during stimulation with aramine (metaraminol). The pump supports the systemic circulation against increased peripheral resistance; LV unloading is marked.

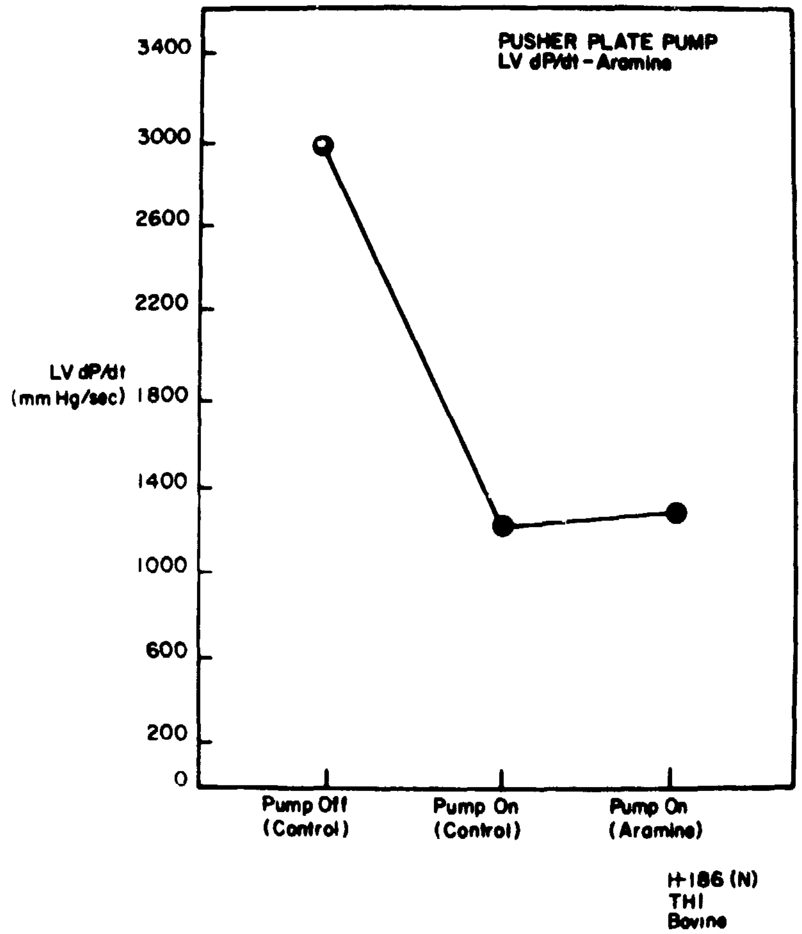

Figure 7. Effect of nuclear fueled circulatory support system on LV dP/dt during aramine (metaraminol) stimulation. The beta-adrenergic effect of the vasopressor is not reflected in dP/dt.

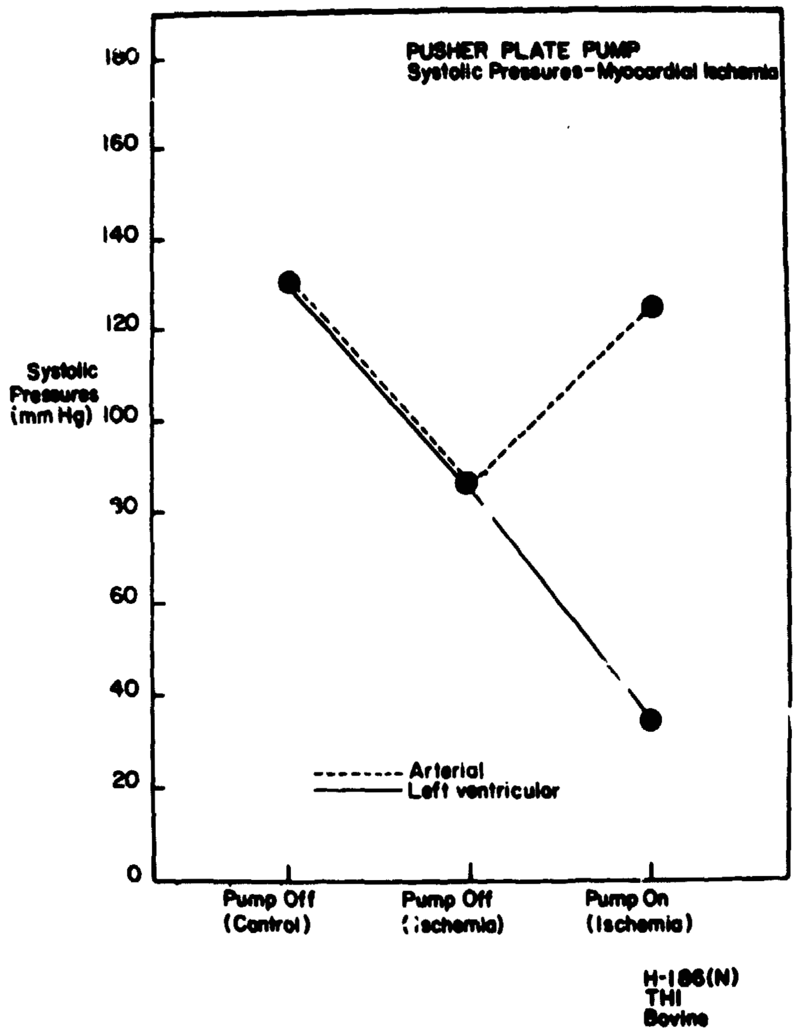

Figure 8. Effects of pusher-plate pump on LV and systemic peak pressures during coronary occlusion. Arterial pressure is returned to normal levels with marked ventricular unloading.

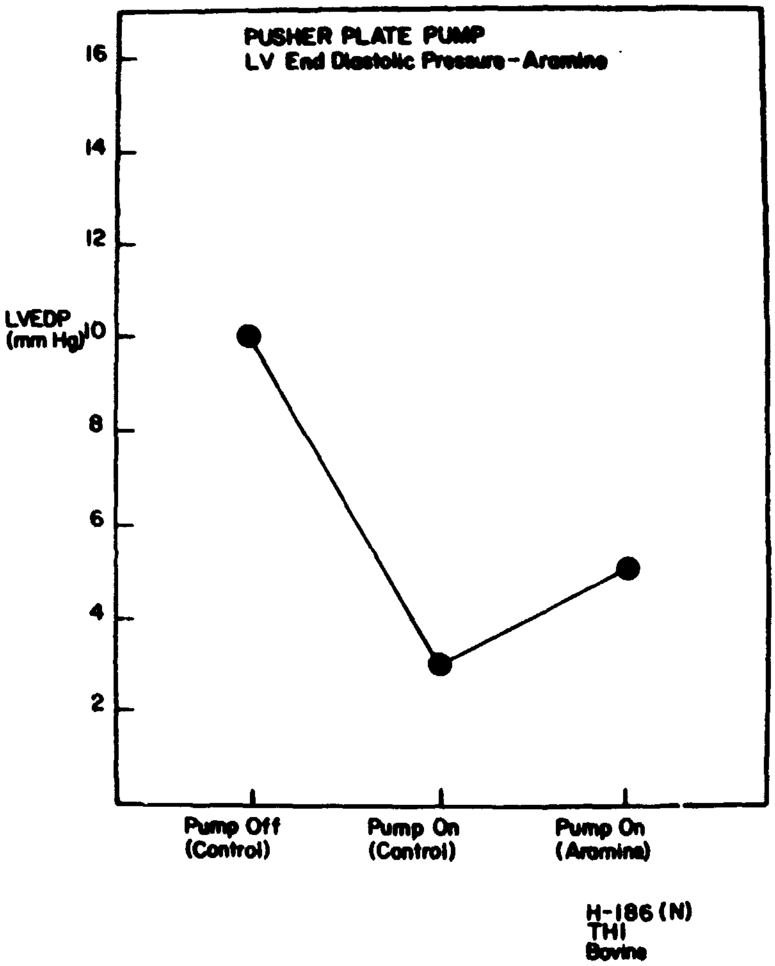

Figure 6. Effects of nuclear powered pusher-plate pump on LVEDP during aramine (metaraminol) infusion. LVEDP remains low.

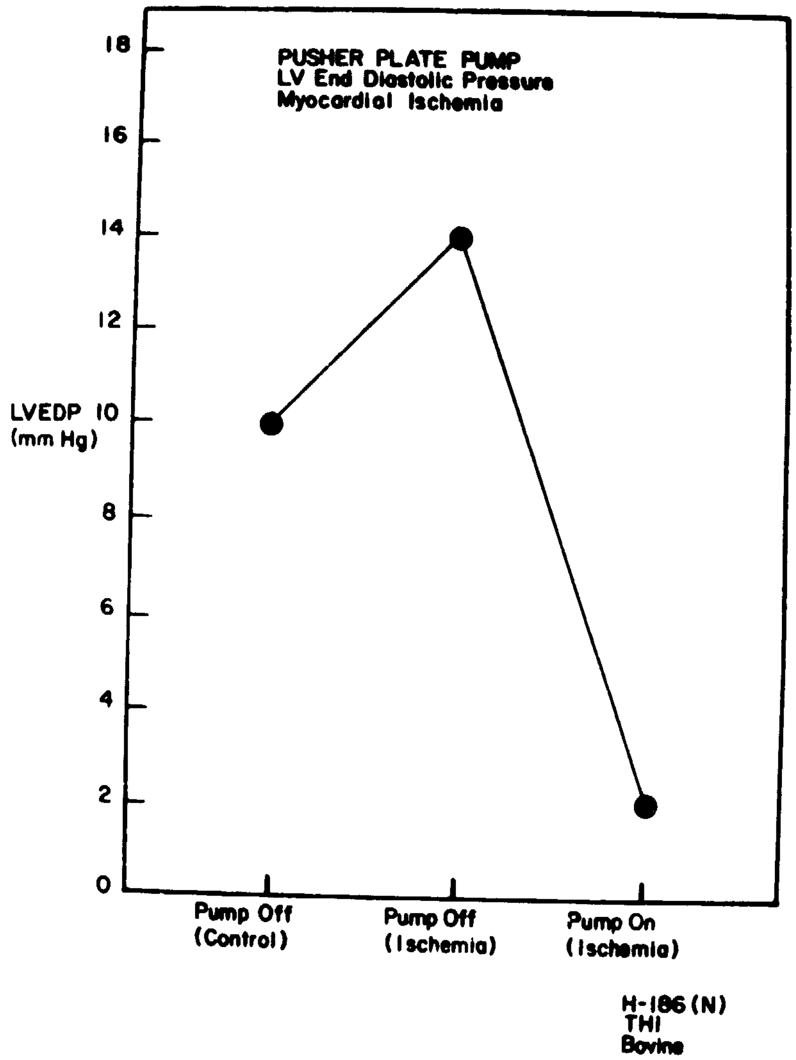

Figure 9. Effects of nuclear fueled LV assist device on LVEDP during coronary occlusion. The elevated EDP is markedly reduced.

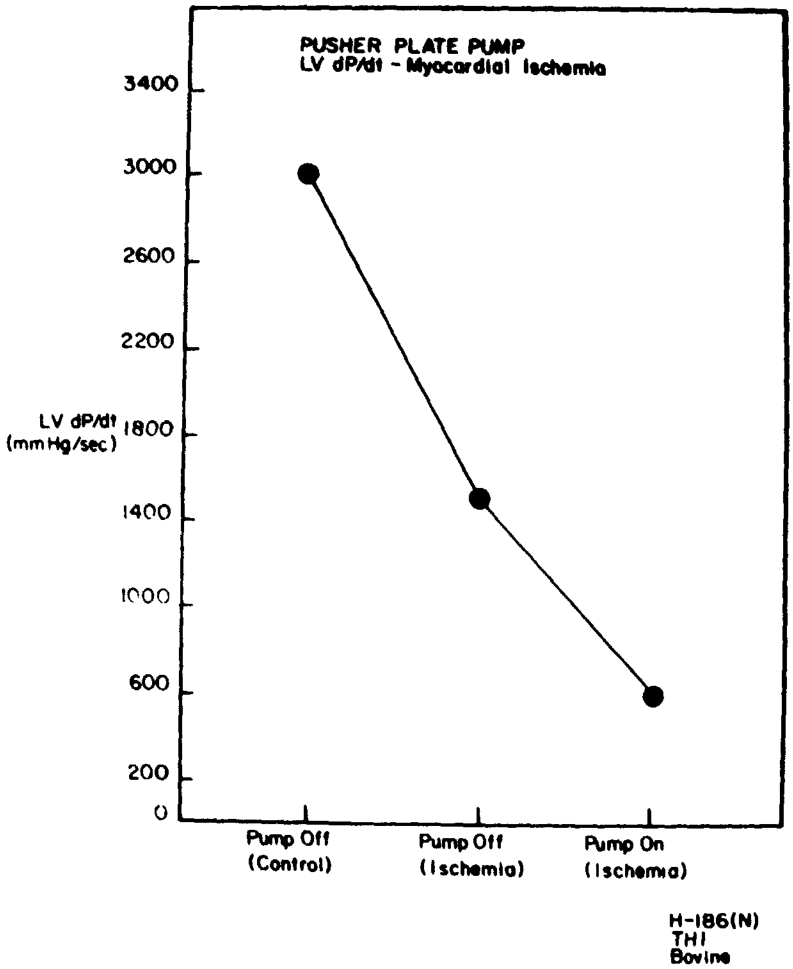

Figure 10. Effects of nuclear powered circulatory support system on LV dP/dt during coronary occlusion. The reduced dP/dt is further lowered 60%.

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SPACE TECHNOLOGY IN REMOTE HEALTH CARE

Norman Belasco

INTRODUCTION

Crewmen and passengers on future long-duration earth orbital and interplanetary missions must be provided quality health services - to combat illnesses and accidental injuries, and for routine preventive care. Earth orbital missions will have the capability for easy return to earth but interplanetary missions will not. Accordingly, the long-duration manned mission will likely require that some members of the crew be specially trained - such as a physician's assistant, hospital corpsman, nurse, or perhaps a physician - but in any case, the responsible individual onboard for health care services must be able to consult with the ground and obtain special assistance and/or supervision to assure quality care. SPECIFICALLY, WE MUST DETERMINE THE MOST EFFECTIVE WAY TO ADMINISTER HEALTH CARE TO A REMOTELY LOCATED POPULATION.

Many similarities exist between administering quality health care in a spacecraft and administering the same care to a remote population on earth. In remote areas on earth, the physician and/or allied health personnel must administer health care under conditions that are not usually optimum (i.e., limited clinical equipment, lack of adequate surgical and therapeutic facilities, coupled with the limited ability to consult with specialists). The medical information obtained from an abnormal electrocardiogram (ECG) on a crewman in a spacecraft and communicated to the ground may be nearly identical to that obtained from the ECG of a patient in a remote location on earth and transmitted to a medical center. A high-resolution television presentation of an x-ray picture of a fracture from a crewman in space might be transmitted and evaluated the same as an x-ray obtained and transmitted from a remote location on earth.

We must determine the probability of illnesses and injuries and provide procedures, equipment, instruments, and pharmaceuticals to diagnose and treat them. We must define the medical and surgical skill required of the onboard allied health personnel and/or physician-astronaut. We also must determine the extent of guidance that can be given in handling serious medical emergencies by two-way voice communication and vehicle-to-ground television links. For example, it can be expected that the onboard physician will be guided through emergency surgery, step by step, by a fully qualified surgeon via the TV-voice link, whenever ground contact is possible.

Significantly, the communication and data processing systems required on long-duration space missions may also be similar to that required for a remote health services system on the ground. Thus, operation of a "test bed" health care system in selected remote locations on earth is intended to provide a reasonable simulation for gathering information applicable to a flight system's design. This approach has "spin-off" potential, in that space technology employed in the basic design of a flight system may be extremely beneficial to improving the quality of health care delivery on earth.

Citizens of remote areas on earth face an ever-increasing problem of acquiring quality health care. This problem results from national shortages of trained physicians, remote areas being unable to attract new physicians, geographical dispersal of populations and medical capabilities, among other reasons. A system which gives physicians (without physically being present) the capability to administer quality health care to patients in remote areas may provide a satisfactory solution.

As a result of these considerations, the National Aeronautics and Space Administration - with the cooperation of the Department of Health, Education and Welfare - is pursuing a program for an earth-based remote area health services system as a necessary step to development and verification of a remote health services spacecraft capability. The content of this demonstration program is described on succeeding pages.

THE STARPAHC PROGRAM: ASSEMBLY OF A GROUND-BASED REMOTE AREA HEALTH CARE DELIVERY SYSTEM AND OPERATION FOR TWO YEARS IN A REMOTE LOCATION

Objectives

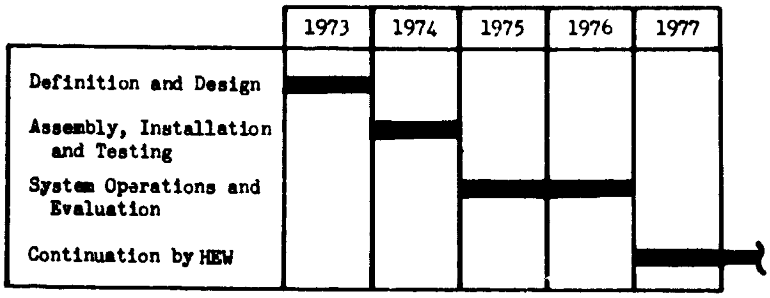
To provide data for developing health care for future manned spacecraft through:

- Further development of the physician-paramedic link
- Clinical evaluation of advanced bioinstrumentation
- Development of computer support for "remote" health care
- Integration of video viewing and display devices
- Definition of skills, training and procedural requirements
- Evaluation of existing techniques for space application
- Identification of technology advancement need areas
- Refinement of protocols and techniques

To improve the delivery of health care to remote areas on earth through:

- Improved communication methods
- Mobile health clinic
- Advanced health care equipment
- Computer aids
- Assistance to allied health professionals and health education programs

Schedule



THE SITE: THE PAPAGO INDIAN RESERVATION, ARIZONA

The Papago site was selected by HEW and NASA based on many reasons, including the community's willingness to support the cost of the system after the test period is completed, and its willingness to accept primary care from physician's assistants. Arizona is one of 28 states which does not prohibit using physician's assistants. Beneficiaries will be the 8-10 thousand permanent residents of 75 villages in the Papago reservation, and also the 2-4 thousand who live outside the reservation's boundaries but return to the reservation for health care. The tribe governs itself through a tribal council and has complete police jurisdiction on the reservation. Average family size is 4.8 persons with a median age of 21 years.

The Papago reservation covers approximately 6,923 square kilometers (4,300 square miles) west of Tucson and south of Phoenix (fig. 1) with the Mexican border on its south boundary. The reservation is in the Sonora Desert - a rough, dry terrain with intermittent mountain clusters. Utilities, where available, are fair to poor in quality. Power outages of six hours or more are a frequent occurrence in July and August, even at Sells and Santa Rosa, the "big cities." Villages have wells which provide water needed for subsistence. Highways are asphalt surfaced while other roads are primarily dusty, unpaved and bumpy which can be hazardous immediately after rainstorms. The main industry is raising cattle with little farming, and the average income is approximately $900.

HEW's Indian Health Service administers health care on the reservation through a hospital at Sells and a part-time clinic at Santa Rosa. A large, well-equipped Indian Health Hospital is also in Phoenix with many specialists on the staff. In the STARPAHC system (fig. 3), Sells and Santa Rosa have been selected as key elements for the Support Control Center (SCC) and the Local Health Services Center (LHSC), respectively. Also, the Phoenix hospital is the Primary Referral Center (PRC). For health care service to remotely located villages, this program will use a Mobile Health Unit (MHU), a well-equipped vehicle-type clinic facility staffed by physician's assistants. These system elements are described in more detail on subsequent pages.

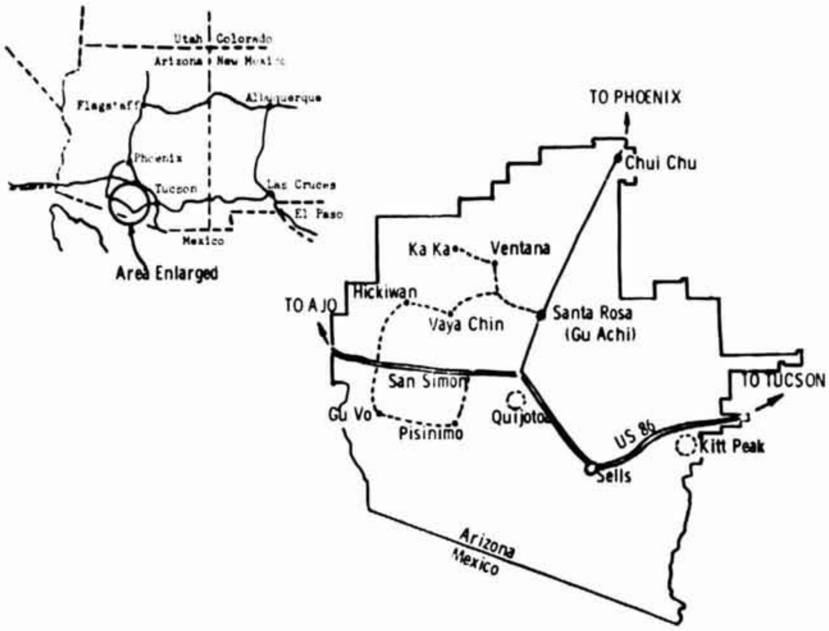


Figure 1. Papago Indian Reservation.

Figure 2. Quijotoa Mountain Range.

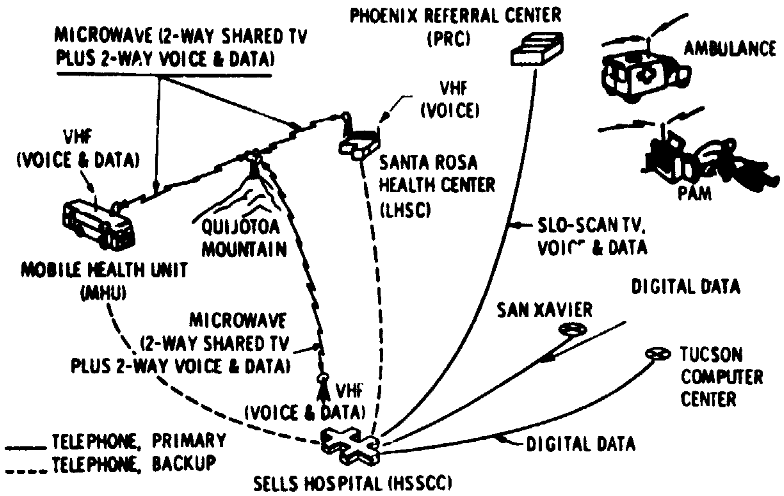


Figure 3. System Configuration.

SYSTEM CONFIGURATION

The STARPAHC system synthesizes a series of basic facilities, service elements and supporting functions into an operating system. Figure 3 presents the system configuration consisting primarily of:

1. The Health Services Support Control Center (HSSCC or SCC) is located in one wing of the Sells Hospital and is analogous to our Mission Control Center. It will be staffed by physicians and a system operator.

2. A Local Health Services Center (LHSC) is the Santa Rosa Clinic. It will be staffed by a physician's assistant and will function as a fixed remote clinic.

3. The Mobile Health Unit (MHU) is a clinically equipped van-type vehicle which is staffed with a physician's assistant and a laboratory technician. It functions as a remote mobile clinic, visiting villages on a pre-selected route and schedule.

4. The Phoenix Referral Center (PRC) is a dedicated room in the Indian Health Service Hospital in Phoenix for access to specialists, through audio and slow-scan television links with SCC, LHSC and MHU.

5. The Tucson Computer Center (TCC) provides STARPAHC data system access to the IHS Health Information System data base.

6. The Quijotoa Relay Station (QRS) is used for microwave and VHF transmission of television, voice and data between major system elements.

7. The Telecare Unit (sometimes called PAM, for Portable Ambulance Module) is a suitcase-size portable, ambulance-carried selection of medical equipment for emergencies and house calls to bedridden patients.

SYSTEM OPERATION

The basic operational features of the STARPAHC system are:

Medically-trained Community Health Medics (CHMs), commonly known as "physician's assistants", are at the fixed clinic (LHSC) and mobile clinic (MHU). These CHMs administer health care to patients under the direct supervision of physicians who are miles away at the Sells Hospital (SCC). The CHMs are linked to the physician through radio and TV hookups, enabling the physician to view the patient or his affected body area, x-rays, microscope slides, etc. Simultaneously, descriptions and responses to the physician's questions (by the CHM and the patient) can take place via the radio link. This in effect extends the high-quality diagnostic and treatment capability of the physician over large distances and areas while he is located in the hospital (the SCC).

An automatic data processing network supports the activities of the physician, CHM, laboratory technician and other system personnel by enabling them to request important information from the computer using typewriter keyboard-type terminals. The requested information is displayed on a TV-type screen almost instantaneously and can include patient histories, instruction for care, diagnostic aids, etc. Following the patient's visit, information is entered into the data system via the same terminals so that all patient information will be current.

In most cases where the physician at the SCC wants to consult with a specialist in the Phoenix Indian Health Hospital through the SCC, he has the capability for transmitting views of x-rays, wounds, lesions, patients, etc., from either clinic to the specialist's station using the slow-scan TV. He also has a direct telephone line for discussion with the specialist.

This combination of capabilities enables patients at the remote clinics to be diagnosed by the physician miles away at the hospital, and to be immediately treated by the CHM in the clinic under the physician's direction. The entire activity is accomplished in minimum time and without the patient traveling considerable distances.

The Mobile Health Unit

The MHU (fig. 4) is a mobile clinic visiting villages on a scheduled basis (see map for MHU route, fig. 1). This mobile clinic, staffed by CHMs and laboratory technicians, gives the physician a flexible "outreach" capability. Its use and features are briefly summarized as follows:

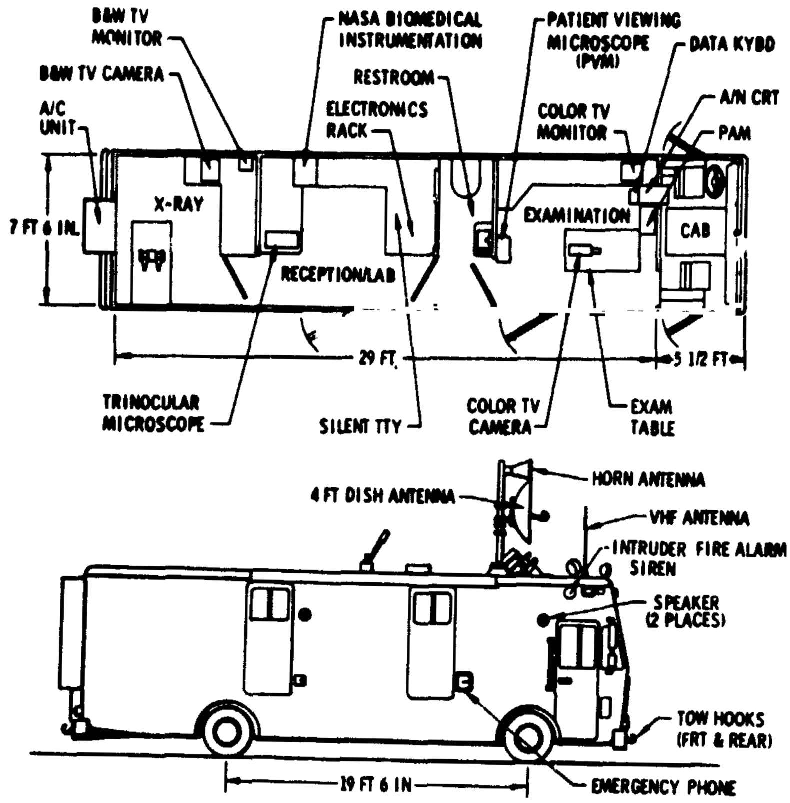


Figure 4. The Mobile Health Unit.

A patient enters the reception area and is interviewed by a CHM as to complaint, symptoms duration, etc. The CHM determines the need to call up a patient history or other pertinent information using the data terminal keyboards. Patient examination takes place in the examining room where the physician is in radio contact with the CHM and can view the patient via TV (CHM uses the color TV camera above the examining table). If the physician decides that a view of a body orifice is necessary (such as ear or throat), then the CHM will use a patient viewing microscope (PVM) under voice direction of the physician while checking with the TV monitor. The PVM (fig. 5) uses fiber optics to both illuminate the viewing area and return the image to a TV camera, where it is televised to the physician at the SCC. Should the physician require viewing of slides, such as blood smear or culture, the trinocular microscope assembly includes a TV camera to transmit to the physician what is being viewed through the microscope. The laboratory area also contains many capabilities for doing biochemical analyses usually required for clinical examinations (blood work, urinalysis, etc.). When x-rays are required, the procedures of taking and developing the x-rays are accomplished in the x-ray room. This room also contains equipment enabling the technician to transmit the x-ray to the physician at the SCC via TV.

Figure 5. Patient-Viewing Microscope in Typical Use During Surgery.

Santa Rosa Health Center (LHSC)

The LHSC (figs. 6 and 7) is an existing clinic whose capabilities are enhanced by the equipment and personnel needed to meet its functions in the STARPAHC system. The LHSC is a well-equipped clinic, and will be staffed with CHMs, laboratory technicians, and a secretary/receptionist. Like the MHU, its function provides the physician at the SCC with "outreach" capability to deliver quality health care to patients through STARPAHC. It has considerably more usable area and more clinical examination, patient treatment and laboratory capability than the MHU. Its operational procedures for patient, CHM, or physician activity are generally identical to those described for the MHU.

Sells Hospital (HSSCC or SCC)

The SCC (figs. 8 and 9) is the base for the STARPAHC operations. It is contained in one wing of the Indian hospital at Sells, Arizona. Here the physician will direct the CHMs, laboratory technicians, communicate with patients, call up data to assist in the patient examination and treatment. He can also consult with specialists at the Phoenix Indian Health Hospital (PRC) and direct system operator for specific functions such as recording the TV image, sending slow-scan x-rays to the PRC or patching in other needed capabilities.

As operational base, the supporting engineering functions such as scheduling, logistics, maintenance, reporting, etc., will

Figure 6. Santa Rosa Clinic.

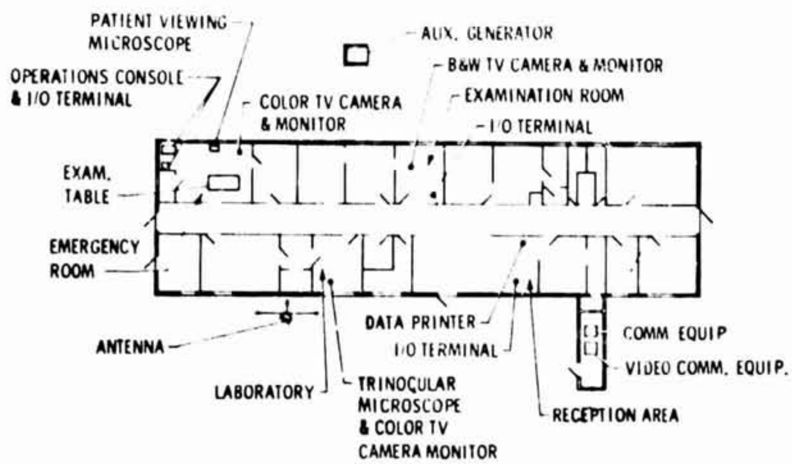


Figure 7. Floor Plan of LHSC.

be managed and controlled from here. In addition, the SCC contains the system data processing equipment and maintenance workshops (not shown).

<u>Physician Console</u>. The physician's console in the SCC (figs. 10 and 11) is the focal point of the system. As the system's control center, it provides physicians with the displays and controls required to perform their comprehensive functions. The controls and displays have been carefully selected to give the physicians command flexibility and a maximum amount of information without diluting their activity with detailed technical functions. An option for the physician to control privacy on the voice and TV circuits is another system feature. Most important to his visual examination of the patient is the capability to remote control the TV camera at the MHU and LHSC directly from his console.

Figure 8. Hospital in Sells, Arizona.

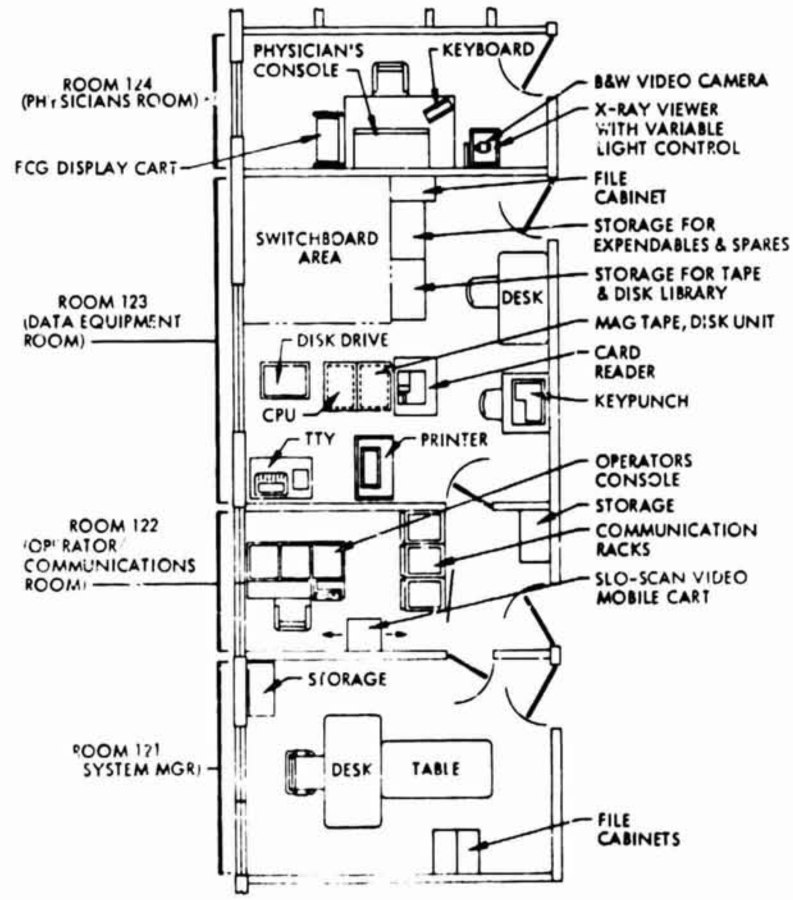


Figure 9. Floor Plan of HSSCC.

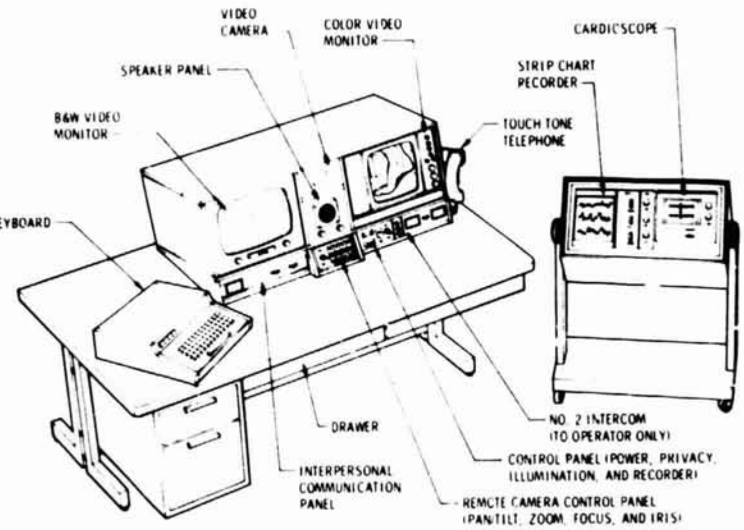


Figure 10. Physician Console at HSSCC.

Figure 11. Physician at Full-Scale Model of HSSCC Physician's Console.

Phoenix Referral Center (PRC)

The Indian Health Hospital at Phoenix, Arizona, referred to as the PRC (figs. 12 and 13), is staffed with and has access to medical specialists. In the STARPAHC system these specialists will be called upon to consult with the physicians at the SCC when unique or complex medical advice is in order. To enhance the consultation

Figure 12. Phoenix Indian Health Hospital.

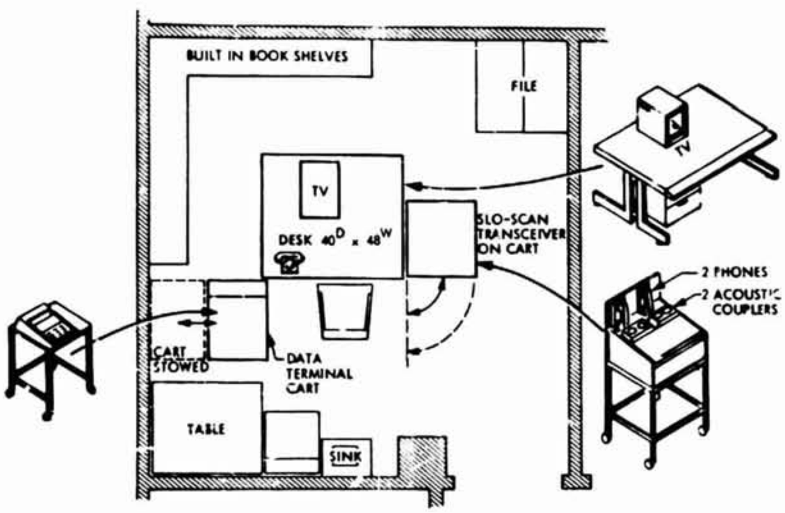


Figure 13. Floor Plan of Diagnostic Center at PRC.

the system provides the capability for transmitting x-rays or pictures of the patient, lesions, etc., via slow-scan TV using existing telephone lines. These same telephone lines also provide capability for voice communication and data transmission between the SCC and the PRC. The slow-scan capability provides x-ray or picture transmission in 45 to 90 seconds. It inherently records the transmission which enables almost unlimited playback capability for extensive, repetitive studying at different times and for various durations.

PROGRAM ORGANIZATION

Participants

The Papago Indian Tribe and its Executive Health Council

The HEW Health Resources Administration

The Indian Health Service Center for Research and Development

The NASA Office of Manned Space Flight

The Lyndon B. Johns-n Space Center, Life Sciences Directorate, Bioengineering Systems Division

The Lockheed Missiles and Space Company, Inc. (contractor to ľ'SA JSC)

Responsibilities

NASA JSC Program Office	HEW IHS Office of R&D	LMSC Program Office
PROGRAM MANAGEMENT	PROGRAM MANAGEMENT TEAM MEMBER	PRIME CONTRACTOR
Program planning and budgeting Technical direction and control Interagency and contractor coordination Program data and documentation control Government-furnished equipment (GFE)	Program and contractor guidance and coordination GFE, facilities, personnel and services Health Information System data base Medical operations management and evaluation Interface with Tribal Council and Indian community	System definition and design responsibility System assembly, installation and checkout Field system operation, maintenance, system evaluation Computer/ software interfaces

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SIMULATION OF TRAFFIC CONTROL SIGNAL SYSTEMS

Paul J. Connolly, Patricia A. Concannon, Robert C. Ricci

INTRODUCTION

TOPICS is a Federal-aid urban traffic operations program to increase capacity and safety. Authority for the TOPICS program is provided in the Federal-aid Highway Act of 1968. TOPICS consists of making traffic operation improvements over a network of arterial and other major streets in an urban area and is intended to maximize the efficiency of an existing street system.

Under the TOPICS program, the Massachusetts Department of Public Works, in conjunction with the City of Boston, has undertaken an ambitious project in computerized automobile traffic control systems along a traditionally busy length of Massachusetts Avenue in Boston (TOPICS Project No. 51)[1]. This project includes the installation of eighteen local intersection traffic control signals under computerized central control equipment with all its peripherals and software, vehicle detectors to perform functions specified in the system specifications,[1] and an interconnection and communication system.

Through the Intergovernmental Cooperation Act of 1968, technical assistance by the Transportation Systems Center is being provided to the Massachusetts Department of Public Works[2] to evaluate the effectiveness of different automatic traffic control strategies proposed for this Mass. Ave. TOPICS Project by the use of computer simulation. Via the Intergovernmental Act the Federal government is able to implement the concept of technology sharing[3] with State and local governments. The study described in this paper is an example of technological collaboration between the Federal government and state and local governments.

In recent years there has been considerable interest in the development and testing of control strategies for networks of urban traffic signal systems by simulation. Simulation is an inexpensive and timely method for evaluating the effect of these traffic control strategies since traffic phenomena are too complex to be defined by analytical models and since a controlled experiment may be hazardous, expensive, and slow in producing meaningful results. This paper describes the application of an urban traffic corridor program, SCOT[4,5] (Simulation of Corridor Traffic) to evaluate the effectiveness of different traffic control strategies for the Massachusetts Avenue TOPICS Project 51.

The SCOT model is a concatenation of two existing models: 1) the UTCS-1 (Urban Traffic Control System)[6] simulation model of urban traffic and the DAFT[7] (Dynamic Analysis of Freeway Corridor Traffic) simulation model of freeway traffic. Vehicles are treated microscopically as individual elements on the arterial street system and macroscopically as platoons on the freeway. Any arbitrary freeway and surface street network containing up to 200 intersections may be represented, and traffic flow may be described by specifying either origin destination volumes along the peripheral entry links or turning movements at each node. Only the urban traffic portion of the program has been used in this work.

For the urban traffic portion of the program, the traffic flow is composed of the time and distance trajectories of individual vehicles which traverse the network in a realistic manner, changing their speed as they approach a red traffic signal, a queue or an alteration in the geometry of the roadway. Statistics are abstracted from the trajectories and provide a measure of the efficiency of the traffic movement.

The simulation is specific to a particular location and embodies its geometric characteristics (dimensions of the roadways and locations of the intersections), the proposed control strategies (traffic signal schedules, lane channelization, and parking restrictions) and the expected traffic demand (in flow volumes and turning movements). Validated car following laws are used to generate the traffic flow under the existing or proposed conditions. This flow is analyzed, and the results are a measure of the effectiveness of the control strategy to cope with the assumed traffic demand under the given geometric conditions.

A computer printout gives a time history of the length of queues on each street. Thus, the build-up and dispersal of queues as the traffic signal changes is an important parameter of the effectiveness of the signal timings. In addition, time histories of street population, number of vehicles discharged through each street and the number of stops made on each street are given. The results also include the locations and number of cycle failures (the inability of a green signal to discharge the entire queue), the locations and times of spillback (the extension of a queue upstream into the intersection blocking cross traffic) and the turning movements at each intersection. Other performance indices printed out include the average delay per vehicle, the average speed, and the average occupancy.

The Model is programmed in Fortran IV for the CDC 6600 computer with a sample rate of one second for arterial streets and four seconds for the freeway. Core requirements are 98,000 decimal words with a computer efficiency ratio of 5:1 (real-time to computer time) for a network of 30 nodes and 500 vehicles.

Specifically, the following major features are incorporated in the model: 1) a stochastic simulation of individual vehicles by type using a simplified car-following model for arterial streets 2) macroscopic treatment of vehicles as platoons on freeway links according to a pre-specified speed density relationship 3) standard output measures that include link volume, average link speed, average link travel time, total vehicle miles of travel, traffic density, vehicle delay, queue length, and number of stops, 4) detailed treatment of both intersection and intra-link behavior, e.g., queue discharge, turning behavior, and intra-link acceleration and deceleration 5) detailed treatment of bus traffic including bus stop dwell times and bus routes 6) treatment of legal and illegal parking, park garage flows and intra-link rare events and 7) placement of alternative surveillance systems, e.g., presence detectors, counter, or spot speed detectors.

The urban part of the model has been calibrated and validated for a twenty intersection network in Washington, D. C.[6] The validation focused on the comparison of "selected measures of effectiveness" derived from a series of model runs with equivalent field data. The freeway portion of the model is presently being calibrated and validated with the Dallas North-Central Expressway as the test site. This model validation consists of the data collection and simulation of traffic flow on a 1.5 mile section of this expressway from McCommas Ave. to Lover's Lane including the parallel sections of the frontage road and all ramps involved. The data being collected by photographic techniques includes lane specific speed and density for each freeway link (8 or 9 sections of the freeway) 2) on/off ramp volumes and 3) statistical distributions of merge delays as a function of link volume on the freeway link immediately upstream of the merge point for all ramp entrances in the test network.

The study reported here consisted of data collection to obtain field data for input to the model, the analysis and simulation of the present Massachusetts Avenue Traffic Control System for calibration of the SCOT model, and finally the evaluation of traffic responsive and semi-actuated control strategies.

PRESENT TRAFFIC CONTROL SYSTEM

The arterial network selected for TOPICS improvement is centered along Massachusetts Avenue between the Harvard Bridge and the Southeast Expressway in Boston's Back Bay section (Figure 1). The roadway can be characterized in the following manner. There are two lanes of moving traffic in both south/north directions. There is no median nor are there any provisions for left turn or right turn pockets. The block lengths are extremely irregular and in some instances very short. For example, between Commonwealth eastbound and Commonwealth westbound, the block length is 148 ft., and between Huntington eastbound and Huntington westbound, the block legnth is 74 ft. These short blocks allow for a minimum amount of vehicle storage while these vehicles wait for a green phase. If the control sequence is not timed properly. queues build-up causing spillback into the upstream intersection and thereby blocking the cross street from movements.

This section of Massachssetts Avenue has heavy traffic flows that are considered generally predictable. There are no obvious or convenient alternate routes to this main arterial. Congestion results largely from variable left turning movements and long platoon lengths entering the short blocks. This congestion creates spillback which in turn causes the progression along the arterial to breakdown. The resulting congestion and delays are costly not only from the standpoint of reduced level of service and capacity, but because of increased hazardous conflicts and possible collisions.

The length of this section of Massachusetts Avenue is about a mile and a half and includes eighteen signalized intersections presently controlled by an interconnected, coordinated system operated in a pre-timed programmable mode (fixed time control). Pedestrian push-button actuations "call" an exclusive phase at each intersection. If this phase is called by a pedestrian at a particular intersection, then 20 sec. of green time is taken away from the main line (in this case along Mass. Ave.) and given to the exclusive walk for pedestrians. If the downstream intersection controls one of the short blocks and if the pedestrian phase is actuated, additional vehicles will be allowed to penetrate into the short block, when the upstream intersection has no pedestrian actuation. This situation creates spillback, congestion, and the loss of progression along the arterial.

DATA REQUIREMENTS

In order to evaluate a proposed traffic control strategy by means of simulation, it is necessary to model first the existing traffic control system and to make sure that the model's output is in agreement with the "real world". Furthermore, as a prerequisite to model the present system, it is essential to determine the field data requirements for input to the SCOT model. After determination of these requirements, the data available from the files of the City of Boston was reviewed. Field studies were then undertaken to verify this data and to gather additional data not found in the files which was required for input to the model.

The actual data collection and reduction was performed by TAMS (Tippetts-Abbett-McCarthy-Stratton), Mass. DPW's Consultant.[8] Data was collected for a fifteen intersection simulation test network (Figure 1) that encompasses the area from the intersection of Massachusetts Avenue and Beacon Street to the intersection of Mass. Ave. and Washington St. (approx. 1 1/4 miles long). Due to construction on the southern section of Mass. Ave. from Washington St. to the Expressway, data was not gathered for three of the eighteen intersections that make up the Mass. Ave. computerized traffic control system. The following types of field data were gathered for the remaining fifteen intersections: 1) volume counts at each intersection for two hours each between 4 pm and 6 pm, 2) turning movements at each intersection for the same time period, 3) ATR (Automatic Traffic Recorder) counts at one intersection for a period of three months and at three locations for a period of one week, 4) the percent of trucks and busses, 5) average speeds and delay times including incidences of lane blockages by the floating car method covering the time period from 4 pm to 6 pm, 6) queue discharge rates for left turn, through and right turn approaches, 7) volume and turning movement counts for vehicles entering and exiting from sources and sink nodes (e.g., parking garages), 8) bus routing, frequency and stop dwell times, 9) pedestrian counts and signal actuations including the percent of cycles actuated for all intersections and 10) signal phasing, offset and timing at each intersection.

As part of this data collection, the actual operation of each traffic signal was recorded in the field. All phasing intervals were timed, and the particular sequences and offset timings were noted and recorded. Over a period of several months the travel times along Mass. Ave. in the northbound and southbound directions were recorded for the 4 pm to 6 pm peak time periods. All of this data collection and reduction was done manually.

Comparison of this field data with the City of Boston file data showed good agreement except in the area of the actual timing, sequencing, and phasing of the traffic lights. This data showed discrepancies with respect to the timing and sequencing diagrams on file. However, for input to the model, the actual field test data was used rather than the timing and sequencing diagram data since this is the "real world".

SIMULATION OF THE PRESENT TRAFFIC CONTROL SYSTEM

After inputting the data into the model, the first computer simulation run was made with no pedestrian actuations at the fifteen intersections of the test network. The time period simulated was during the peak hour from 5 pm to 5:10 pm. This simulation run resulted in an average travel time of 320 secs. per vehicle as opposed to 500 secs. as measured in the field for southbound traffic (Figure 2). Throughout the study, total travel time through the network was used as the principal model output criteria to make comparative evaluations between successive simulation runs or between simulation results and field test data. Other critical parameters used for evaluation were the number of stops made on each street.

A second simulation run was then made similar to the first but with one exception, the pedestrian phase was actuated at every intersection. The resultant travel time per vehicle for this case was 695 sec., i.e., much higher than the field test data. However, it was immediately apparent that these two simulation cases had bracketed the field test data. A third run was made designating certain intersections as always having the pedestrian phase actuated. This resulted in a travel time of 370 secs., which was a step in the right direction but not close enough to represent the real world.

At this point, it was realized that it was not possible to determine how often the pedestrian phase had been actuated during the floating car field test measurements. Consequently, the model was then modified to allow random activation of the pedestrian phase at each intersection. A fourth run was then made randomly activating the pedestrian phase. The travel time per vehicle derived from this simulation run was 420 seconds. Comparison of this travel time with the actual average travel time measured in the field showed that the simulation results closely approximated the real world field test data to within 15%.

Based on these simulation runs, it was felt that the SCOT model had been calibrated such that the input volumes, turning movements, free flow speeds, queue discharge rates, and lost times were accurate enough to proceed with the evaluation of the new proposed signal controls for Massachusetts Avenue. Figure 2 shows graphically the results of the calibration study for the southbound direction and Figure 3 the northbound direction.

PROPOSED TRAFFIC CONTROL SYSTEMS

The proposed traffic control system for Massachusetts Ave., as outlined in the specification document, is an extremely sophisticated system managed by a digital computer. The traffic engineer in charge of this installation can select either of two basic types of operation, automatic or pre-scheduled. The pre-scheduled control is preselected by the operator for a specific day of the week and in turn for a specific time of the day. The automatic control mode is based on real-time measurement of volume and occupancy and the on-line modification of traffic control strategy. It is this mode of operation that this paper describes. Before describing this automatic mode of operation, it should be noted that the mile and one-half arterial has been sectioned into three subsystems and that each subsystem is capable of operating in a mode different than the other subsystems at any given time. Figure 1 shows the outline of the individual subsystems and the location of the detectors.

At Boston City Hall, a digital computer will be located that will have direct control over each local controller. Volume and occupancy data will be received every 500 milli-seconds from detectors embedded in the roadway. At five minute intervals, this data will be analyzed on a subsystem basis. From this data the mode of operation for each subsystem will then be determined. Each subsystem is capable of working in the following modes of operation:

a) traffic responsive with pre-determined timing
b) semi-actuated coordinated
c) fully-actuated (coordinated and isolated)
d) pre-scheduled and pre-determined timing
e) pedestrian actuation
f) congestion override
g) fire pre-emption
h) bus priority

The Transportation Systems Center's primary role in this project is to evaluate the system performance on a normal day's operation for peak hour traffic conditions. This means simulating control modes a) thru d) as noted in the above paragraph.

The specific mode of operation for the computerized traffic control signal system is selected by measuring the volume and occupancy at specific detectors along the arterial in each subsystem and then entering a table stored in the computer memory that is structured in the following manner: for low volume and occupancy the fully-actuated isolated mode (F.A.) is selected; for medium volumes and occupancy the semi-actuated co-ordinated mode (S.A.) and for high volume and occupancy the traffic responsive mode (TR).

TRAFFIC RESPONSIVE MODE

Simply stated, this mode consists of a number of fixed time, predetermined controls based upon historical data gathered in the past and stored in the computer memory as tables of cycle length, offset, and split plans. The computer can select at each 5 minute interval any one of six different cycle lengths, six different offsets, and six different splits. This means that at any five minute interval, it is possible to select any one of 216 possible controls for each sub-system. Although the simulation model is capable of simulating numerous detectors, some modifications would have been required in order to model the transition from one cycle length, offset, and split plan to another. Rather than modify the model, it was decided to use the existing model and simulate the traffic conditions for five minutes and then to use the computer output results, specifically the "vehicle trips" and the "average saturation percentage" to calculate the required cycle lengths, offsets, and splits for a five minute interval. These computer outputs correspond to the real-time detector outputs for volume and occupancy on each link during a five minute interval (Figure 4).

To determine the appropriate cycle length to be used in a five minute interval, the lane occupancy (average saturation percentage) along Massachusetts Ave. in the North and South direction at critical intersections is measured. The detectors associated with these intersections are located at the extremes of the subsystem as can be seen in Figure 1. By determining the larger of the two values and entering Table 1, the cycle length to be used for the next five minute interval is selected. This corresponds to using the average saturation percentage generated by the simulation at the end of a five minute interval. An offset for each intersection is now calculated so that signal progression along Mass. Ave. is attained. By using the detector outputs from the past five minutes, the computer computes the ratio of volumes (southbound to northbound) and enters Table 2 with this value. The output of this table is an offset plan number which is then used to enter specific tables associated with each intersection to obtain the desired offset. By taking the simulation results for a five minute segment, specifically the "vehicle trips" associated with the critical links and by performing a simple hand calculation and then entering the tables the desired offset plan number is determined. Now that the cycle length and the offset have been determined, the only remaining parameter is the "split", (the distribution of green time at each intersection). The computer determines the split plan in the following manner:

- compares the volumes northbound and southbound along main

street (Mass. Ave.); takes the larger number and calls it X.
- compares the volumes east and west along the side street: takes the larger value and calls it Y.
- computes the ratio of main street/side street; then enters the table for split section and determines the plan number
- enters the table associated with each intersection with this plan number and selects the split.

Once again, using the computer simulation output and performing simple hand calculations, the correct split for each intersection is selected by entering the tables manually.

In summary, the technique developed to simulate the automatic traffic responsive mode is described below. From the calibration effort it is known that the input volumes, turning movements, speed, and queue discharge rates are representative of the real world. Given this input data, the simulation is run for five minutes using the existing control strategy. The critical simulation output parameters of volume and speed are examined. The simple hand calculations previously described are then made, and from the appropriate tables the new cycle length, offset and split are determined. New input cards are key punched, and another simulation is run for five minutes. This procedure is iterated a number of times until an optimum flow of traffic along Massachusetts Ave. for PM conditions is obtained; optimum in the sense of travel time.

The results of these simulations are displayed graphically in Figure 5 as travel time curves along the arterial. As in most traffic responsive systems for PM conditions, the cycle length approached the maximum possible, i.e., 116 secs. The best travel time attained by the traffic responsive mode was 450 sec. as opposed to 500 secs. as measured in the field for southbound traffic. This is a slight improvement but not nearly the magnitude of improvement expected by the City of Boston traffic engineers. At this point, it was obvious that the design engineers would have to re-evaluate the historical data upon which all the tables for cycle lengths, offset and split were based. The simulations also pointed out other poignant facts such as a) a breakdown in cohesive traffic flow between subsystem 2 and subsystem 3 b) longer delays than expected being incurred in subsystem 3 due to more sophisticated phasing such as green leading and lagging signals and c) additional roadway is needed at critical intersections due to heavy left turn movements.

These results were studied jointly with TAMS, the design engineers. The conclusion was that the historical data taken in 1966 upon which all the design tables were based needed to be updated to reflect the current traffic volumes and flow rates. Consideration of the current traffic volumes resulted in an adjustment of the original traffic responsive strategy to a modified one, i.e., the proposed traffic responsive tables were modified. New cycle lengths, splits, and offsets were developed, and it was agreed to join together subsystem two and subsystem three.

The simulation results of this modified traffic responsive mode have been most gratifying in that it has been possible to reduce the travel time along Mass. Ave. by 30% from the previous design as dictated in the TAMS specification document. The cycle lengths simulated were as follows: 1) subsystem SS-1 60 secs. and subsystem SS-2 64 secs., 2) subsystem SS-1 80 secs. and subsystem SS-2 92 secs., 3) subsystem SS-1 100 secs. and subsystem SS-2 112 secs. With each of these cyle lengths the phasing for certain intersections was varied, i.e., 2 phase, northbound lead and back to back left turn operations. For each of these situations travel times and the number of cycle failures for main and side streets have been plotted. Illustrative of the results obtained is a travel time of 320 secs, with two phase operation for a cycle length of 80 secs. for subsystem SS-1 and 92 secs. for subsystem SS-2, compared to a travel time of 500 secs. as measured in the field (Figure 6). The variation in results when using 30/92 sec. cycles or the 100/112 cycle lengths and the various phasing operation is minimal as can be seen from Figures 6 and 7.

SEMI-ACTUATED CO-ORDINATED CONTROL

In this mode of operation long loop detectors are embedded on the side streets to determine the presence of a vehicle. The main line (Mass. Ave.) is given a minimum green phase time. At the end of this time the controller enters what is called a "permissive period". It is during this permissive period that the controller will honor all side street actuations. Once the green has shifted to the side street it will remain in that state until: 1) there are no more vehicles in the loop or 2) the co-ordination point has been reached (force off point). Even if vehicles are present on the side street when the force off point is reached, control must return to the main line (Mass. Ave.) in order to preserve the established progression along the arterial. This is truly a real time, demand responsive control system as compared to a traffic responsive table look up control system based on historical data.

Figure 8 shows the results that have been obtained using this mode of operation with a background cycle length of 80 sec. for SS-1 and 92 sec. for SS-2. The travel time in the northbound direction is 320 secs. while the travel time in the southbound direction is 290 secs. These are the best results that have been obtained thus far in our simulation experiments. There are a few more side street cycle failures as one might expect than in the traffic responsive mode, but it is hoped that these will be eliminated in the near future. Eight cycle failures for 15 intersections in 480 secs. of simulation time is very good considering the operation is during pm peak conditions. Even background cycle lengths of 60 secs and 72 secs. in the semi-actuated mode provide for better movement of traffic along the arterial than does the traffic responsive mode operating at cycle lengths of 100 secs. and 112 secs.

HYBRID MODE

At the present time, a hybrid mode of operation is being studied wherein some intersections are fully-actuated while others are semi-actuated, all intersections being co-ordinated. The intersections to be fully-actuated are those critical intersections which generally carry heavy main street volumes and their associated side street also carries a heavy volume. The fully-actuated intersection shall operate on a first-come first-served basis and will yield to the next phase when (1) no more vehicles are present (2) time has reached a maximum and (3) a force off point has been reached. It is hoped that any minimum green time which is associated in the semi-actuated mode and which would not have been utilized because of lack of vehicles can now be shifted to the side streets in the fully-automoted mode.

RECOMMENDATIONS

The simulation has established the following design features that have been presented to the Mass. DPW and the City of Boston traffic officials:

1) PM peak traffic conditions should be handled with the semi-actuated mode of operation as opposed to the traffic responsive mode as suggested in the design engineering specification.

2) Rather than 3 subsystems (each operating independently) which the initial designs specified, the simulation has shown that it is more efficient to operate only 2 subsystems.

3) The new cycle lengths, splits, and offsets developed as a result of the simulation should replace those presently being contemplated for the traffic responsive mode.

4) There must be absolutely no parking permitted on the stretch of Mass. Ave. between Marlborough St. and Beacon St. in the northbound direction. If this is not done, subsystem 1 will breakdown.

5) There must be absolutely no parking allowed for at least 200 ft. prior to the Columbus Ave. intersection heading in the southbound direction along Mass. Ave. because of left turn movements.

6) The TAMS specification document specifies that there shall be no parking along the length of Mass. Ave. between the hours of 4 and 6 pm. If no parking were permitted along Mass. Ave., three ten foot lanes in each direction would be created as opposed to two twelve ft. lanes with parking. The resulting simulation runs with no parking showed that the travel time curves were no better and in some cases worse than those with parking. This is due to the geometry between Huntington Ave. and St. Botolph which makes it impossible to have more than two lanes. As a result, a traffic squeeze takes place at this spot.

SUMMARY

The simulation process described in this paper is site independent and therefore applicable to the modelling of traffic control signal systems in other cities. However, a data collection and reduction effort as previously described is necessary in order to calibrate the model and to make sure that the model's output is in agreement with the real world for those intersections being modelled. Also, the specific site, geometric characteristics, and proposed control strategies are needed. This study has demonstrated that simulation is an inexpensive and timely method for evaluating the effect of different traffic control strategies in the place of expensive and slow, "live" experimentation. In addition, via this simulation it has been possible to identify the turn-on strategy that will be used initially when the system is first put into use. In this way, a possible hazardous traffic situation will have been avoided.

ACKNOWLEDGEMENT

The authors are indebted to Jeremiah Murphy and Michael Karas of the Massachusetts Dept. of Public Works for their advice and encouragement throughout the project, to Robert Drummond and his staff of the City of Boston Traffic and Parking Deparment for their cooperation in the study and to George Casper, H. Leuthardt, and G. Sultan of TAMS, the designers of the Mass. Ave. computerized traffic control system.

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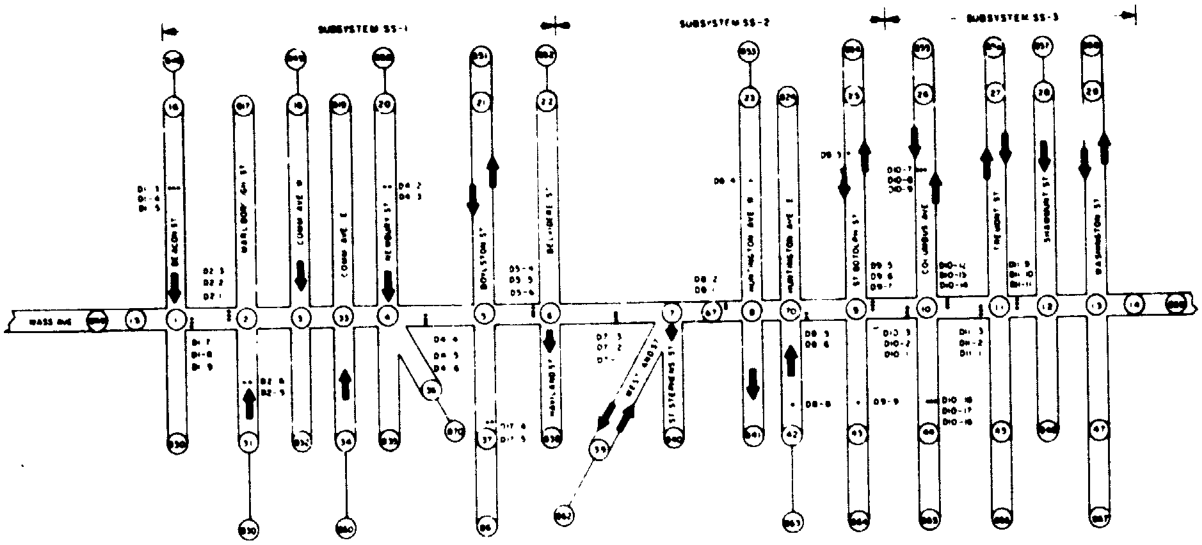

• DETECTOR LOCATION

FIGURE 1. MASSACHUSETTS AVENUE NETWORK

TABLE 1. CYCLE LENGTH SELECTION PLAN[1]

MODE OF OPERATION: TRAFFIC RESPONSIVE				
PARAMETER: LANE OCCUPANCY				
THRESHOLD LOWER %		UPPER %	CYCLE NO.	CYCLE LENGTH (SECS.)
1	-	10	1	60
7	-	14	2	74
11	-	18	3	84
16	-	20	4	94
19	-	30	5	110
26	-	100	6	120

TABLE 2. OFFSET SELECTION PLAN[1]

% OCCUPANCY	RATIO OF VOLUMES PER LANE VOL. S. BD/VOL. N. BD LOWER	UPPER	MAXIMUM VOLUME PER LANE, PER HOUR LOWER	UPPER	OFFSET PATTERN	OFFSET NUMBER
35	0.05	0.65	1	200	NORTHBOUND LIGHT	1
35	0.05	0.65	170	800	NORTHBOUND HEAVY	2
	0.60	1.66	1	200	BALANCED LIGHT	3
	0.60	1.66	170	800	BALANCED HEAVY	4
35	1.54	20.00	1	200	SOUTHBOUND LIGHT	5
35	1.54	20.00	170	800	SOUTHBOUND HEAVY	6

IF RATIO OF VOLUMES IS LESS THAN .05 AND OCCUPANCY IS MORE THAN 35%, GO TO SOUTHBOUND HEAVY

IF RATIO OF VOLUMES IS MORE THAN 20 AND OCCUPANCY IS MORE THAN 35%, GO TO NORTHBOUND HEAVY

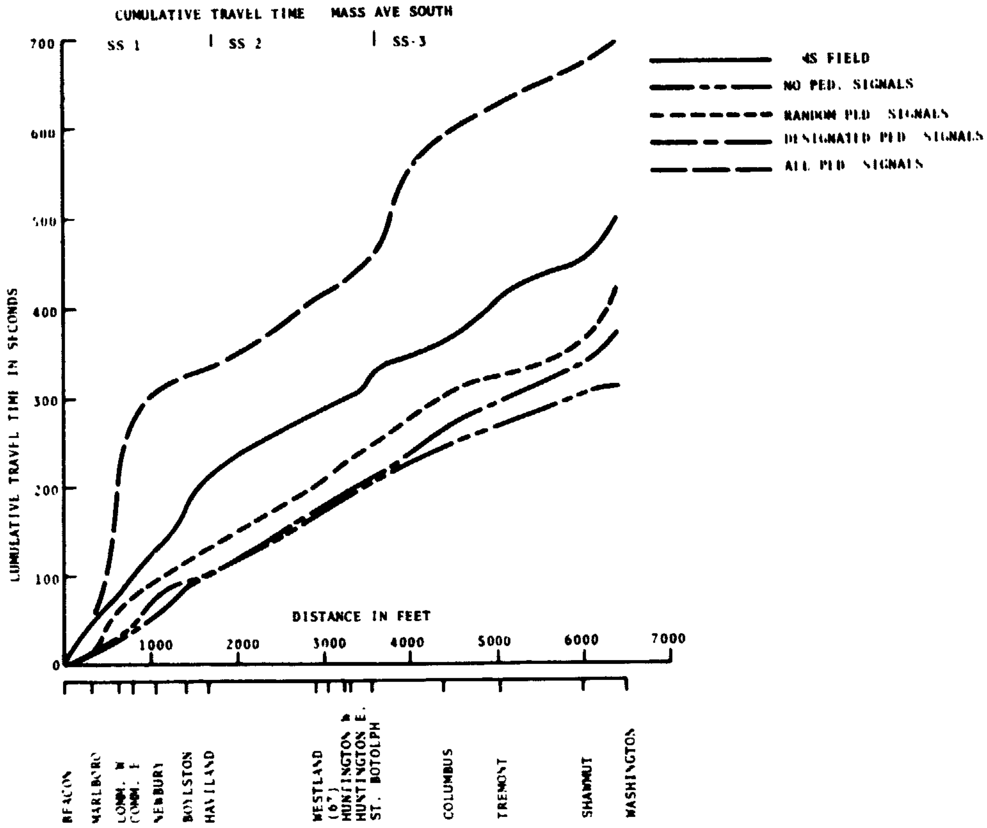

FIGURE 2. SOUTHBOUND CALIBRATION RESULTS

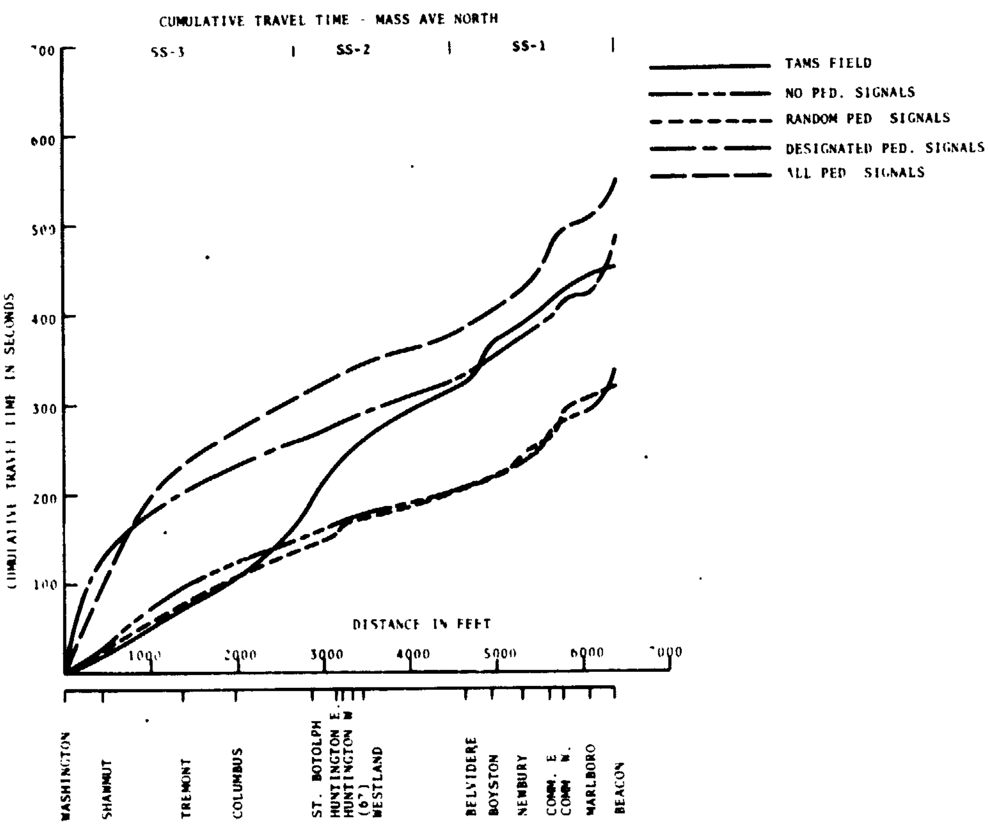

FIGURE 3. NORTHBOUND CALIBRATION RESULTS

CUMULATIVE STATISTICS SINCE BEGINNING OF SIMULATION

PRESENT TIME IS 17 5 0. ELAPSED SIMULATED TIME IS 5 MINUTES. 0 SECONDS

LINK STATISTICS

LINK	VEH-MILES	VEH TR.	MOV. TIME V-MIN	DELAY TIME V-MIN	M/T	TOTAL TIME V-MIN	T-TIME / VEH. SEC	T-TIME/ VEH-MILE SEC/MILE	D-TIME / VEH SEC	D-TIME/ VEH-MILE SEC/MILE	PCT STOP DELAY	AVG SPEED MPH	AVG. OCC.	STOPS /VEH	AVG SAT PCT	CYCL FAIL
(70, 9)	3.6	77	7.5	15.1	.33	22.5	17.6	379.8	11.7	253.9	54	9.5	4.4	.42	10	0
(9, 10)	11.9	76	23.8	73.7	.24	97.5	77.0	491.7	58.2	371.7	88	7.3	19.5	.88	24	3
(10, 11)	8.9	74	17.9	15.9	.53	33.8	27.4	228.6	12.9	107.6	73	15.7	6.8	.30	11	0
(11, 12)	16.6	91	31.6	37.1	.46	68.7	45.3	248.7	24.5	134.4	67	14.5	13.7	.85	15	0
(12, 13)	6.7	88	13.4	8.2	.62	21.6	14.7	194.5	5.6	73.4	36	18.5	4.3	.23	10	0
(13, 14)	3.0	81	6.1	1.6	.79	7.7	5.7	152.1	1.2	31.9	0	23.7	1.5	0.00	10	0
(14, 13)	3.3	87	6.5	25.2	.20	31.6	21.8	575.0	17.3	457.9	76	6.3	6.2	.52	31	0
(13, 12)	8.1	95	16.4	17.4	.49	33.8	21.4	250.0	11.0	129.0	70	14.4	6.7	.29	15	0
(12, 11)	13.1	76	31.1	49.9	.38	80.9	63.9	372.0	39.4	229.2	80	9.7	16.2	.96	17	1
(11, 10)	9.3	80	19.4	14.9	.56	34.3	25.7	221.4	11.2	96.4	70	16.3	6.8	.25	11	0
(10, 9)	14.3	87	30.9	31.1	.50	62.0	42.8	259.6	21.4	130.1	74	13.9	12.4	.62	15	0
(9, 70)	4.1	76	8.6	2.7	.76	11.3	8.9	167.1	2.2	40.4	8	21.5	2.3	.03	9	0
(25, 9)	.5	9	1.7	24.7	.06	26.4	176.1	3099.2	164.8	2899.9	96	1.2	5.3	1.56	35	3
(9, 25)	.7	12	1.7	1.0	.62	2.6	13.2	241.1	5.0	90.6	40	14.9	.5	.42	4	0
(43, 9)	.5	8	1.2	50.9	.02	52.1	391.1	6883.8	382.1	6725.0	99	.5	10.4	1.38	69	3
(9, 43)	.8	15	2.0	.7	.74	2.7	10.9	198.4	2.9	52.2	7	18.1	.5	.13	4	0
(26, 10)	3.0	53	6.6	33.3	.16	39.8	45.1	793.5	37.7	663.0	88	4.5	7.9	.77	26	0
(10, 26)	2.6	46	6.3	1.6	.79	8.0	10.4	183.6	2.1	37.9	13	19.6	1.6	.09	6	0
(27, 11)	3.4	59	7.2	40.5	.15	47.7	48.6	854.5	41.2	725.1	89	4.2	9.5	.76	32	1
(11, 27)	2.1	38	5.4	1.5	.78	7.0	11.0	194.2	2.4	42.9	1	18.5	1.4	.03	6	0
(44, 10)	3.2	57	7.4	40.1	.16	47.5	50.0	879.5	42.2	742.1	89	4.1	9.4	.79	31	0
(10, 44)	3.1	56	7.8	1.8	.82	9.5	10.2	194.1	1.9	33.9	3	19.6	2.0	.05	8	0
(11, 45)	2.8	49	7.1	2.1	.78	9.2	11.2	197.8	2.5	44.5	6	18.2	1.8	.06	7	0
(45, 11)	2.3	41	6.0	90.5	.06	96.5	141.2	2485.9	132.4	2330.2	97	1.4	19.2	1.29	64	2
(28, 12)	3.0	53	8.3	36.4	.19	44.8	50.7	892.3	41.3	726.0	87	4.0	8.9	.94	30	0
(13, 29)	2.8	50	6.7	1.4	.83	8.1	9.7	172.2	1.7	29.4	2	20.9	1.6	.04	6	0
(29, 13)	1.8	31	5.1	19.1	.21	24.2	46.8	823.3	36.9	649.7	84	4.4	4.8	.84	16	0
(13, 47)	2.0	35	4.3	1.1	.80	5.4	9.3	166.4	1.9	33.8	17	21.6	1.1	.09	4	0
(47, 13)	2.7	47	7.0	34.8	.17	41.7	53.3	937.8	44.4	781.6	88	3.8	8.3	.94	28	0

NETWORK STATISTICS

VEHICLE-MILES= 140.01 VEHICLE-MINUTES= 979.3 VEHICLE-TRIPS (EST.)= 523 STOPS/VEHICLE= 1.51

MOVING/TOTAL TRIP TIME= .311 AVG. SPEED (MPH)= 8.58 MEAN OCCUPANCY= 195.1 VEH. AVG DELAY/VEHICLE= 77.35 SEC

TOTAL DELAY= 674.3 MIN. DELAY/VEH-MILE= 4.82 MIN/V-MILE TRAVEL TIME/VEH-MILE= 6.99 MIN/V-MILE

STOPPED DELAY AS A PERCENTAGE OF TOTAL DELAY=82.9

SEED FOR RANDOM NUMBER GENERATOR IS 54152149

FIGURE 4. SIMULATION OUTPUT

ORIGINAL PAGE IS OF POOR QUALITY

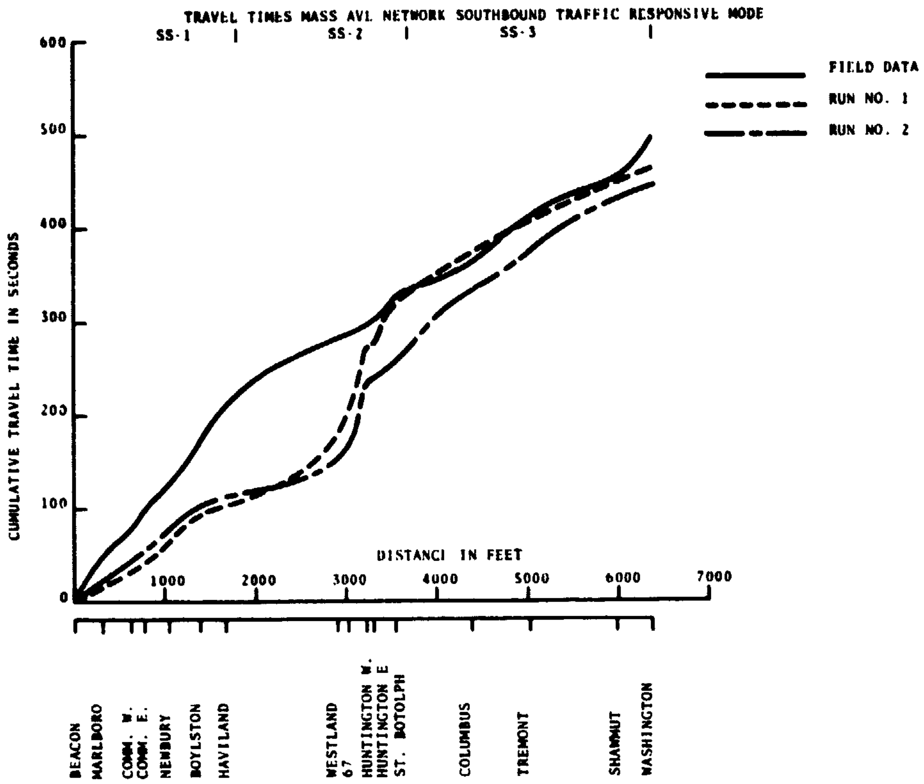

FIGURE 5. TRAFFIC RESPONSIVE RESULTS

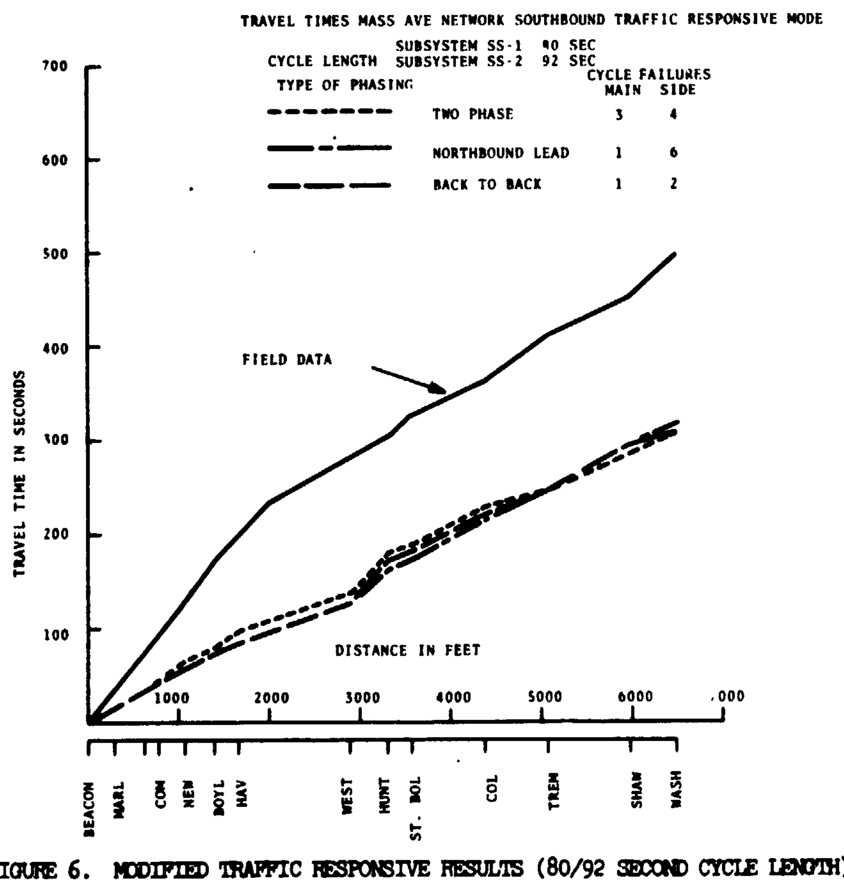

FIGURE 6. MODIFIED TRAFFIC RESPONSIVE RESULTS (80/92 SECOND CYCLE LENGTH)

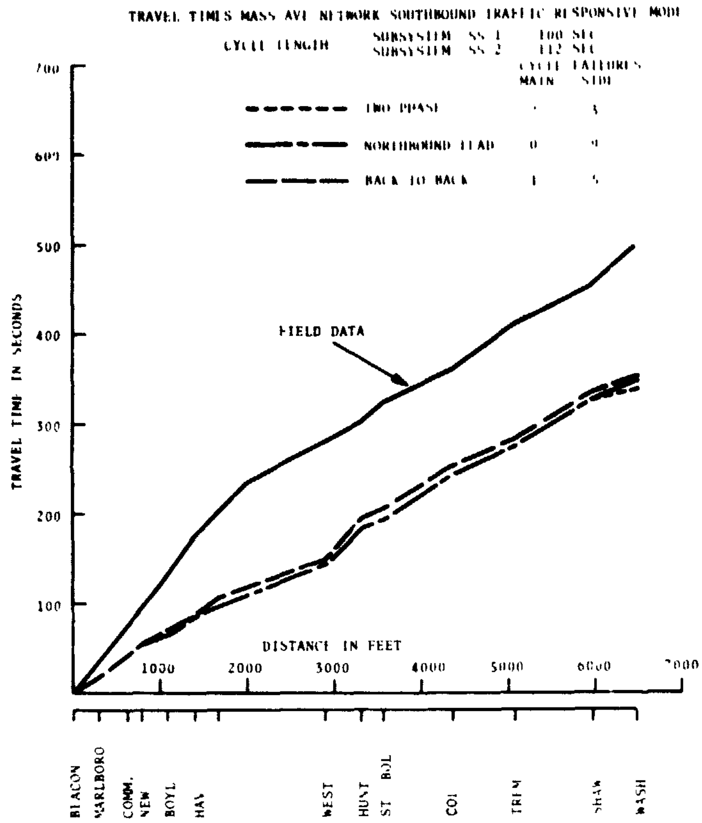

FIGURE 7. MODIFIED TRAFFIC RESPONSIVE RESULTS (100/112 SECOND CYCLE LENGTH)

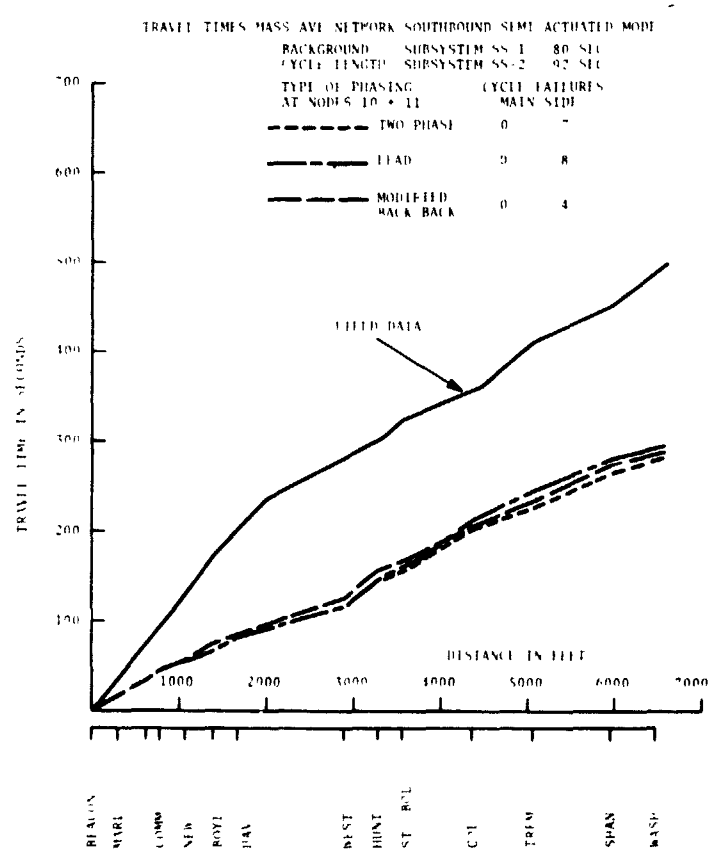

FIGURE 8. SEMI-ACTUATED RESULTS

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N75 17220

FLAIR-FLEET LOCATION AND INFORMATION REPORTING

Earl R. Norman and Merle E. Dunlap

INTRODUCTION

An early successful and seemingly unrelated technology transfer set the stage for the FLAIR program. To support its aerospace technology, The Boeing Company had built up huge computer related resources: hardware, software, management capability and the people who could analyze and program all types of problems from payrolls to complex war games to simulation of moon landings. With mushrooming requirements for computer solutions springing up over all sectors of the economy, in mid-1970 Boeing set up a wholly owned subsidiary, Boeing Computer Services, Inc. (BCS), to try to match these large resources to the requirements of all types of commercial customers.

The Wichita Police Department was an early client of BCS and from this propitious association came the following challenge: "We would like to see Boeing apply its technology to help us accurately know the location of all our patrol cruisers at all times." In early 1971, Lt. Col. Kenneth Duckworth of the Wichita Police Department was referred by Boeing Computer Services to the Avionics Staff of the Boeing Wichita Engineering Department to further quantify this long standing operational requirement. It was envisioned then that a solution for the Wichita Police would also be useful throughout the rest of the law enforcement community. This has since proved to be exactly what has transpired, and cities from literally all over the world have requested Boeing FLAIR proposals.

Although FLAIR didn't fit in any traditional Division charter, top management at Boeing Wichita was willing to back what appeared to be a business opportunity based on a valid customer requirement, where the experience and resources of the Division also appeared to be a good match. As continuing technical and marketing research substantiated the initial limited go-ahead, increasing Boeing Internal Research and Development (IR&D) funds were committed over the next three years. This, along with a small, dedicated cost-conscious business and engineering team, has made FLAIR possible.

DEVELOPMENT APPROACH

After conferring with Col. Duckworth, the whole spectrum of aerospace navigation, communication and data processing techniques were considered as candidates to solve the Wichita Police Department requirement. While it was easy to postulate many approaches, mechanization costs that could be justified against a moon mission would look ridiculous in a city budget, and the 50 foot accuracy that Col. Duckworth specified for some police missions appeared difficult to achieve at any cost.

One of the aerospace navigation approaches considered is called "dead-reckoning." This concept is based on the fundamental principle that if the original location of a vehicle is known, its location at any future time can be determined if the distance traveled along a given heading is added to its original location. While this concept is very complex to mechanize for a space vehicle moving in three dimensions, away from a rotating and translating earth, it can be accomplished using only the automobile's odometer and a compass as sensors when driving across town. However, because of inaccuracies in the compass and the odometer and computation, uncertainties in location build up with time or distance traveled until the navigation prediction soon becomes useless.

Before discarding dead-reckoning as unsuitable, Boeing decided to evaluate the concept for this application to see just what its limitations were. With a small car compass purchased locally, Mr. Richard Lewis, Boeing Specialist Engineer, drove over Wichita streets recording headings each time the odometer indicated that one-tenth of a mile had been traveled. He then plotted his travels, starting from his known location. The solid line in Figure 1-a shows his path as derived from this crude dead-reckoning process, with the errors described above accounting for the increasing divergence. However, in looking at this plot it became obvious that another valid source of information was available to the automobile mechanization that was not available to the space craft -- that cars don't have the freedom to move without constraint through yards and buildings but normally drive only on surfaces that can be known *a priori*. Further, these roads are usually arranged in such a pattern that if you are able to keep a somewhat current assessment of the auto's position, it is usually logical which road the auto is on. Combining this additional information with the recorded data, Dick was able to reconstruct the exact path of the vehicle as shown by Figure 1-b. The question then became: "If a man can supplement a dead-reckoning procedure by comparing the continual navigation prediction with a map and making a logical update when appropriate, can a computer do the same thing?"

The next experimental phase involved use of small home entertainment type cassette and reel-to-reel tape recorders to collect data which had by then been processed into a tone coded pulse stream, and sampled at approximately one second intervals rather than once each tenth of a mile. These tapes were played into a decoder in the laboratory and activated a plotter on which the true map sector was placed. Concurrently, work was started on computer algorithms to handle the dead-reckoning and map-matching computation.

Results were quite encouraging so planning for establishment of an experimental radio data link between a vehicle and the laboratory was accelerated. The team established a good working relationship with the Federal Communications Commission early in the program in order to assure two-way confidence in negotiations for the all-essential license authorizing a radio data link for tests. On March 13, 1972, the FCC authorized Boeing to operate UHF station KQ2XPI and mobiles KQ2XPJ during experiments with various modulation methods and with several bandwidth limiting schemes.

With a communication system required to provide the car's location and status back at police headquarters, it was an easy decision to centralize all computations as well. In addition to coded messages, each car supplies the heading and distance traveled since the last update on a time-multiplexed basis. Clocks in all vehicles are synchronized every two seconds by a signal from the base station. A central mini-computer performs the dead-reckoning and map matching described earlier and processes the information for display. This system concept is illustrated by Figure 2.

Each automobile's spatial location was initially computed in X-Y coordinates and displayed in the correct relative position on a cathode-ray tube as a bright dot. This image was optically combined with a map of the city or area streets being traversed and viewed with a standard industrial closed circuit television camera. A composite signal resulted and was viewable on one or more standard television monitors and storable on a standard video recorder. While this mechanization gave a good dispatcher presentation, it was expensive and unreliable.

The analogue television was replaced in 1973 with a completely digitally generated display and the black and white display screen was replaced with a color television monitor. A Sony Trinitron is now used and accepts the various timing and coded signals which produce the image of the map of the city streets in BLUE color, the operator-controlled-cursor cross in RED, a GREEN indicator of orientation/magnification, and a system area coverage outline in VIOLET. The moving symbols representing tracked cars are in ORANGE, as well as a computer-generated officer STATUS tabulation along the left side of the screen which is GREEN. This video display and the corresponding controls are shown in Figure 3.

Digital transmission of coded messages from the police cars to the Command and Control Center significantly reduces voice communication congestion. This was a design feature from the outset. Coded message transmissions are initiated by use of a keyboard in the police car which also features an emergency button. When an officer depresses the emergency button an audible alarm sounds in the Command and Control Center and the officer's symbol flashes rapidly. This positive, instantaneous communication plus the location features of the FLAIR system gives the dispatcher the capability to send help immediately. The total data word contains location and message information and is transmitted in one-hundredth of a second. The coded message unit, as well as other vehicle equipment, is shown in Figure 4.

An additional FLAIR feature that is deemed valuable by most potential users and one which is offered as an option is that of PLAYBACK. This is accomplished by recording the digital data at the interface of the radio receiver's output and computer's video processor input. The tape can then be played into the computer at any later time at the usual speed or at higher speeds. Many police officials have viewed the playback at ten times and at fifty times regular speed. At the latter speed an entire eight hour police watch activity can be reviewed in a few minutes. This offers a valuable training feature.

The FLAIR system, as now produced, automatically updates each vehicle's location and corresponding officer's status once each two seconds and presents this information to police dispatchers in the Command and Control Center. The position of all vehicles "available for assignment" is displayed on a color video map at each dispatcher's console to an accuracy of 50 feet. This gives the dispatcher a continuous picture of the deployment of the total available force and thus complete command and control of all police under his responsibility.

By utilizing long range radio communications equipment, FLAIR can be extended to cover state-wide police operations. Other applications of FLAIR include local, state and interstate commercial vehicles such as trucks, and military ground vehicles where precise location, tracking and tactical status information is needed.

FLAIR PROGRAM HISTORY

FLAIR development began as a Boeing funded program in February 1971. Researchers from four other firms conducted tests of automatic vehicle locating systems in 1972 in Philadelphia under contract to the U. S. Department of Transportation. Several other projects are known to have been initiated in the past six years.

Messrs. A. J. Henson and R. L. Lewis were granted U. S. patent number 3789198 covering FLAIR on January 4, 1974, assigned to The Boeing Company. Mr. Henson is FLAIR Program Manager and Mr. Lewis is a principal FLAIR research engineer.

On March 28, 1973, the St. Louis Metropolitan Police Board allocated $90,000 to implement the start of a program to procure an Automatic Vehicle Monitoring system, the major portion of which would be funded by a grant from the Justice Department's Law Enforcement Assistance Administration's (LEAA) regional allocation.

On October 22, 1973, The Boeing Company was the successful bidder in the St. Louis AVM competition. Fifteen firms had been invited to bid by the city's purchasing department. Boeing was placed under contract on November 7, 1973, to produce and deliver a twenty-five vehicle FLAIR system.

All of the mobile sets were delivered to St. Louis Police on July 16, 1974. All remaining subsets of the system equipment were delivered on August 1, 1974, a month ahead of schedule. St. Louis accepted the system on August 14, 1974. Boeing will support the St. Louis Police system test and evaluation through October of

1974 and Public Systems Evaluation, Inc., of Winthrop, Massachusetts, will monitor system effectiveness for LEAA by contract.

In June of 1974, Boeing, under contract to the London Metropolitan Police, conducted a highly successful tracking test of basic FLAIR equipment in the city of London, sending recorded data back to Wichita by DATEL telephone circuits.

Staff officers and beat patrolmen of both the Wichita Police Department and the St. Louis Metropolitan Police Department were of great assistance to Boeing during FLAIR design and during prototype testing and contributed their professional opinions so that the new system would include those capabilities most useful in law enforcement work.

NO UPDATE

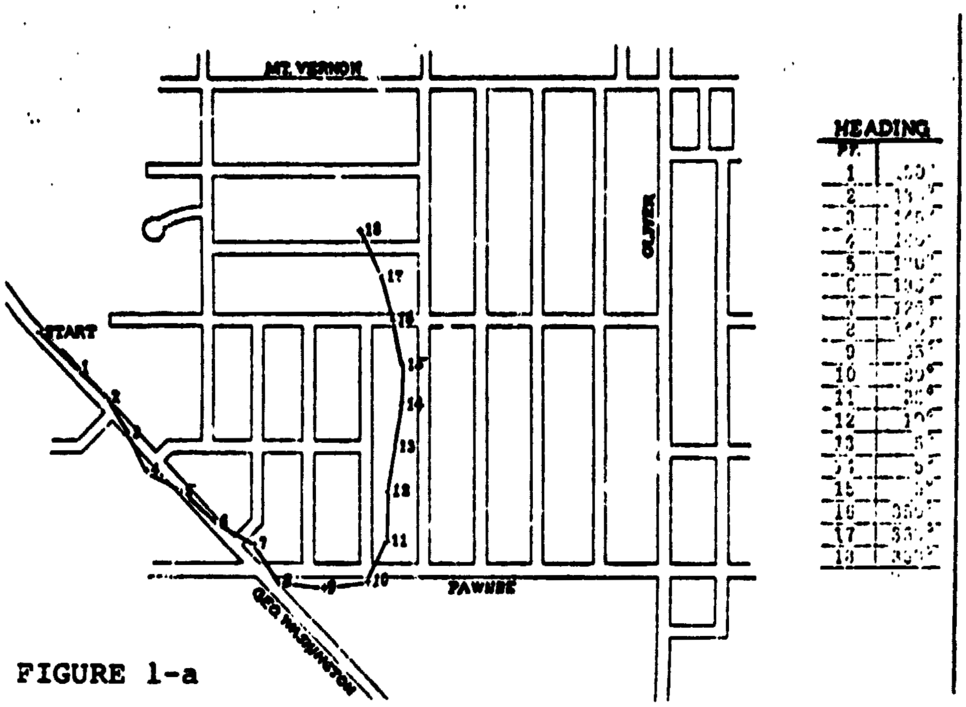

FIGURE 1-a

WITH UPDATE

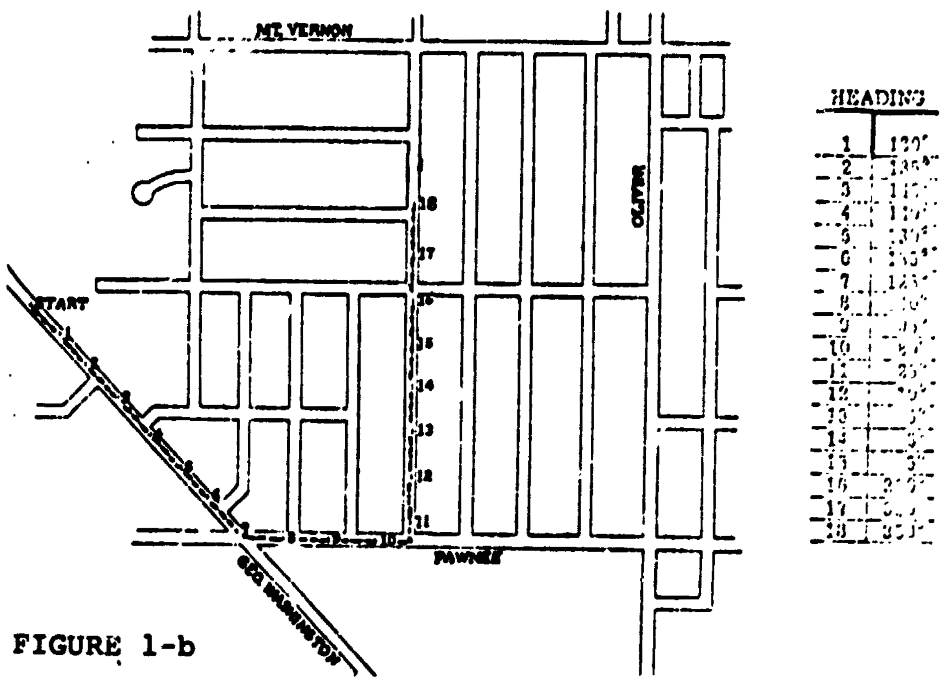

FIGURE 1-b

FIGURE 1 - INITIAL FLAIR DEAD-RECKONING UPDATE EXPERIMENT

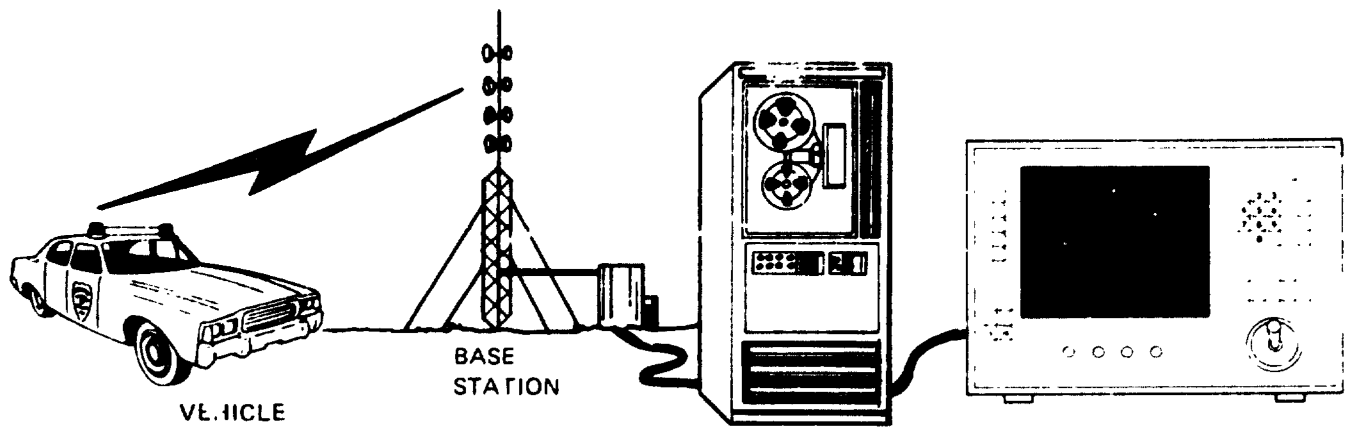

FIGURE 2—SYSTEM CONCEPT

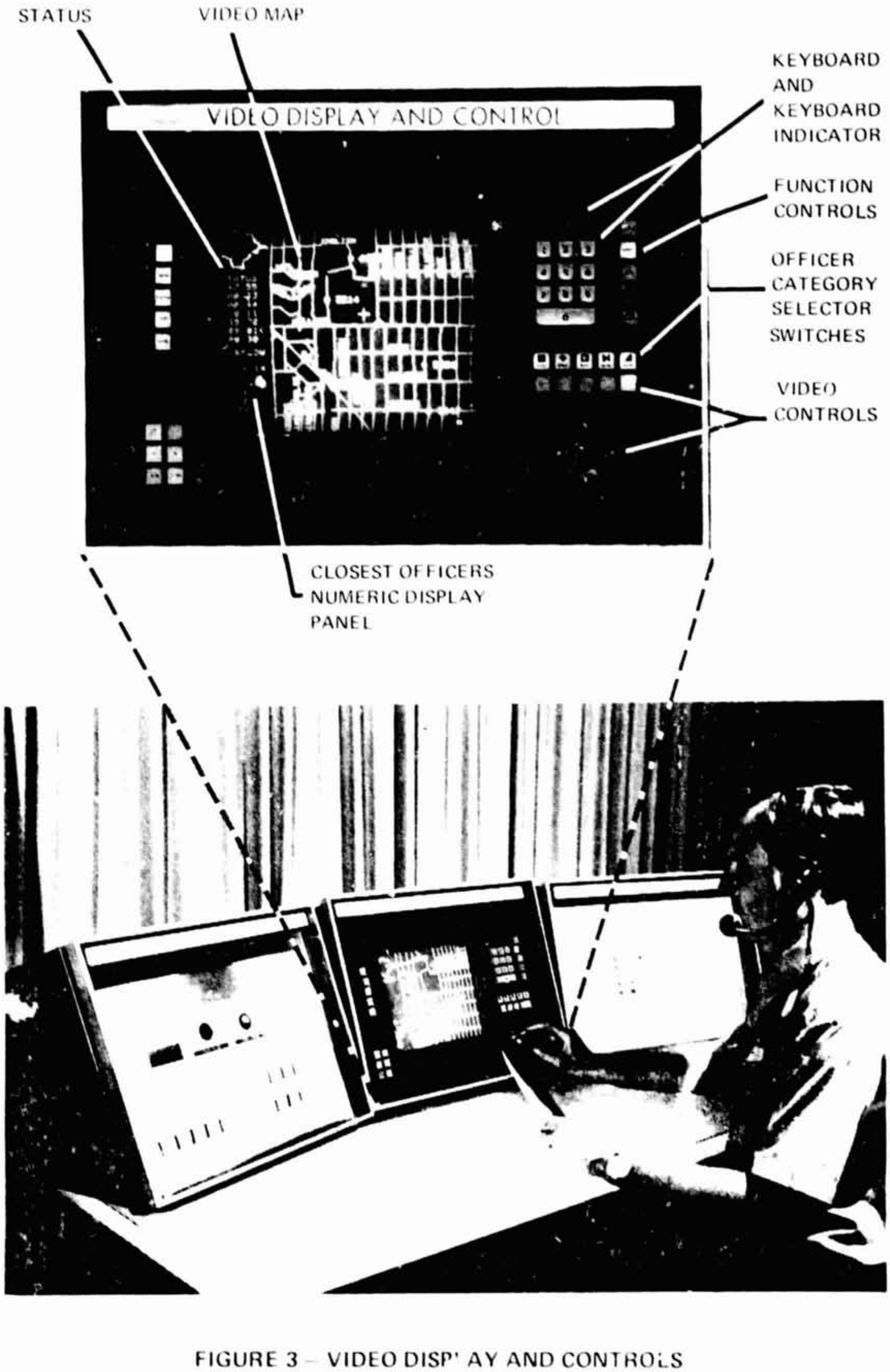

FIGURE 3 – VIDEO DISPLAY AND CONTROLS

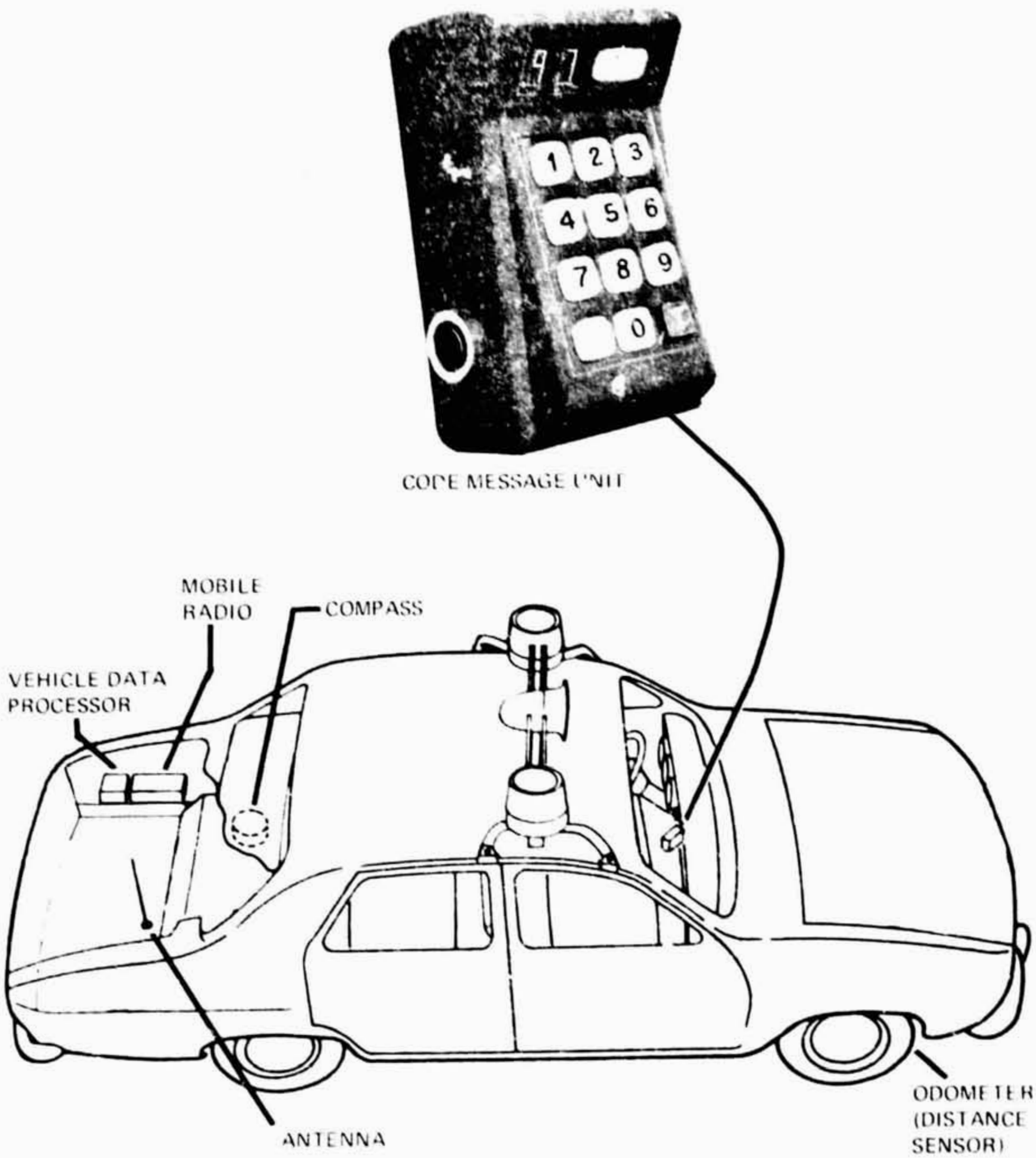

FIGURE 4— VEHICLE EQUIPMENT

N75 17221

DYNAMICS COMPUTATION METHODOLOGY APPLIED TO RAILCAR VIBRATIONS

Robert R. Vlaminck

INTRODUCTION

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Historically, the analysis of railcar dynamics has been limited in scope because of the complexity and time-consuming nature of the calculations required to solve multi-degree of freedom systems. Large numbers of simultaneous equations may be necessary to accurately and completely describe the ride quality, equalization or dynamic loading of a car body or truck. For example, the dynamic and static analysis of a complete car body structure can best be made using a finite element model which may have as many as 3000 degrees of freedom and perhaps an equal number of structural elements. The degree of complexity required to obtain a total systems analysis of a rail car can be appreciated by comparing the artist's concept of the Boeing CTA rapid transit rail car (Figure 1) to the dynamics engineer's perception of the same vehicle.

At the time the major bulk of the intra-urban and inter-city vehicles in use today were analyzed and constructed, a total systems solution of a complex problem of this type was not possible. The high-speed electronic computer and associated programs that have been developed over the past decade can now permit a total system approach and provide solutions to these railcar dynamic and static problems on a timely basis permitting analysis to guide a vehicle design. The relationship of vehicle parameters and subsystems and their effect on ride quality, for example, can be seen in Figure 2.

It is the intent of this paper to illustrate how computer analyses can be applied to railcar problems. Although some analytical data is presented, emphasis is placed on showing examples of analyses that were developed to solve engineering problems rather than emphasizing detailed and specific results of computations.

APPLIED COMPUTER PROGRAMS

Computer programs that were previously developed to analyze aircraft structures and dynamics problems now utilized to analyze the models described in the subsequent paragraphs include:

- IBM Continuous System Modeling Program (CSMP): This IBM developed program (1) uses digital integration techniques to obtain time history solutions of simultaneous differential equations.

- NASTRAN: The NASTRAN finite element analysis program (2) was developed by NASA to solve large dynamic and static structural problems.

- Language for Structural Dynamics (LSD): This program (3) developed by Boeing derives the equations of motion of a system from the potential, kinetic and dissipation energy equations using LaGrange's technique.

- WATFOR: A system used at Boeing Vertol which permits the engineer to prepare a Fortran program for solution of a specific problem. Execution time on the IBM 360 can be obtained approximately five times daily for checkout and computation purposes.

DISCUSSION OF ANALYTICAL MODELS

The analytical models discussed present typical examples of analyses performed to optimize vehicle parameters and solve specific engineering problems. Subjects investigated include:

- Car body structural dynamics
- Vehicle dynamic motions and loads
- Truck equalization

SLRV Car Body Structure Model

In the design stages of a vehicle the assessment of the dynamic characteristics of the car body structure is necessary to avoid undesirable vibration under actual operating conditions. Historically, calculations of the natural frequencies and mode shapes of the car body were performed by representing the structure as a uniform beam or a series of beam elements. This may be a very misleading approach since railcar structures are far from being uniform beams due to their many cutouts for doors and windows. Even attempts to represent such a complex structure by a series of beam elements with shear and bending stiffness properties is unlikely to yield correct results. Effects of local structure such as floor beams, side sills, and attachments of heavy components demand representation of three-dimensional effects such as section breathing, bulging or lateral parallelograming.

A detailed finite element structural representation of the car body provides a method for accounting for actual details of the structure, including effects of cutouts for doors and windows. It consists of a three-dimensional grid work of node points and coordinates. The node point locations and properties of connecting structural members are specified. Mass data for the vehicle may be distributed (lumped at the node points. The computer program uses these data to form mass and stiffness matrices and finally computes natural modes and frequencies from the free vibration equations of motion:

$$[M]\,[\ddot{X}] + [K]\,[X] = 0$$

The NASTRAN finite element program was used for car body dynamic analysis of the SLRV articulated tram being manufactured for the Massachusetts Bay Transportation Authority and San Francisco Municipal Railway. This same structural model was also used to calculate stresses and deflection under static loading.

The primary objectives of the dynamic analysis of the car body structure were:

a. Detune car body structure to insure minimal flexible car body vibration. The primary sources of excitation in the operating speed range which were avoided by detuning the car body structure are shown in Figure 3.

b. Optimize any structural changes required to achieve placement of the car body natural modes above a 12 Hz objective with minimum weight penalty. This insures that these modes will not cause amplification of the vibration in the important frequency range of 4 Hz to 7 Hz where human sensitivity is greatest.

Since the car body is suspended at low frequencies the structural natural frequencies can be considered decoupled from the rigid body suspension frequencies. This allows the car body to be an analyzed as a "free-free" structure with, of course, deletion of the zero frequency rigid body natural frequencies.

Early in the design of the SLRV, calculations using this finite element type of model indicated that the first vertical bending frequency, the primary source of car body flexible vibration, was only 8 Hz with the structural members sized on static load considerations. This meant that the frequency of the first harmonic of wheel rotation, a major source of excitation, would coincide with this natural frequency in the operating speed range resulting in high vibration throughout the car. To eliminate this problem several structural modifications were evaluated to raise the first vertical bending frequency above 12.0 Hz. The lightest and simplest design which met the 12.0 Hz frequency objective involved making a truss arrangement at the rear of the longitudinal equipment enclosure compartments mounted on both sides of the car underframe. This arrangement provided two longitudinal beams approximately 24 inches deep running almost from the forward bolster to the articulation bolster. The SLRV NASTRAN structural model, shown in Figure 4, consisted of 140 nodes, 350 structural elements and 846 degrees of freedom. Computer execution time on the IBM System 360 was 25 minutes for each structural configuration analyzed at a cost of approximately $750.00.

The car body detuning study was performed in approximately six weeks and the results available in time to impact the car body structure design. On the basis of these results, structural changes were made which will improve the vehicle ride quality.

SLRV Torsion Loads Model

The SLRV is a three truck articulated vehicle consisting of two car bodies connected by an articulation section. Although this type of vehicle has been in service in Europe for many years the existing articulation designs do not permit an exterior asthetic appearance and have sliding surfaces which expose gaps capable of injuring human limbs when the vehicle is negotiating a turn, hill or valley. The unique articulation design of the SLRV eliminates these problems but requires that the relative motion between the car body sections be kept below .2 inches.

To determine the dynamic torsion loads in the articulation beams, the lateral relative motions between the "A" and "B" car body sections due to cross-level track inputs and the car body roll frequencies, an analytical model of the SLRV was developed and is shown in Figure 5. The existing car body structure included articulation beams located at underframe height. An additional structure was evaluated, a car-to-car and articulation-to-car linkage at the roof of the vehicle. The effect of car body torsion was included in the analysis, with the first torsion natural frequency and mode shape determined from the NASTRAN finite element model.

Roll degrees of freedom were considered for the two powered trucks at the ends of the cars, the unpowered truck under the articulation section, the "A" and "B" car bodies, and the articulation section. One flexible torsion mode was included for each car body section along with damping in the secondary suspension system. Primary and secondary suspension elements, chevrons and airsprings, and the articulation beams were represented as linear equivalent rotational springs. Phased cross-level track inputs were applied as angular rotations to each truck.

The equations of motion were derived using computer program LSD; and CSMP used to determine the time histories of the forces and motions while the vehicle was excited by the track cross-level perturbations.

Critical car body lateral relative motions were calculated at the top of the car body 90 inches above the articulation beams. The effect on articulation to car body relative motions of the torsional stiffness of the articulation beams was investigated and the results shown in Figure 6. The data is presented for empty car weight and a speed of 40 mph without an inter-car lateral link and is the maximum positive and negative amplitudes during the complete time history.

This study indicated that the lateral displacements were exceeded with any practical articulation beam design; and the lateral link was required.

The effect on "A" car body to "B" car body and articulation to car body relative motions of this link is shown in Figure 7. The data are presented at empty car weight as a function of vehicle speed. With a car-to-car spring rate of 30,000 lb./in. and an articulation to car spring rate of 1000 lb./in. the relative displacement of the "A" car relative to the "B" car was reduced from .90 inch to .02 inch. Load transmitted to the articulation structure by the link was calculated to be approximately 700 lb. maximum. The load transmitted to the car bodies by the link is approximately 700 lb. maximum for half-sine cross level inputs. Several other track dynamic profiles were employed to determine the maximum expected loads in service.

The model described above was developed and checked out in only 32 manhours. Computer execution time was on the order of 30 seconds for computation of 5 seconds real time data at a cost of $30.00 for each link configuration or track profile analyzed.

Based on the results of this analytical study, an inter-car link was designed and incorporated in the SLRV and its function is to minimize car body to articulation relative motions. Without an inter-car link these motions would have caused interferences between the structural components in the articulation section resulting in wear and possible damage.

CTA Ride Quality Model

The 13-degree of freedom railcar vertical model described and shown in Figure 8 was developed for the prediction of ride quality and primary and secondary suspension dynamic loads. This capability is necessary in the technical evaluation of car body, truck, and suspension parameters. This model considers the dynamics of the entire system, truck, and car body which permits a total systems analysis. Historically, truck and car body parameters evolved independently and consideration of the total vehicle dynamic characteristics was neglected.

The differential equations of motion were derived from the energy equations using computer program LSD and programmed on CSMP. The model includes the following degrees of freedom: Vertical, pitch, and roll of the car body and truck sprung mass as well as two flexible car body modes. The effects of non-linear suspension elements (springs and dampers) along with truck spacing, wheel base, and car body geometry are included. Phased, dynamic track profiles at each wheel are used to excite the model. A typical dynamic track profile of jointed rail used in parametric studies is shown in Figure 9.

To validate this model a CTA 2000 Series car was modeled and the analytical prediction of car body vibration compared to test data. Correlation was good over the speed range investigated; and a sample comparison of the test data and analytical prediction is shown in Figure 10.

The analysis shows the mixed frequency response resulting from super-position of the low frequency rail joint and higher frequency wheelbase excitations. This model is currently being used for ride quality studies to optimize the suspension system of the Boeing designed CTA rapid transit railcars to insure low vibration levels. Execution time for computation of 5 seconds of real time data is approximately 100 seconds at a cost of $70.00.

SLRV Truck/Propulsion Unit Dynamic Model

This model, shown in Figure 11, was generated to calculate the coupled truck/mono-motor propulsion unit natural frequencies and vibrations resulting from coupling unbalance forces. The primary objective of the

the analysis was to select the optimum motor mount stiffness to separate the propulsion unit vertical/pitch frequencies from the motor, wheel and coupling first and second harmonic unbalance force frequencies in the operating speed range. Such a resonant condition would induce high loads and perhaps cause failure of the motor or gearbox. It was subsequently shown that a simplified two-degree of freedom system of the propulsion unit with the motor mounts fixed to ground would have yielded results which were in error because of the strong dynamic coupling between the propulsion unit and the truck frame suspended on relatively soft chevron primary suspension springs.

In the analysis the propulsion unit and the truck frame were given all six degrees of freedom and each suspension element had stiffness components in three directions. Calculation of the system's twelve natural modes and frequencies was accomplished in the following steps, many of which were performed by the computer.

1) Write potential, dissipation and kinetic energy expressions.

2) Input these equations to computer program LSD to derive the equations of motion.

3) Arrange the resulting equations of motion into damping, stiffness and inertia matrices.

4) Using WATFOR, calculate the matrix coefficients from the system mass, stiffness, damping parameters and geometry.

5) Use a computerized QR algorithm to solve for natural frequencies and mode shapes.

Computation of the damped forced response was performed using the matrices derived by LSD. A WATFOR matrix manipulation program was generated to perform the following calculations.

$$\underbrace{\begin{bmatrix} K - M\,\omega^2 & \ldots & -C\,\omega \\ C\,\omega & \ldots & K - M.\,\omega^2 \end{bmatrix}^{-1}}_{24 \times 24} \quad \underbrace{\begin{bmatrix} F \end{bmatrix}}_{24X1} = \underbrace{\begin{bmatrix} D \end{bmatrix}}_{24X1}$$

where

$$\begin{bmatrix} K - M.\omega^2 & \ldots & - C\,\omega \\ C\,\omega & \ldots & K - M.\omega^2 \end{bmatrix}$$ is formed from the stiffness (K), damping (C) and inertia (M) matrices.

$$\begin{bmatrix} F \end{bmatrix}$$ is a column matrix of phased coupling generated forces and moments.

$$\begin{bmatrix} D \end{bmatrix}$$ is a column matrix of displacements.

ω is the motor excitation frequency.

Inversion of the 24 X 24 matrix is required at each discrete excitation frequency. Clearly this repetitive calculation performed manually would have been a monumental task and subject to numerous arithmetic errors. Calculation of the stiffness (K), damping (C) and inertia (M) matrix coefficients, formulation and inversion of the 24 X 24 dynamic matrix, and the matrix multiplication required approximately 10 seconds of computer time at a cost of 1.00 dollar. A sample frequency response curve showing the theoretical predictions of the truck and motor vertical accelerations as a function of vehicle speed for the detuned configuration is presented in Figure 12. As can be seen from this figure, the maximum vertical acceleration of the motor and gearbox is only .08 g's up to 60 miles per hour.

CTA Truck Equalization Analysis

Evaluation of a truck's ability to safely negotiate vertically misaligned rail is generally defined in terms of its static equalization characteristics. Equalization requirements are expressed as percent changes in vertical wheel loads when one wheel or journal box is raised a specified height. A generally accepted criteria is that jacking one wheel 2 inches the vertical load on any other wheel shall not change by more than 20%. In order to provide the capability to determine the truck equalization characteristics of the Boeing Vertol CTA rapid transit railcars, a computer analysis of the vehicle with a proposed truck design was developed and is shown in Figure 13. The 19 degree of freedom model includes the effects of journal box elastomers, primary suspension, secondary suspension and appropriate geometry. A rigid car body and truck frame were assumed.

The system stiffness matrix was generated using LSD with the kinetic and dissipation energy expressions set equal to zero.

The matrix method of solution employed to obtain the load changes is described by the following equations.

The load deformation relationship for a structure may be expressed in matrix form as:

$$(1) \quad [K]\,[X] = [F]$$

where $[K]$ is the uncollapsed stiffness matrix of the structure, $[X]$ is a matrix of deflections, and $[F]$ is a matrix of forces.

The above matrix equation may be written in partitioned form as:

$$(2) \quad \left[\begin{array}{c|c} KU & KN^{T} \\ \hline K_N & K_{NN} \end{array}\right] \left[\begin{array}{c} XU \\ \hline X_N \end{array}\right] = \left[\begin{array}{c} F_A \\ \hline F_B \end{array}\right]$$

where the submatrices are:

X_u = unknown deflections

X_n = known deflections

F_a = applied loads

F_b = boundary reactions

expanding partitioned form yields:

$$(3) \quad K_u X_u + K_n^T X_n = F_a$$

$$(4) \quad K_n X_u + K_{nn} X_n = F_b$$

Solving equation (3) for X_u

$$(5) \quad X_u = K_u^{-1}\ F_a - K_n^T X_n$$

Once the unknown displacements are computed the spring forces and wheel reactions are easily determined. A flow diagram illustrating the logic of the computer analysis is shown in Figure 14.

Alternatively the NASTRAN finite element approach may be used if a large number of degrees of freedom are required as in the case of the Wegmann truck design which equalizes by truck frame flexibility rather than deflection of the primary suspension. A comparison of computed wheel reactions using the matrix manipulation program described above and a NASTRAN model of a rigid frame truck is shown below in the table. As could be expected, correlation is very good.

COMPARISON OF CLOSED FORM SOLUTION
VS
NASTRAN

WHEEL NO.	LOAD BEFORE JACKING LB	(CLOSED FORM MATRIX MANIPULATION PROGRAM) LOADS AFTER JACKING-LB	% CHANGE	(NASTRAN) LOADS AFTER JACKING LB	% CHANGE
1	-6500.	-5675.5	-12.7	-5698.4	-12.3
2	-6500.	-7324.8	12.7	-7301.5	+12.3
3	-6500.	-6616.[illegible]	+ 1.8	-6593.6	+ [illegible] 4
4	-6500.	-6384.1	- 1.8	-6406.4	- 1.4
5	-6500.	-6145.7	- 5.5	-6143.8	- 5.5
6	-6500.	-6854.3	+ 5.5	-6856.2	+ 5.5
7	-6500.	-6145.7	- 5.5	-6146.3	- 5.4
8	-6500.	-6854.3	+ 5.5	-6851.7	+ 5.4

Computer execution time for the closed form solution is 5 seconds while the NASTRAN analysis of a rigid frame truck requires approximately 60 seconds at a cost of approximately 5.00 dollars. This type of analysis is being used to insure that the CTA truck suspension system provides adequate wheel load equalization and safety against derailment.

Additional Analytical Models

Many additional analytical models have been developed using NASTRAN, CSMP, LSD and WATFOR matrix manipulation programs to solve production oriented engineering problems on the SLRV and CTA vehicles. Calculations were performed to determine:

- Optimum vertical and lateral suspension spring and damper values for the SLRV truck to provide low vehicle vibration levels. (Similar studies are currently being performed for the CTA vehicle). (LSD, CSMP)

- Dynamic loads in the suspension elements of the CTA trucks to insure that dynamic stress levels are acceptable. (LSD, CSMP)

- Dynamic loading of the SLRV track brake support beams, again to minimize dynamic stress levels. (LSD, CSMP)

- Stiffness requirements of SLRV seat support structure to avoid amplification of vibration in the 4 Hz to 8 Hz frequency range, a region particularly discomforting to humans. (NASTRAN)

CONCLUDING REMARKS

The computer technology exists today to solve many railcar dynamic problems that only a decade ago were treated with perhaps over-simplified analyses. Many complex dynamics problems can be described easily by matrix equations and solved using the high speed digital computer which is idealy suited to perform large matrix operations such as inversion, multiplication, etc. Digital or even analog solutions can quickly be obtained for large numbers of differential equations describing a dynamic system such as a railcar. These computations can be performed accurately for relatively low cost in short periods of time permitting analysis to impact a design; reducing costs and lowering the possibility of problems on the production vehicle. As electronic advances are made and computer storage increases while execution time decreases, more sophisticated models can be generated giving even further in depth understanding of complex problems. The time, however, has arrived when meaningful, accurate analyses can be performed to lead and impact a vehicle design, not merely follow it.

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2. The NASTRAN User's Manual (Level 15), NASA Document NASA SP-222(01).

3. Computer Language for Structural Dynamics, Boeing Document D2-139514-1.

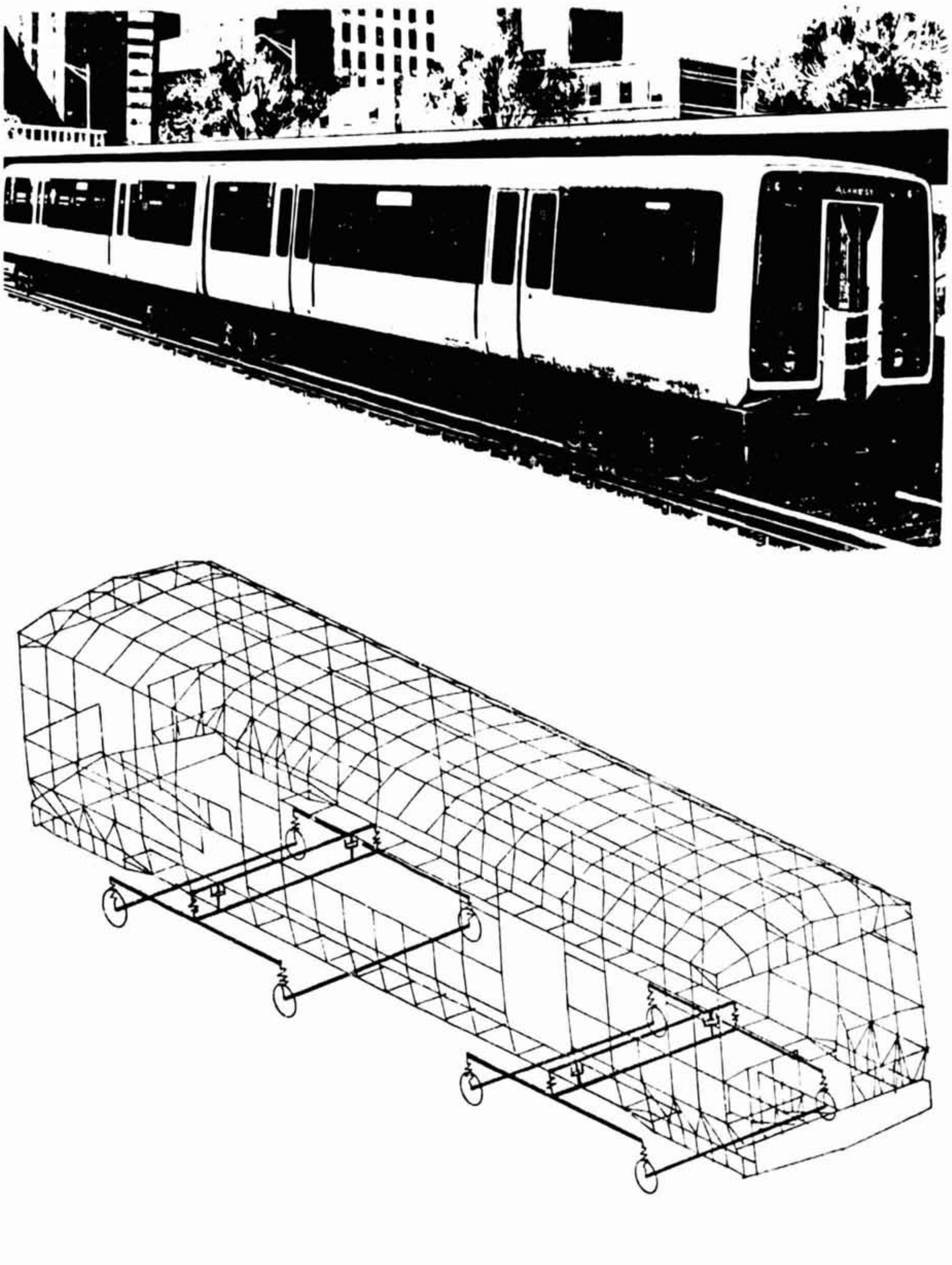

FIGURE 1 - CTA RAPID TRANSIT RAIL CAR AND DYNAMIC MODEL

RIDE QUALITY PREDICTION CHAIN

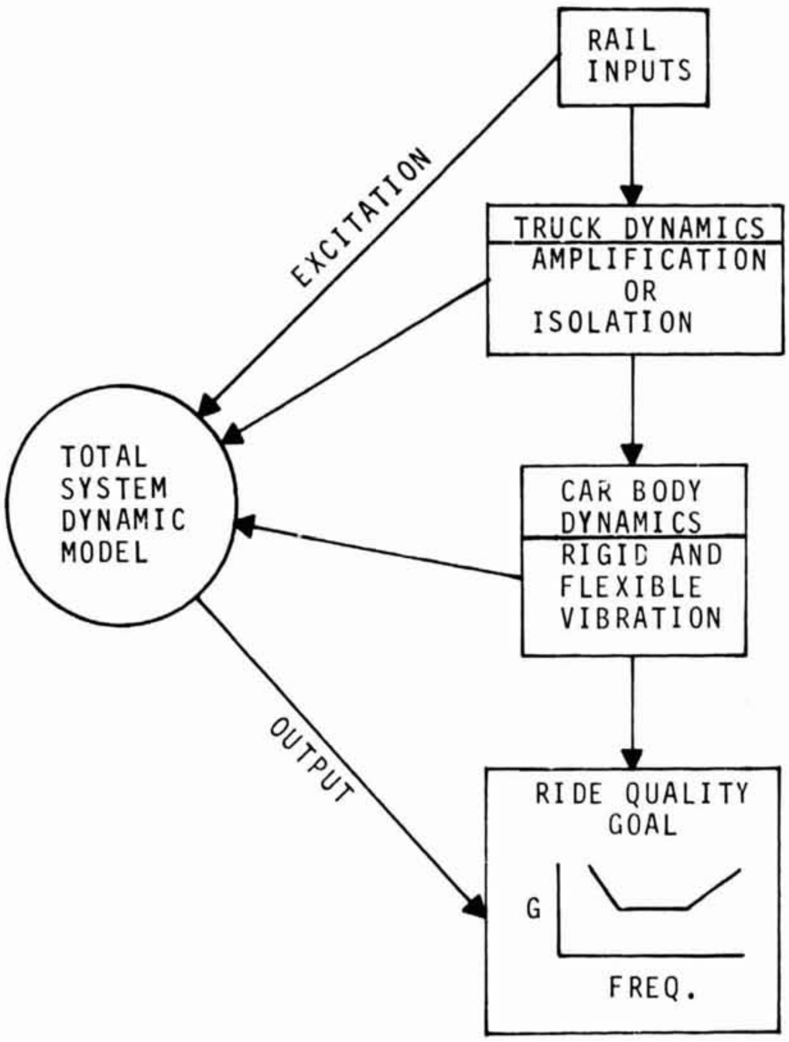

FIGURE 2 - RIDE QUALITY PREDICTION CHAIN

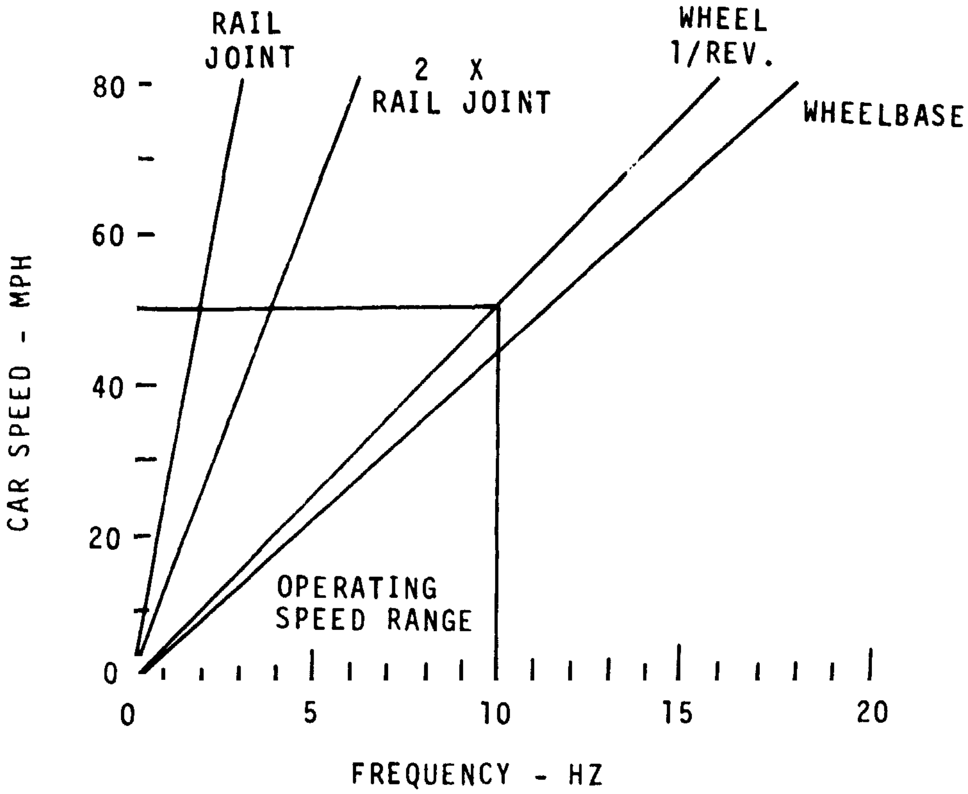

FIGURE 3 - RAIL/WHEEL EXCITATIONS

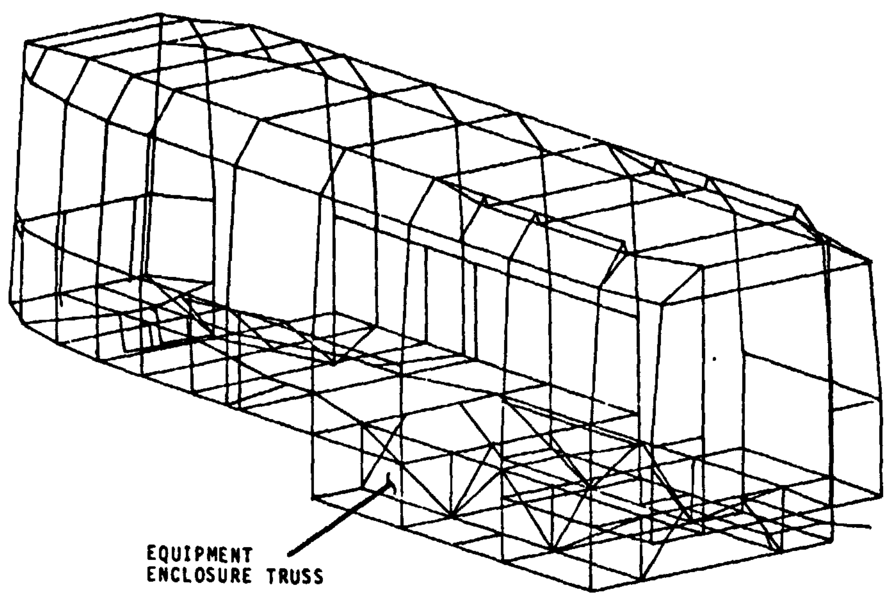

FIGURE 4 - COMPUTER GENERATED SLRV NASTRAN CARBODY DYNAMIC MODEL

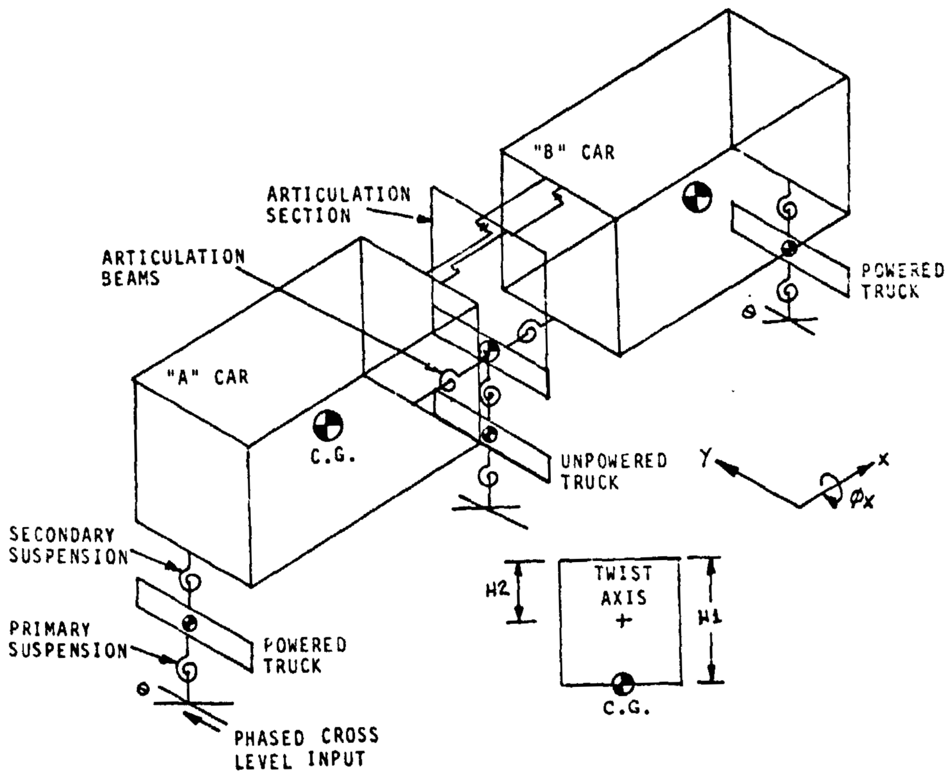

FIGURE 5 - SLRV TORSION LOADS MODEL

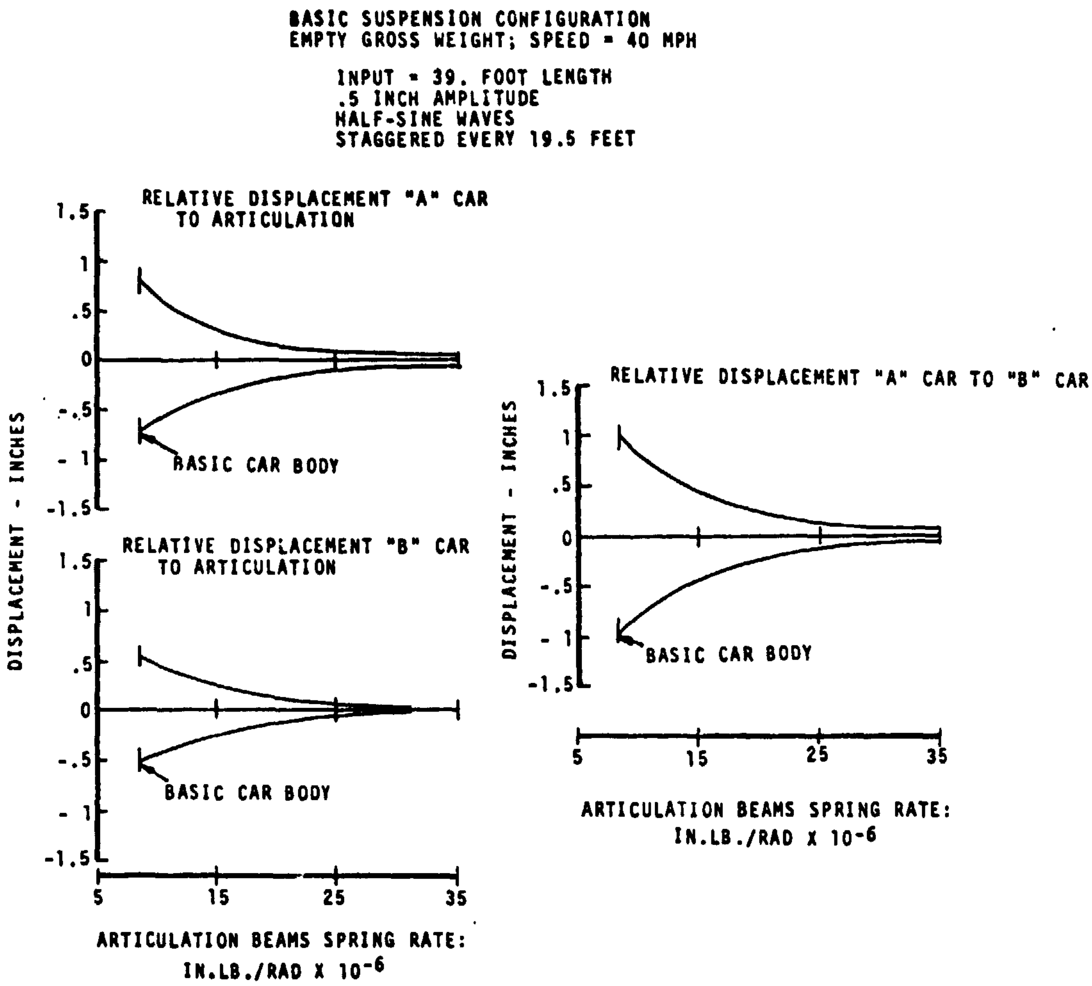

FIGURE 6 - SLRV ARTICULATION/CAR BODY MOTIONS
EFFECT OF ARTICULATION BEAMS

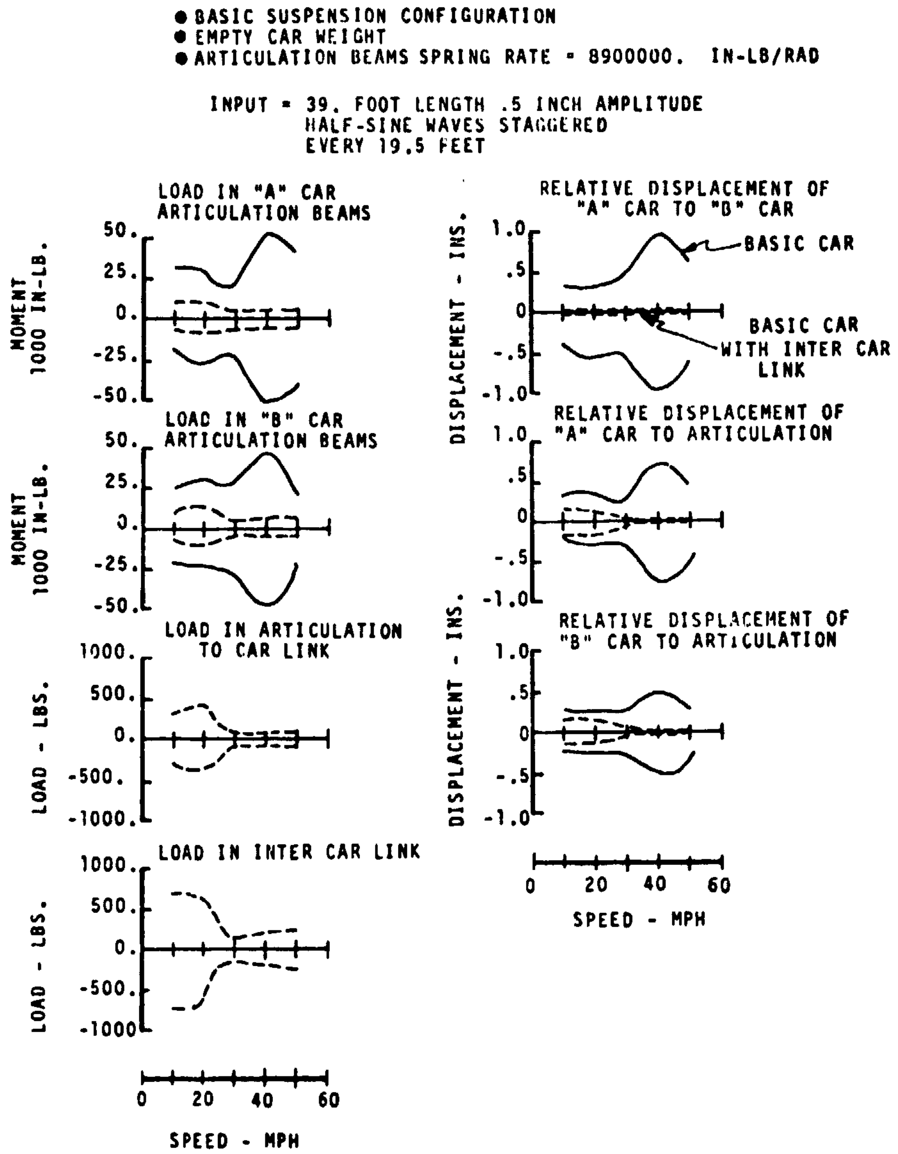

FIGURE 7 - SLRV CAR BODY MOTIONS AND LOADS

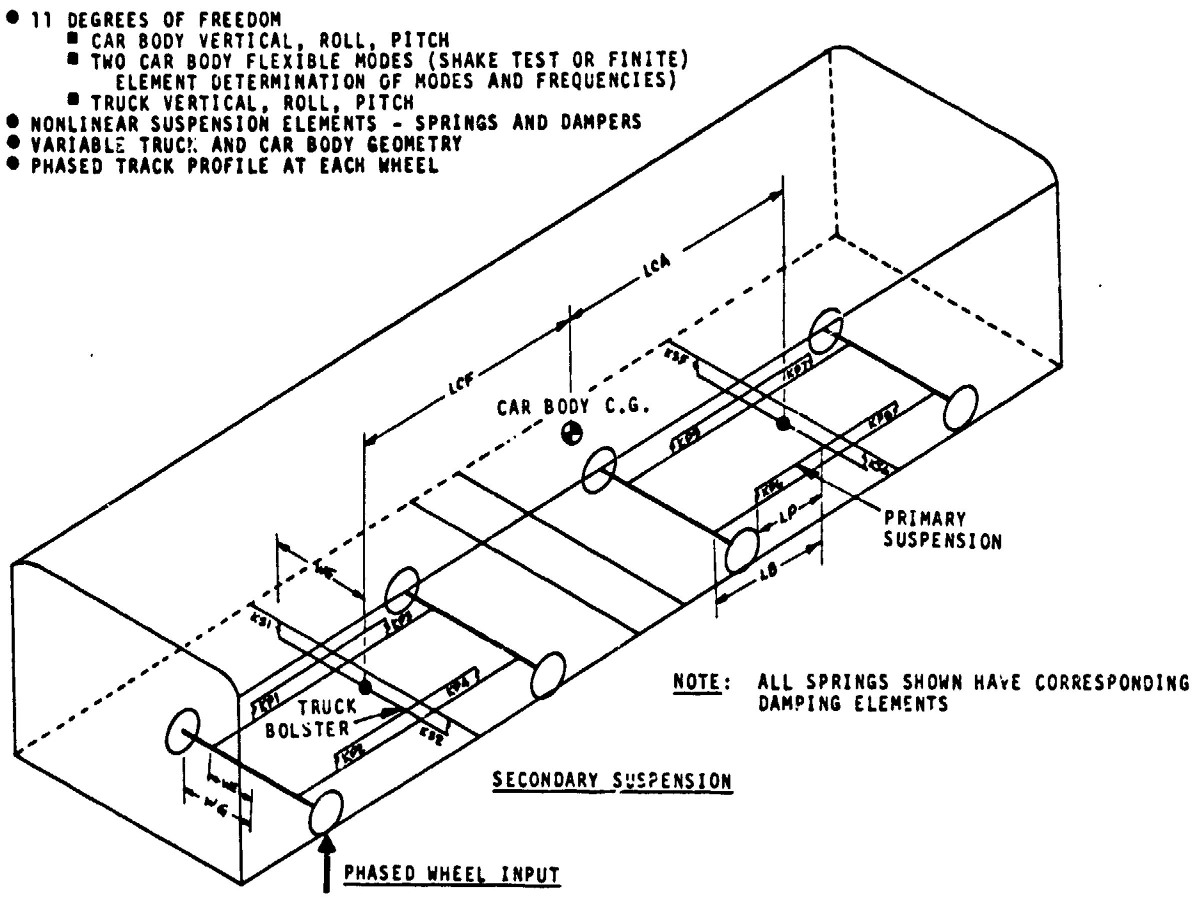

FIGURE 8 - 11 D.O.F. RAIL CAR VERTICAL RIDE QUALITY MODEL

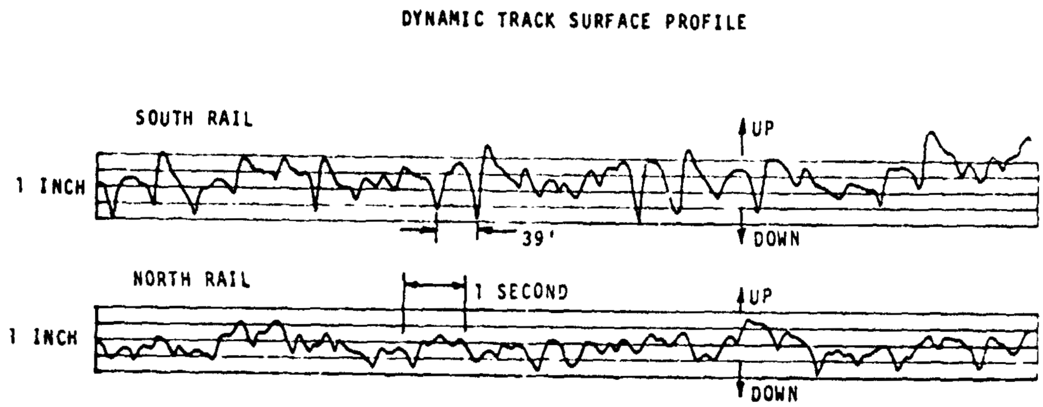

FIGURE 9 - JOINTED RAIL

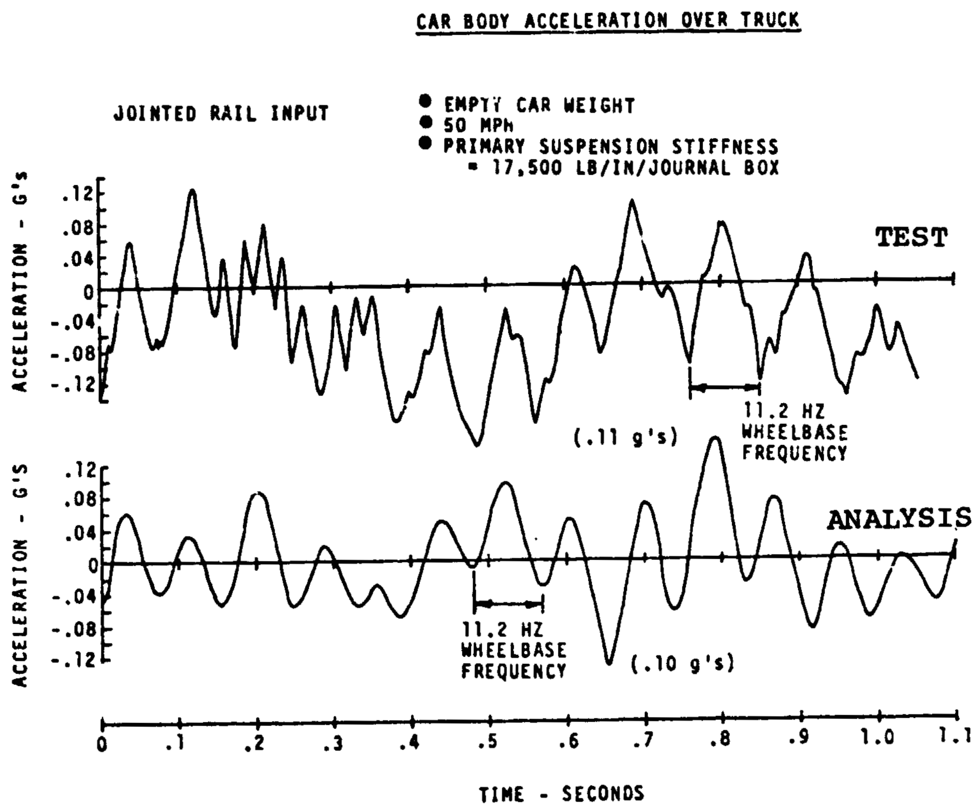

FIGURE 10 - COMPARISON OF TEST AND PREDICTED CTA
RIDE QUALITY

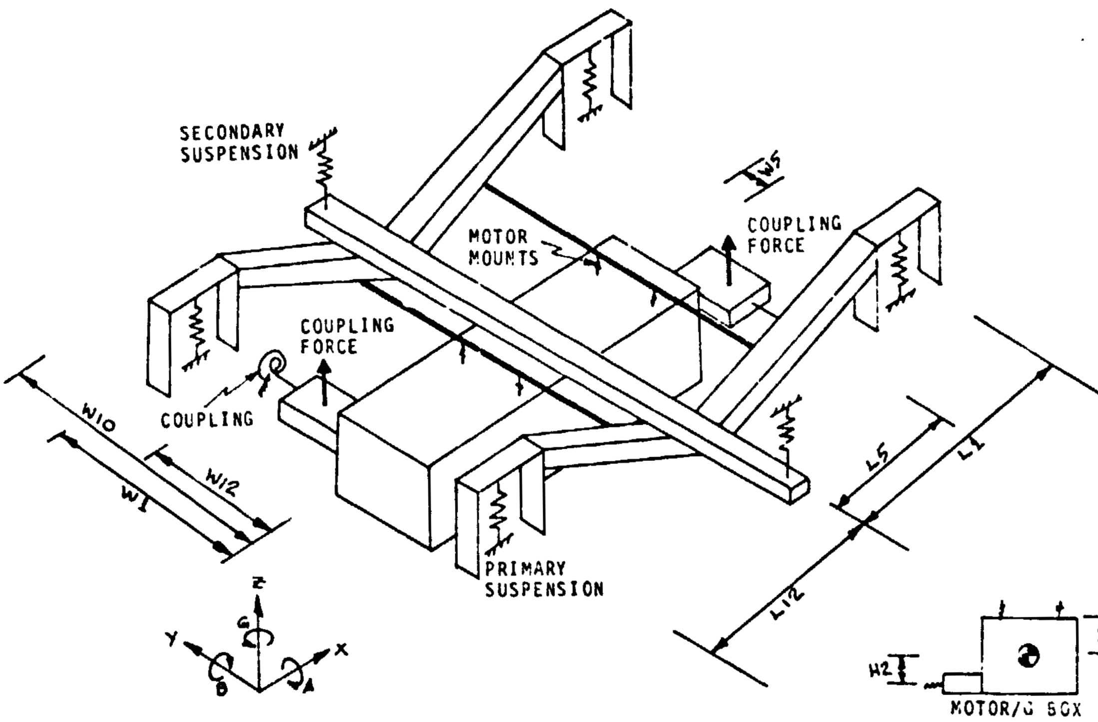

FIGURE 11 - TRUCK/PROPULSION UNIT ANALYTICAL MODEL

	SPRING RATE - LB./IN.		
	Long.	Lat.	Vert.
Primary Suspension	153,000	20,600	8,850
Secondary Suspension	934	934	1,510
Motor Mounts	18,300	55,000	55,000
Rockwell Coupling	,280	2,450	3,280

COUPLING OFFSET = .25 IN. (MAX.)
NOTE: 15% CRITICAL DAMPING

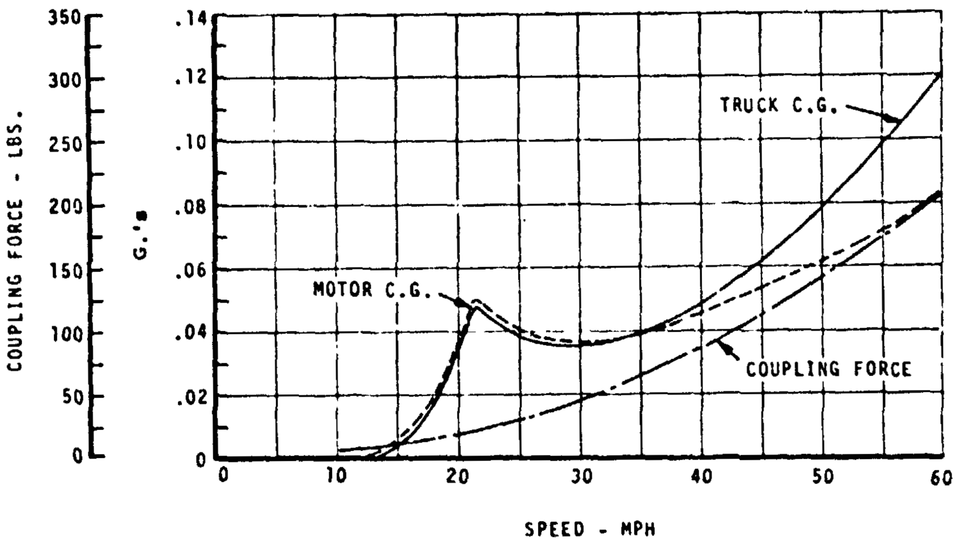

FIGURE 12 - TRUCK/PROPULSION UNIT FORCED RESPONSE

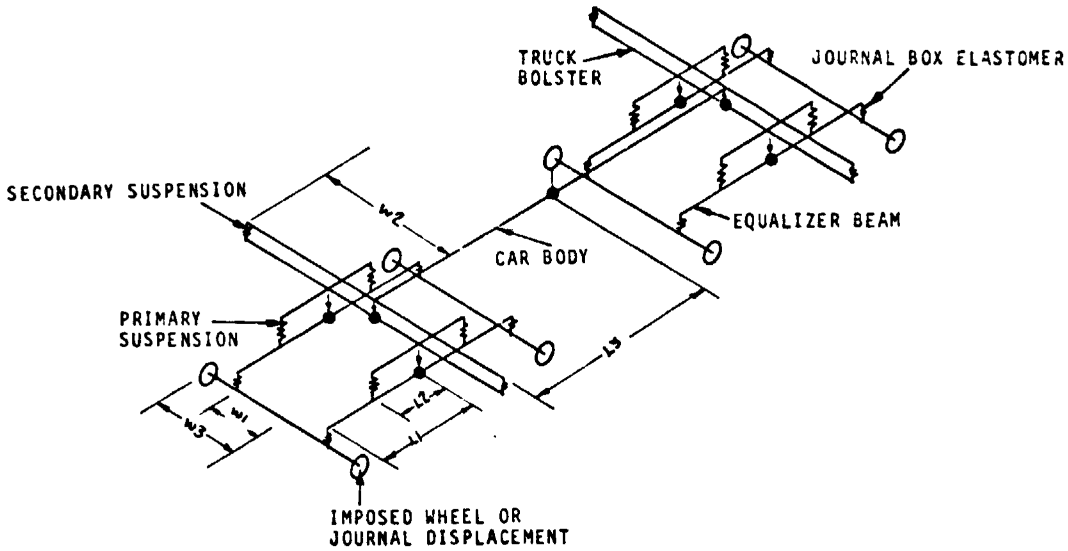

FIGURE 13 - GENERAL TWO-TRUCK EQUALIZATION MODEL

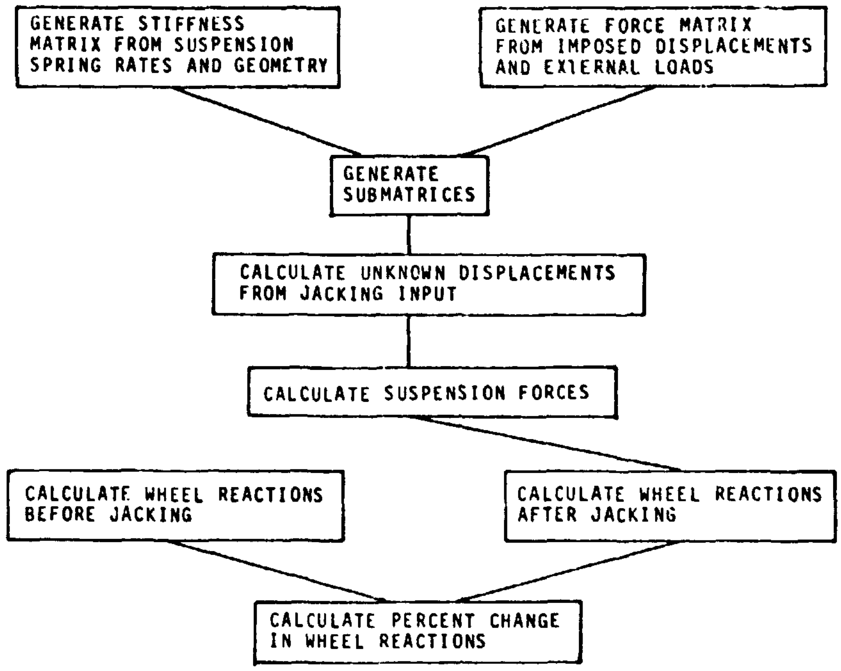

FIGURE 14 - TRUCK EQUALIZATION ANALYSES FLOW DIAGRAM

THE TECHNOLOGY APPLICATION PROCESS AS APPLIED TO A FIREFIGHTER'S BREATHING SYSTEM

Pat B. McLaughlan

INTRODUCTION

The National Aeronautics and Space Administration (NASA), through its Technology Utilization Program, makes advances in technology developed in the space program available to the public. During recent years this has coincided with a growing demand for improved protective equipment and a better breathing system within fire service organizations. Because of its experience in providing life support systems for space flight, the Johnson Space Center (JSC) was asked to determine the feasibility of developing an improved breathing system for firefighters. Such a system was determined to be within the current state-of-the-art and JSC is completing a development program for an improved Firefighter's Breathing System (FBS). The FBS consists of compressed air stored in a backmounted pressure vessel, a series of valves and pressure regulators that meter the flow of breathing air and a face mask that covers the mouth, nose and eyes.

PROGRAM PLAN AND OBJECTIVE

The involvement of NASA in the FBS Program resulted from two inputs. First, fire department inquiries to both NASA and Congressional leaders raised the point that if NASA can sustain life in a space environment, NASA should be able to assist the fire services in the improvement of their breathing apparatus. Secondly, a survey conducted by Public Technology, Incorporated, defined an improved FBS as the number one technology improvement desired by cities. As a result of these inputs, JSC conducted a preliminary survey to determine whether aerospace technology and, more specifically, technology developed within the Crew Systems Division at JSC could be applied to the fire services to develop a more effective FBS. Our preliminary survey indicated technology did exist that could satisfy the objective. A program proposal was formally defined and submitted to the NASA Headquarters Technology Utilization Office and the program was approved and authorized.

During preliminary phases of the FBS Program, it became apparent that many requirements would develop that normally are outside of the scope of past NASA programs. In its aerospace role, NASA is basically its own customer. To accomplish a mission NASA defines its own requirements and specifications. NASA is responsible for manufacturing or contracting its own hardware and accepts or rejects this hardware. NASA trains its own personnel in use of equipment and the use of the equipment is under NASA direction. This process is significantly different for a public technology program and the awareness of these differences play an important role in program planning.

One of the first tasks following program approval was the establishment of a User Requirements Committee to formulate requirements in terms of performance objectives. This User Requirements Committee was composed of fire department and city representatives. The committee consisted of deputy chiefs in charge of equipment and department chiefs from both large and small cities. Breathing apparatus manufacturers and regulatory agency representatives were not included because the committee was encouraged to define desired FBS performance objectives without constraint by previous designs or by current regulatory specifications.

At the initial meeting of the User Requirements Committee the FBS technical objectives defined in order of priority were: (1) increased duration with a reduction in weight and bulk; (2) improved human factors; (3) moderate cost that did not significantly exceed the cost of presently available systems; and, (4) simple maintenance/recharge. The committee defined the following desirable characteristics: (1) minimum training requirements for the firefighter; (2) simple and infrequent maintenance operations; and, (3) low cost and simple recharge operations. Based on these User Requirement Committee objectives, a program plan was formulated. This program plan defines five phases that were: (1) concept selection; (2) prototype design; (3) fabrication; (4) testing; and, (5) evaluation in firefighting conditions. In addition, coordination with the regulatory agencies, potential manufacturers, and fire service organizations was to be accomplished throughout the duration of the program to ensure widespread acceptance and commercialization of the FBS. Following the program through to commercialization by industry was chosen as the end objective of the program rather than a shorter term objective consisting of only report preparation or demonstration of a single prototype. To achieve the commercialization and acceptance by fire departments, a field evaluation program by participating fire departments was judged to be mandatory.

The technology survey indicated many specific items of applicable technology were not truly unique to NASA. These items of technology developed by NASA have been described in technical publications or, the technology may have been developed by industry under NASA contracts, thus providing industry first hand knowledge of the technology. Therefore, why has the private sector not previously implemented this advanced technology, and what specifically can NASA contribute in the technology implementation? An initial need was to define the barriers to the innovation and commercialization of improved breathing equipment for firefighters. The following factors relative to FBS marketing became apparent.

1. The fire service is a relatively diversified market that requires an extensive sales force and marketing effort. It is difficult for a new manufacturer to enter this market with a new product because of the complex coordination required between the various regulatory agencies, fire service organizations, and individual fire departments.

2. The financial return may not justify the new capital expenditures required to commercialize the technology. Frequently a manufacturer has established a market position as the result of past investments in production equipment, advertising and sales force training. The manufacturer is reluctant to commit development funds to a new product that may result in no great return on investment. The prospect of new markets or a greater share of the market is mandatory, otherwise an innovative product may compete only against the manufacturers existing products and no net increase in sales will result.

3. The fire service recently demanded better breathing equipment. Previously, the fire service used inadequate filter type masks with limited use of self contained systems or no breathing protection at all. Only recently has the fire service actively accepted the use of breathing apparatus and requested improvements.

4. The current equipment procurement practices do not stress improved technology. The specification defined by fire departments have in the past been based on market availability. Also, specifications have tended to be product oriented rather than performance oriented, thereby, placing an innovative but unknown product at a disadvantage. In addition, regulatory agency specifications are generally based on a series of requirements that have been developed through the years and are seldom designed to force technology innovations. Thus, a status quo results that is caused by the inability of a manufacturer or fire department to force the technology.

5. The ultimate sales price of the system is a key factor in the fire department acceptance because they generally operate under budget constraints. To encourage greater expenditures the system improvement must be clearly relatable to an increase in firefighting efficiency.

SYSTEM DESCRIPTION

The first step in the FBS development program was selection of the optimum system concept to fulfill the needs of the user. Based on information obtained from the User Requirements Committee, design goals were set for a system weight, configuration, and a true 30 minute system operating duration. Current systems are rated as 30 minute systems but generally have a shorter duration during actual firefighting conditions. To determine the optimum system concept based on these requirements an engineering study was conducted. A systems approach which considered both user and FBS as an integrated man/machine system was utilized. Respiratory physiological requirements of working firefighters were defined, which included parameters of oxygen consumption and carbon dioxide generation rates, breathing flow requirements, and the required quantity of breathing gas. To assist in the development of a minimum fatigue support harness a study of human factors associated with load carrying was conducted. The concept selection study considered all technical approaches to portable breathing apparatus. Included in the study were various combinations of expendable compressed air, chemical and liquified gas in open loop, closed loop and rebreather configurations. Comparison of the performance, operational and cost advantages and disadvantages of the various systems resulted in the selection of the compressed air open loop demand type system.

After definition of the system concept, a lightweight pressure vessel development program was initiated. Concentration of effort was placed on this program for two reasons: (1) the pressure vessel was considered the key candidate for weight reduction; and, (2) the pressure vessel was expected to have the longest development lead time. The pressure vessel selected is cylindrical in shape and designed to store air at a pressure of 4500 psi as opposed to the current 2200 psi. Other shapes such as spherical, toroidal and coiled tubing were considered as was the possibility of using two or more small pressure vessels instead of one large vessel. However, these ideas were rejected because of cost. The 4500 psig pressure level was selected as the optimum for reducing the system bulk yet not exceeding regulator technology and commercially available charging compressors. Several pressure vessel materials and construction methods were considered and a composite vessel made up of a metal liner and a glass filament overwrap was selected as the best vessel based on cost, durability and safety. Figure 1 illustrates this type of construction. Materials and fabrication techniques result in a vessel weight of approximately one half of comparable all metal vessels.

To satisfy the design goal of 30 minute duration, an air storage capacity of 60 standard cubic feet (SCF) was selected. It must be recognized that exact duration is dependent on work rate and individual physiological factors. When the potential weight savings that could be realized by using filament wound pressure vessels became apparent, fire department representatives indicated a smaller capacity vessel would be desirable. The smaller vessel would be approximately the size of the vessels used on current short duration 'sling paks', but would offer longer breathing duration and reduced weight. It was decided to develop two different sizes of pressure vessels, 60 and 40 SCF, either of which would be interchangeable with the FBS.

In addition to the goals of reduced weight and envelope and increased operating duration, another major objective was to design an FBS that is improved in human factors over current systems. The system should be more comfortable, easier to don and doff, provide less encumbrance to the working fireman, provide an effective depletion warning system, and reduce breathing resistance by providing a regulator with increased flow capacity. A comparison between the existing system and NASA FBS will show the NASA approach for obtaining these objectives. Figure 2 illustrates a typical currently available breathing system. The existing harness design has most of the weight being carried by the shoulders. Often the harness is difficult to don due to multiple straps and adjustments. The existing systems have a harness mounted regulator located in front or on the side and a bulky breathing hose from the regulator to the mask. These items complicate donning problems and generally are an encumbrance to the firefighter. Helmet interference is frequently a problem with the existing mask and head straps.

Figure 3 illustrates the NASA developed FBS. The support harness distributes the load on the hips by making use of a wide waist belt and frame that conforms to the lower back. Studies indicate that hip-carried loads are more comfortable and less potentially injurious to the back than shoulder carried loads. The FBS support harness concept provides adequate stability with only a single shoulder strap in addition to the load carrying waist belt. Therefore, the FBS is considerably easier and quicker to don. The FBS has a two stage regulator. The first or pressure reducing stage is mounted on the back frame while the second or demand stage, which is very light, is mounted on the face mask. There is nothing mounted on the chest or side to interfere with the movement of the firefighter. As a further improvement, the mask mounted demand regulator is easily detached from the face mask by actuating a release lever. With the regulator detached, the user can breathe through a hole in the face mask. The detached demand regulator is stowed in a pouch on the belt.

The face mask is a significant improvement, see Figure 4. The bubble type facepiece is held in place by a nylon net and single adjustable strap. The net concept offers a quick don capability and reduces the problem of helmet/mask interference. The total size of the mask is reduced and interference problems with the helmet in the forehead area are eliminated. The smaller size and fewer straps of the advanced FBS face mask allow this mask to be considerably lighter than current face masks. The mask contains an oral nasal deflector that aids in reducing visor fogging during exhalation. To clear away slight visor fogging that may occur the demand regulator incorporates a spray bar for channeling the inlet flow over the visor during inhalation. Inward leakage has been reduced by this mask.

The most significant improvement in the FBS is the increase in operating duration and reduction in system weight. Figure 5 provides a comparison of weight, nominal duration, and cylinder dimensions of the system. If the 60 SCF capacity pressure vessel is used the system weight is 26 pounds. This compares to 33 pounds for the current 45 SCF system. If the 40 SCF capacity pressure vessel is used, system weight is 20 pounds. This compares favorably to the present 'sling pak' system which has 25 SCF gas capacity and weighs 24 pounds. In tests of the NASA FBS, the test subjects indicate a lower air consumption rate than from the existing systems and this will allow a longer duration from a given quantity of stored gas. This lower relative consumption rate is attributed to reduced weight and breathing resistance and improved comfort. The durations presented on Figure 5 should be considered for comparative purposes only because the tests were conducted on trained test subjects at only moderate work rates in a nonstress environment. In actual firefighting conditions consumption rates in the range of 2 SCF per minute may be experienced resulting in shorter actual durations. Additional design improvements are also summarized on Figure 5.

In addition to the system development, another major aspect of the program was the coordination between regulatory agencies, manufacturers, and evaluating fire departments. Coordination was vital to develop a unified market demand from the fire services, which provides the proper incentives for commercial manufacturers to enter the field. A particular problem is the composite pressure vessel, which is a key component of the system. The design of the pressure vessel dictates that for fabrication complex and costly manufacturing equipment be used. Currently it is estimated that a production rate for the pressure vessels of at least 10,000 units per year is required to achieve a satisfactory sales price. Initially, fire department requirements for the FBS will not satisfy the required vessel production rate. Fortunately, similar breathing systems are needed by industrial concerns handling hazardous materials and by underwater users. Recreational and commercial scuba users have expressed a desire for reduced weight pressure vessels to minimize the above water handling weight problems and for higher vessel pressure for increases of gas volume. Current objective is to combine the underwater and portable breathing markets which will result in a common pressure vessel, high-production rates, and ultimate lower cost for the user.

FIELD EVALUATION

The final stage of the NASA FBS Program will be an evaluation of the system performance and feasibility in actual firefighting conditions. Prior to field use of the FBS, it will have satisfactorily completed a qualification test program and man testing in nonhazardous environments. A field evaluation plan has been prepared that defines the responsibilities and requirements of NASA and the evaluating cities. The NASA will provide enough FBS with extra pressure vessels to the cities to equip one firefighting company. Houston, Los Angeles and New York Fire Departments are to serve as evaluation sites. The field evaluation programs will be conducted concurrently at each site and continue for a period of six months. During this period, continuous technical support in terms of performance verification, maintenance of the FBS and support equipment, spare parts, and design analysis is planned. In addition, technical field personnel will provide a detail briefing for fire department officers and cooperate in instructing each fireman assigned to the evaluating fire company in the FBS operation and use. Personnel from NASA will conduct periodic FBS performance verifications and review field evaluation data with the evaluating fire company. The fire company will keep data sheets regarding the frequency of use of the FBS, duration experience, type of fire service, and unusual problems. This will aid the fire officer responsible for the field evaluation in comparing the effectiveness of the NASA FBS with the currently used breathing system and in formalizing suggested modifications or revisions to the system. Following the field evaluation, all FBS will be returned to NASA and a final report of the program prepared.

CONCLUSION

The FBS Program indicated that applications of advanced technology can result in an improved FBS that will satisfy the requirements defined by municipal fire departments. To accomplish this technology transfer, a substantial commitment of resources over an extended period of time has been required. This program has indicated that the ability of NASA in terms of program management such as requirement definition, system analysis, and industry coordination may play as important a role as specific sources of hardware technology. As a result of the FBS program, a sequence of milestones was passed that may have applications as generalized milestones and objectives for any technical application program. These milestones are: (1) identify the specific areas of potential technology transfer; (2) conduct a preliminary technical analysis to determine whether the desired improvements are technically feasible; (3) coordinate with committees, manufacturers, Government agencies, and other interested parties; (4) define obstacles to technology transfer; (5) define a detailed and formalized program plan with specific attention to the final end product and objective of the program; and, (6) conduct the program. Throughout the program the potential for commercialization and widespread user acceptance, in addition to technical improvements, was a predominant factor. Industry and user response indicates that these objectives will be satisfied.

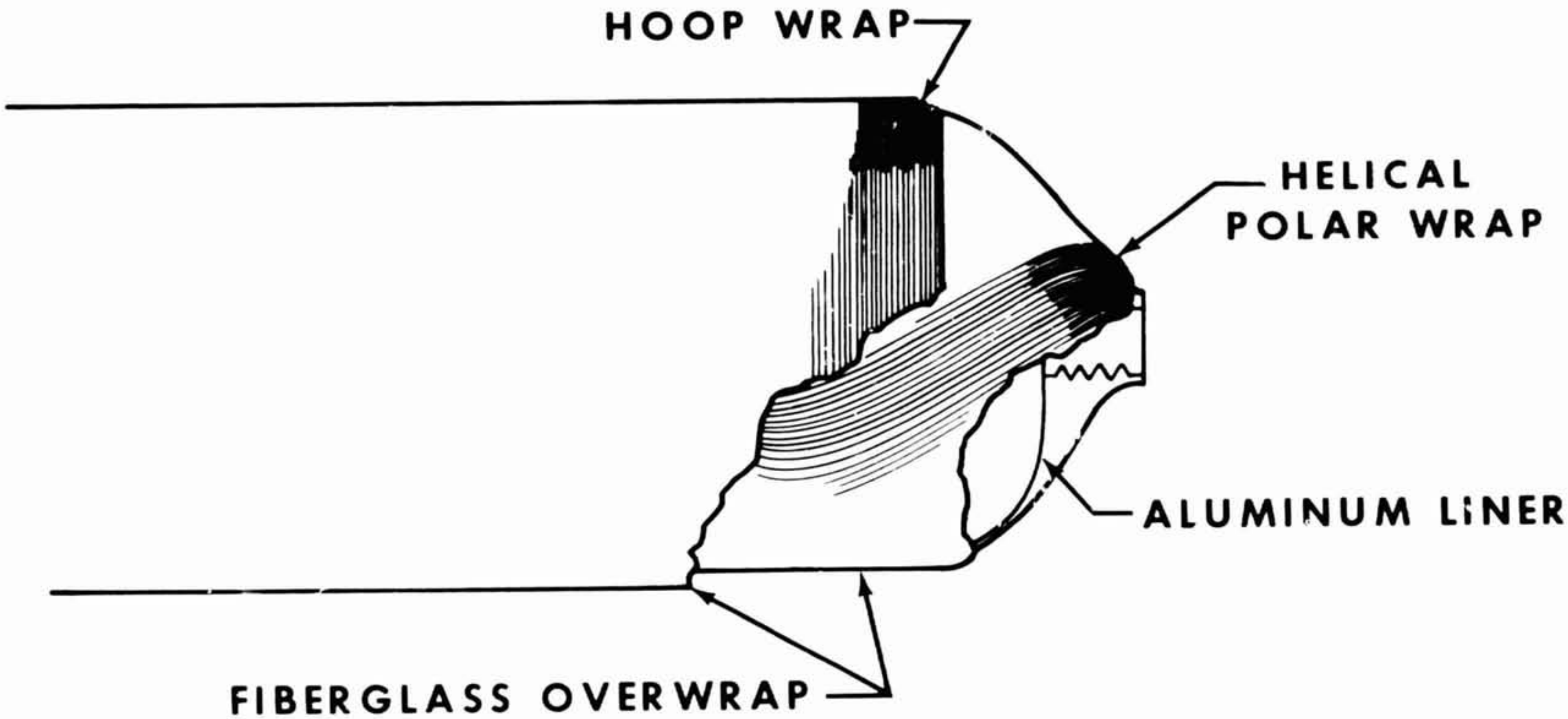

FIGURE 1 - Filament Wound Pressure Vessel

FIGURE 2 - Typical Existing Breathing
Apparatus

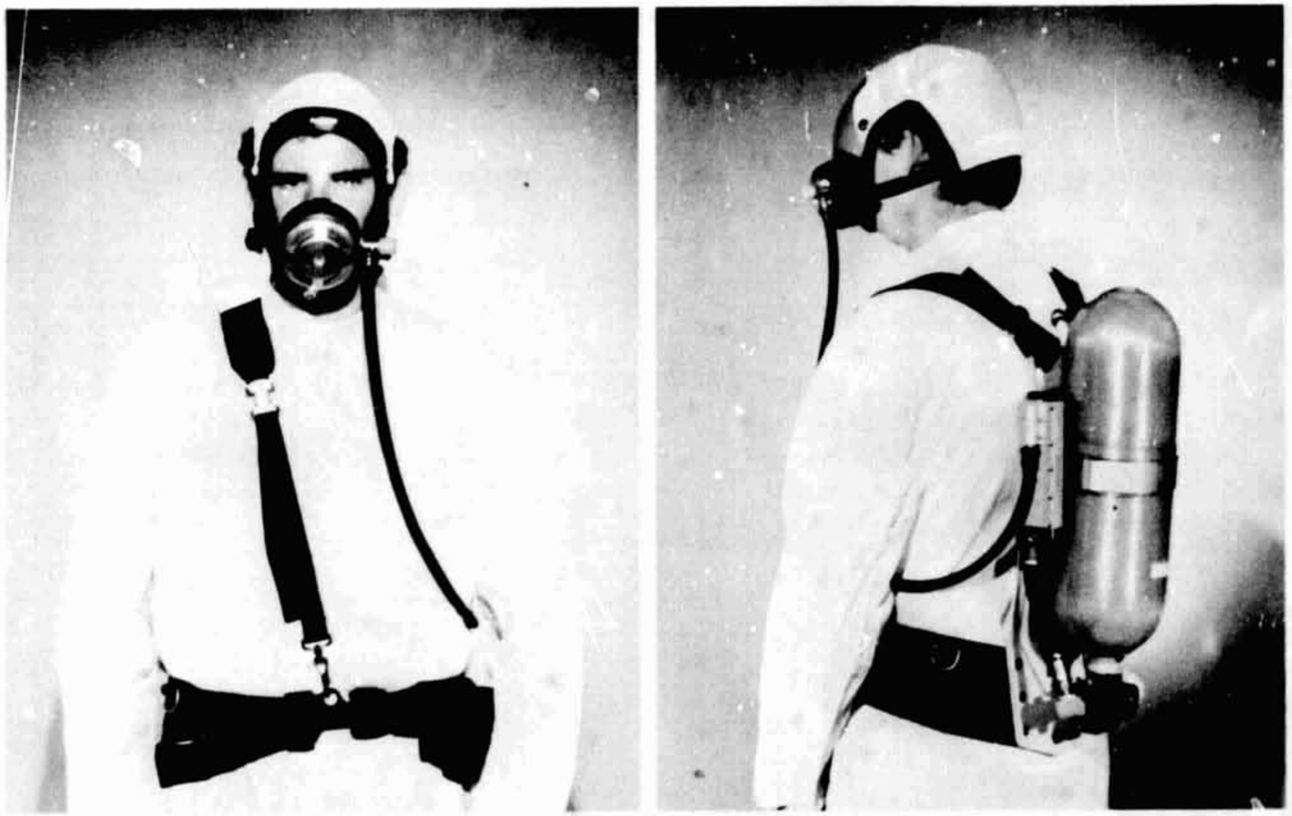

FIGURE 3 - NASA Firefighter's Breathing System
(Single strap configuration in left photo)

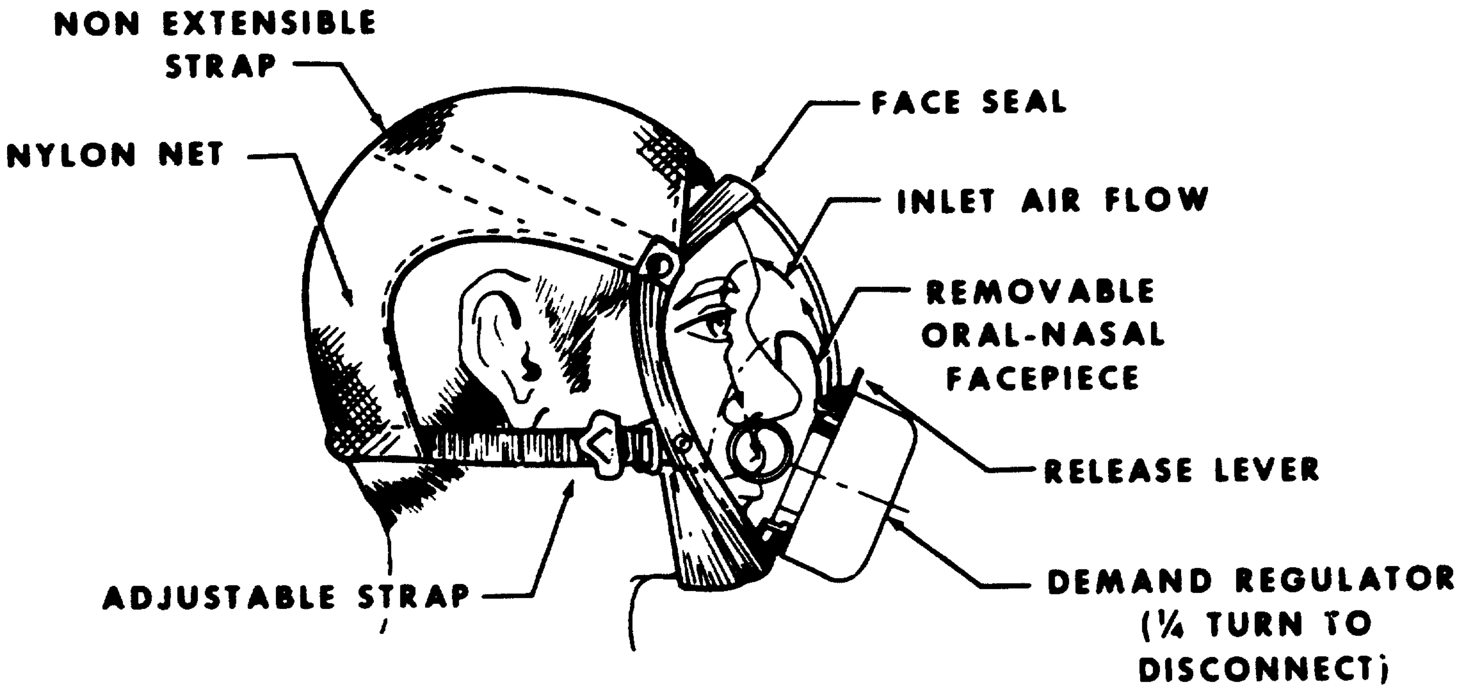

FIGURE 4 - NASA Firefighter's Breathing Facemask and Demand Regulator

FEATURES	EXISTING SYSTEMS	NASA FBS	NASA FBS
STORED GAS CAPACITY (STANDARD CUBIC FEET OF AIR)	45 SCF	40 SCF	60 SCF
OPERATING PRESSURE (POUNDS PER SQUARE INCH)	2200 PSI	4000 PSI	4000 PSI
TEST DURATION* (MINUTES)	36 MIN*	40 MIN*	56 MIN*
TOTAL CHARGED WEIGHT (POUNDS)	33 LBS	20 LBS	26 LBS
CYLINDER DIMENSIONS (INCHES)	6.8 IN. DIAM x 19.5 IN. LONG	5.6 IN. DIAM x 18.6 IN. LONG	6.5 IN. DIAM x 19.7 IN. LONG

*DURATION BASED ON AVERAGE ACTUAL TIMES OF TRAINED SUBJECTS TESTING ON A TREADMILL AT 3.5 MPH AND 3 DEGREE SLOPE. ACTUAL DURATION IN HIGHER STRESS CONDITIONS IS EXPECTED TO BE LESS.

DESIGN IMPROVEMENTS:

- REDUCED WEIGHT/INCREASED DURATION
- SIMPLIFIED HARNESS WITH WEIGHT CARRIED ON HIPS
- REDUCED BREATHING RESISTANCE
- IMPROVED REGULATOR CONFIGURATION
- IMPROVED MASK HARNESS
- REDUCED MASK LEAKAGE

NASA-JSC

FIGURE 5 - Existing System vs. NASA Firefighter's Breathing System

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AEROSPACE MATERIALS FOR NONAEROSPACE APPLICATIONS

Robert L. Johnston and Frederick S. Dawn

INTRODUCTION

The aerospace materials discussed herein are high-temperature and flame-resistant materials which were used or proposed for use in the design of systems and equipment used in manned spacecraft. Many unique requirements were placed on materials to be used in space flight and lunar space environments. In the habitable portions of spacecraft, materials were used in pure oxygen or oxygen enriched environments. Because of the cramped quarters, the limited hygienic facilities and the closed loop recirculating oxygen supply, special physiological problems also need to be considered. Outside the spacecraft, materials were exposed to a hard vacuum, the deep space thermal environment, electromagnetic radiation and particulate flux bombardment. Materials used for these purposes not only were required to be nonburning during exposure to a spacecraft oxygen enriched environment but also were required to withstand an exterior pressure of 10^{-14} torr, temperature extremes of $\pm 250°F$, bombardment by micrometeoroids and impingement by the total electromagnetic spectrum and the solar wind particulate flux. Materials were required to retain all functional properties, such as flexibility tensile strength, abrasion resistance and coefficient of friction, as required for each end item application.

The flame-resistant requirement was particularly limiting because most nonmetallic materials that are relatively nonburning in air burn violently in pure oxygen.

A number of nonmetallic materials were selected that were used satisfactorily in aerospace applications. In addition, in the search for usable materials a large number of materials were tested which, although they had specific inadequacies which ruled out their use in enriched oxygen environments, constituted a marked improvement in flame-resistance or some other property to those currently in use in industry and commerce.

The aerospace program added impetus to the development of many other nonmetallic materials. Typical aerospace materials and new materials with potential future aerospace applications are presented in the following sections.

TEXTILES

As indicated in figure 1, textiles were used extensively in the manned space program. At the beginning of the space program a large number of common types of textile fibers were available including such natural fibers such as cotton, wool, silk, jute, flax, ramie hemp, abaca, sisal, and asbestos and synthetic fibers such as rayon, nylon, dacron, orlon, vinyon, metal, glass, etc. However, as one would now expect the flammability criteria imposed by the enriched oxygen environment selected for the manned spacecraft eliminated all of the natural and most of the synthetic fibers for exposed spacecraft applications. Cotton was used, however, in the undergarments where it was shielded by the space suit. Properties of textile fibers are shown in figure 2 and discussed in the following sections. It should be noted that basic material cost was not a major material

Figure 1

Typical Applications of Textiles

Description	Applications
Polybenzimidozole (PBI) Fiber	Harnesses, Tethers, Straps, Belts, Restraints, Sleep Restraints, Containers, Thread
Teflon Fiber	Apollo Flight Coveralls, Abrasion-Resistant Patches for Space Suit
Asbestos Fiber (Asbeston)	Flame Barrier and Thermal Insulation
Nomex	Comfort Liner for Apollo Space Suit Thread, Outerlayer of Gemini Space Suit
Durette	Skylab Flight Coveralls
Beta	Outerlayer of Space Suit, Spacer in Thermal Insulation of Space Suit, Spacecraft Window Shades, Medical Kit, Rucksacks, Towel Bags, Tissue Dispenser, Helmet Stowage Bags, Suit Accessory Kit, Life Vest Assembly Kit, Backpack Covers, Oxygen Hose Cover, Spacecraft Insulation, Accessories on Crew Provision and Survival Equipment Items, NASA Emblems, Mission Emblem, Flags, Name Plates, Ground Tape for Astro Velcro, Astronaut Couch (Teflon Coated), Fire Protective Barriers
Nylon	Space suit pressure restraint layer

Figure 2. Properties of Textiles

Description	Specific Gravity gms/cc	Tensile Strength gm/denier	Elongation %	Service Temp °F	Flammability LOI*	Flammability Smoke Den.**
Beta (glass fiber)	2.50	15	3-4	900	95	3
Asbestos - Asbeston	2.10 - 2.80	1.5	3-4	1200	100	4
Nylon (polyamide)	1.14	3-6	26-40	300	24	1 R***
Teflon (tetrafluoroethylene)	2.10 - 2.30	1.6	15	450	93	3
Nomex (aromatic polyamide)	1.38	5.0	18	500	30	5
PBI (polybenzimidazole)	1.34	4.5	45	800	49	3
PBI (polybenzimidazole) treated	1.36	3.5	35	800	67	2 R
Durette (400) (mod. aromatic polyamide)	1.40	3.8	12.6	500	36	7
Durette (420) (mod. aromatic polyamide)	1.40	3.0	10	500	54	4
Kynol (phenolic)	1.25	1.8	47	500	33	37 R
BBB (Bisbenzimidazobenzophenanthroline)	1.35	5-6	12-15	1000	50	4
Polyimide	1.40	4.2	25-50	600	40	7
Kevlar (aromatic polyamide)	1.45	18-20	3-4	500	29	5 R
CTFE/TFE	2.10	2-3	15	500	90	2
CTFE/E	1.68	3-4	8-25	450	51	2
FR Spandex	1.80	0.8	450	500	95	32
Spandex	1.21	0.8	550	300	19	68
Wool	1.30	1-2	20-40	200	28	46
Wool-Treated	1.35	1-2	20-40	200	44	53
Cotton	1.50	3.0-4.9	3-10	200	19	26 R
Cotton-Treated	1.55	2.5-4.0	2.5-8.0	200	29	41
Acetate (rayon)	1.30	1.2-1.4	23-45	200	18	5 R

* Limiting oxygen index ** Flaming *** Radiant

selection driver since in the comparatively small production of any particular type of item, the material costs were invariably a small fraction of the engineering design, test, and verification costs.

1. Typical Fibers for Aerospace Applications

Nomex Fiber. Nomex, an aromatic polyamide became available in 1964 and was used for most textile applications in the Gemini Program. Nomex exhibits excellent physical properties, has a high service temperature (500°F) and is nonburning in air. Although it does burn in oxygen, the burn rate was the slowest of all available organic fibers. Additionally, Nomex does not drip molten particles while burning as does the polyamide (nylon). Nomex fire suits are being worn by firemen in New York and other cities. The carpet, upholstery, and drapery fabrics made of Nomex fibers are now used in aircrafts by major airlines.

Beta Fiber. In 1964, a program was initiated for the development of nonflammable fabrics from a 3.75 micron diameter glass fiber known as Beta fiber. Because of the extremely fine diameter, Beta fiber does not cause itching or skin irritation as do larger diameter glass fibers. However, glass fiber does exhibit low abrasion resistance. Two types of fabrics [illegible]veloped that meet the requirements of the Apollo Program. One [illegible]plished by coating the individual yarns with teflon before the [illegible]s woven, and the other was produced by applying teflon c[illegible] onto the fabric. Beta decorative fabrics are specified in numer[illegible] commercial and institutional buildings because of their inherent fire-safe qualities as well as their asthetic appeal.

The average home owner also benefits from the fire-safe qualities of noncombustible Beta fabrics in draperies, bedspreads, and table cloths. Fires have reportedly burned houses practically to the ground without consuming the fiberglass draperies.

Typical applications in the space program are listed in figure 1. The outer layer of the lunar space suit is made of Beta fabric and is shown in figure 3.

Polybenzimidazole (PBI) Fiber. Another fiber which has been used extensively is polybenzimidazole (PBI), a high-temperature, flame-resistant organic fiber. Although PBI withstands temperatures in excess of 900°F and is nonburning in air, it burns slowly in pure oxygen in all forms except the most densely woven webbing. The use of PBI in the space program was primarily in cords, tapes, and webbing applications and where the dynamic abrasive loadings were too severe for Beta fiber. Efforts to treat PBI with a proprietary treatment to render the fibers nonburning in pure oxygen atmosphere were successful. Fire-protective suits made of PBI fabrics are worn by Air Force pilots. The high cost of this fiber has prevented its use in many commercial applications. Typical PBI fiber applications are listed in figure 1 and PBI Skylab sleep restraint systems are shown in figure 4.

Teflon Fiber. A fabric made entirely from Tetrafluoroethylene

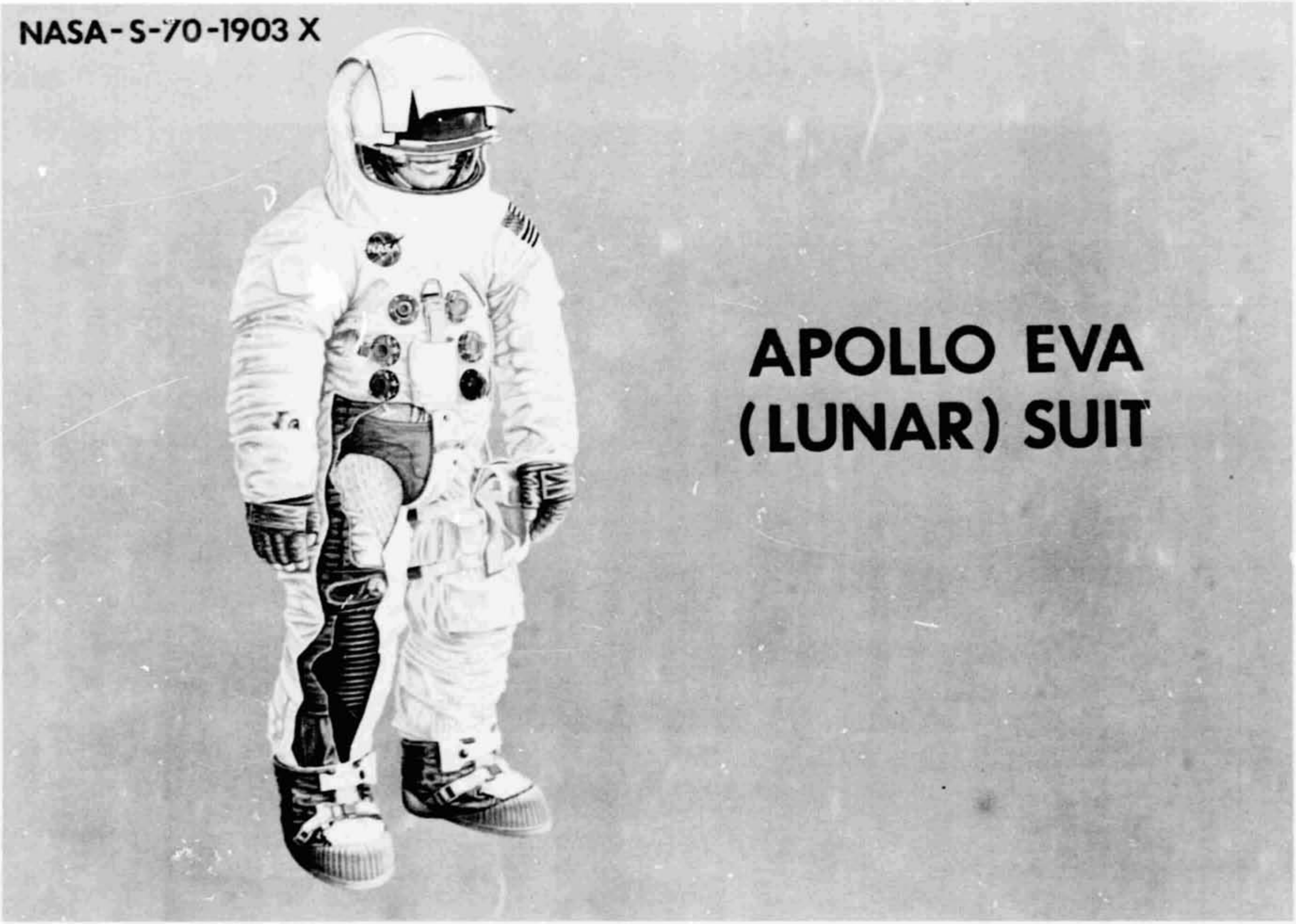

Figure 3. Apollo EVA Suit

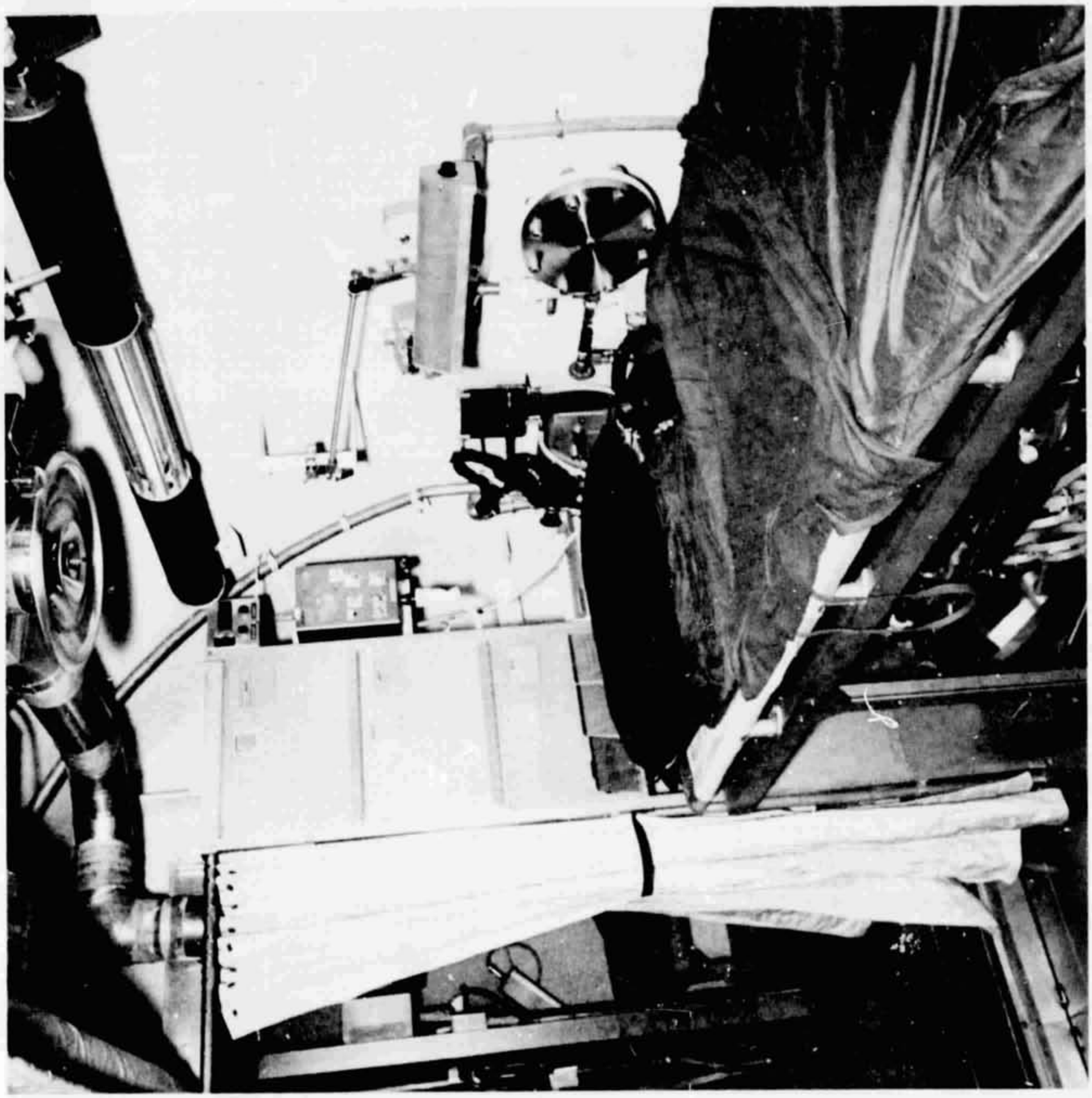

Figure 4. Skylab Sleep Restraint System

(teflon) fiber was also used. Teflon, because of its high halogen content, is totally nonburning in air. Though it does burn slowly in oxygen, it was used as abrasion patches on the space suit, and the intravehicular flight coveralls were made of teflon fabric. The excellent chemical resistance, good wearability and low friction coefficient of teflon recommends it for many applications. For example, teflon fabrics are being used as hospital patient gowns, for treatment in oxygen-rich hyperbaric chambers, missile fuel handler suits, chemical filtration, and bearing systems. The pile tape of the Astro Velcro fasteners which is used extensively in the space program is made of this fiber. An Apollo intravehicular flight coverall is shown in figure 5.

Modified Aromatic Polyamide Fiber - Durette. Because of the flammability of Nomex in oxygen-rich atmospheres, Durette fabrics gained applications for the Skylab Program. Durette is the material which results from the treatment of Nomex fabric with phosphorous and halogen compounds at elevated temperatures. This material is self-extinguishing in the Skylab 70% oxygen environment. Durette compromises the physical properties of the base Nomex to obtain the improved flame-resistance and high-temperature performance. The Durette process results in gold-to-brown-to-black fabrics, with different exposures. The Durette fabrics do not melt in fire and thus dimensionally are stable. The flame-resistance cannot be removed by repeated laundering or dry cleaning because the treatment has formed a chemical bond to the fibers. The Skylab shirt-sleeve garments and some of the crew equipment items are made of Durette. It is gaining acceptance in protective clothing for both the military and commercial usage. Several leading race car drivers wore Durette coveralls as protection against the possibility of fire. The fabrics used for the structural fire suits developed by NASA-JSC were made of Durette. The firemen reported that the suits wore well and comfortable. An entire Monsanto executive aircraft has been outfitted with Durette fabrics for pilot and passenger seats, draperies, curtains, and baggage compartment liners. Figure 6 shows the Skylab intravehicular flight coverall made from Durette.

Flame-Resistant Spandex Fiber. Regular spandex fiber is made of urethane and exhibits excellent elastomeric properties but burns in air. A flame-resistant spandex fiber has been developed under NASA-JSC contract which was self-extinguishing in an oxygen-enriched environment and which attained 450% elongation and 2000 psi tensile strength. This fiber is made from the copolymer of hexafluoropropylene and polyvinylidene fluoride. A flame-resistant urethane spandex fiber was also developed which has physical properties similar to commercial spandex but with an increase in limiting oxygen index from 19 to 25 and which is self-extinguishing in air. The unique properties of spandex fiber offer certain specific advantages in the manufacture of foundation garments, swim and sports wear, surgical hose, and other elastic products. Three companies have expressed interests in using this new spandex fiber for manufacturing these products.

The flame-resistant spandex fiber has been successfully used in the Skylab Medical Experiment Altitude Test and Skylab Program.

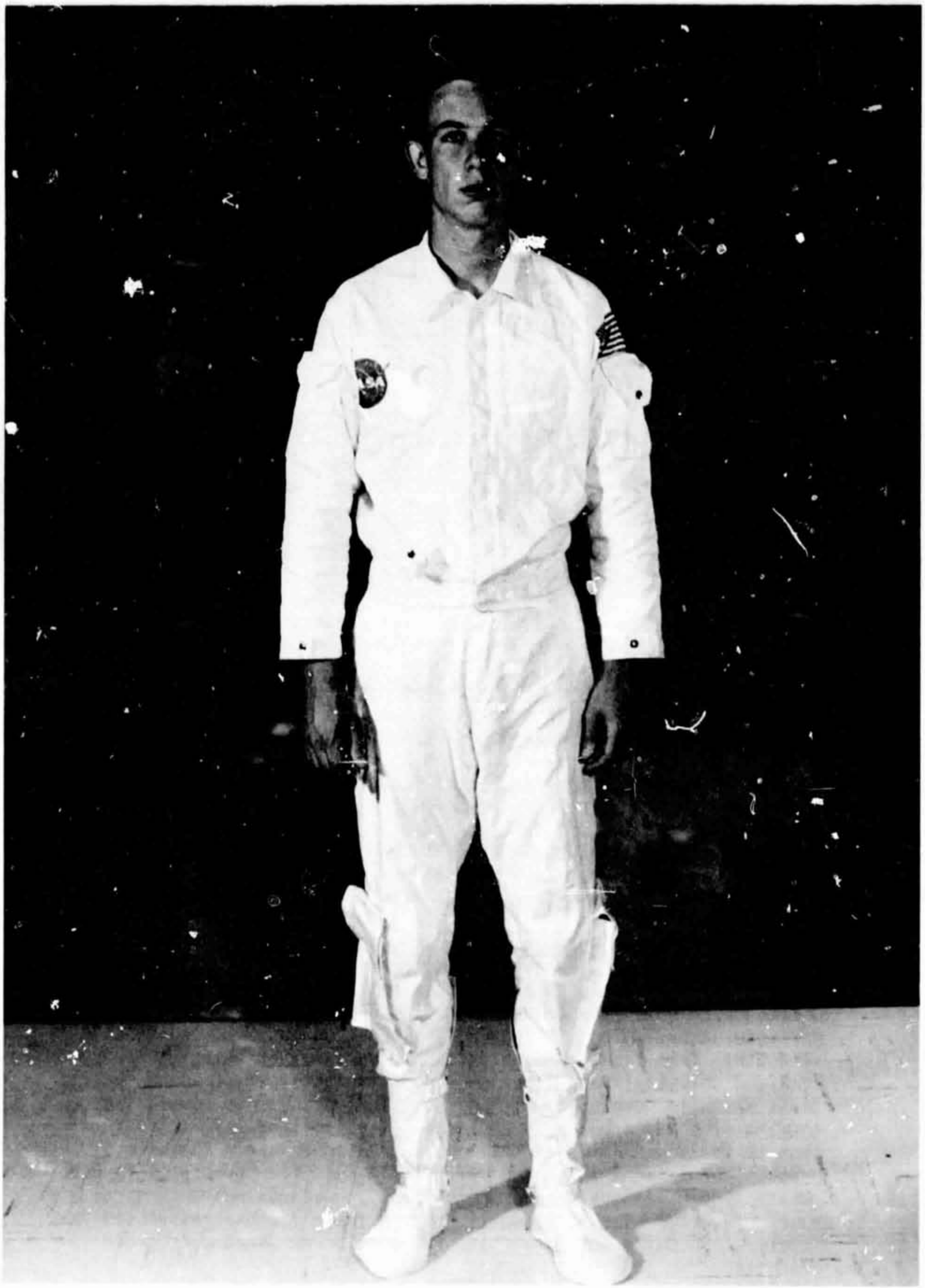

Figure 5. Apollo Intravehicular Flight Coverall

Figure 6. Skylab Intravehicular Flight Coverall

Figure 7 shows the typical application of this fiber in the sleep monitoring system of the Skylab Program.

2. New Fibers with Potential Aerospace Applications

Chlorotrifluoroethylene/Tetrafluorethylene Fiber (CTFE/TFE) and Chlorotrifluoroethylene/Ethylene Fiber (CTFE/E). These are flame-resistant fibers recently developed under NASA-JSC contract and are available only in experimental quantities. The CTFE/TFE copolymer has been spun into monofilament fibers, is self-extinguishing in oxygen-enriched environments, and produces practically no smoke. The CTFE/E copolymer fiber is available in multifilament fiber and light-fast colors. The mechanical properties of CTFE/E fibers are superior to commercially available teflon fibers and approach those of Nylon-6. The tenacity of this fiber is 3.5 grams per denier and elongation of 8 to 25%. This fiber has excellent flammability resistance and chemical inertness. In fabric form it will not ignite or propagate flame in atmospheres which contain as much as 51% oxygen. CTFE/E fabric will not melt or drip when exposed to direct flame. It is inert to hot acids, bases, and to strong oxidizing agents, and no known solvent dissolves this fiber at temperatures below 260°F.

Kynol Fiber. Kynol is a phenolic fiber which, upon exposure to flame, carbonizes immediately without the propagation of a flame front and is self-extinguishing on removal of the ignition source. The capacity to char with minimal shrinkage (15%) indicates that Kynol fiber will contribute to ablation while still providing substantial reinforcement. The insulating properties far exceed those of silica or carbon fiber composites. It is used in felts and battings as a fire barrier. The excellent resistance of Kynol to all organic solvents and most acids renders its use in filter applications ranging from hot engine oil to processes in which 300°F phospheric acid is used. Suits were made from this fiber, and were worn by firemen and drivers in the Indianapolis 500 race. The relatively low density of Kynol fiber also represents an important weight savings advantage.

Kevlar Fiber. Kevlar fiber has recently become commercially available. This modified aromatic polyamide fiber has twice the modulus of glass fiber and breaking strength three times that of nylon. This fiber holds considerable promise for reinforcing high performance laminates, where high-temperature and high-strength to weight ratios are important. Kevlar is flame-resistant in air and also has potential for nonreinforcing, static applications such as high-strength cables and specialty fabric where dynamic abrasion is not required. The stress fatigue and vibration damping properties are superior to those of glass fiber. Its high strength and low density over fiberglass (1.4 versus 2.5) results in significant weight and volume savings.

Improved Aromatic Polyamide Fiber - HT-4. Ht-4, an improved aromatic polyamide, promises to give improved flammability protection. As a comparison, Nomex flame break-open time is 1.2 second, where the equivalent time for HT-4 is 60 seconds. Fabrics from HT-4 fiber offer a major advance in protection over Nomex in fire

Figure 7. Skylab Sleep Monitoring System

exposures just as Nomex was a major advance over nylon and cotton. The protection characteristics of HT-4 have been obtained with no sacrifice such as comfort, abrasion resistance, coloration and light fastness. This fiber will become available commercially in 1975.

Bisbenzimidazobenzophenanthroline - BBB Fiber. In recent years a considerable amount of research effort has been expended on the development of polymeric fibers with significantly better high-temperature performance than commercially available materials. Polybisbenzimidazobenzophenanthroline polymer has been successfully formed into fibers. The fiber exhibits superior thermal stability and excellent resistance to ultraviolet radiation. No significant change in tenacity, elongation or modulus is evident after 400 hours simulated solar exposure by Xenon arc. It retains 50% of original strength after long term (30 hours) high-temperature exposure in air (680°F) and 55% at 1110°F in air after one minute exposure. Its zero strength is 1400°F. This fiber should find many applications as high-temperature insulation, parachutes, composites, and fire-protective clothing; however, it will not be available until public interest warrants its usage in production quantities.

Polyimide Fiber. The demand on high-performance fibers have intensified due to many aerospace applications and increased public awareness towards safety standards. Therefore, a new fiber development program has been initiated by NASA-JSC utilizing polyimide polymer which is known for its low-smoke generation, high-temperature, and flame-resistance performance. Preliminary experimental work on processing of the polyimide polymer indicated that breaking tenacity of over 4 grams have been achieved and can be improved significantly with further process development. Temperature resistance up to 1060°F has been observed. Fibers still retain 50% of their original strength after 100 hours at 575°F. Flammability test results show that fibers are inherently self-extinguishing in air and will not propagate flame under 40% of oxygen atmosphere. This fiber has potential applications as a lightweight thermal insulation as well as fire safe clothing.

New Treatment. Previous work with aromatic polyamides verify that improvement of flame-resistance is feasible through chemical modification such as phosphorylation. Such treatments, however, have resulted in fibrous products which are brown or black and which exhibit severely degraded physical properties. A flame-resistant, fabric treatment development program has been initiated by NASA-JSC. This new proprietary chemical treatment is being developed and has exhibited no alteration of color or loss in physical properties. The treatment, on a laboratory basis, effectively protects aromatic polyamides fibers from ignition and flame propagation, while simultaneously improving its tactile comfort.

PLASTICS

Plastics have many applications in the space program. Their use, however, does not imply nonflammability in the usage environment. Flammable plastics were protected with fire-resistant covers or were of small enough size in each location so as not to constitute fire hazard. The application of plastics in the space program is shown in figure 8 and ranges from transparent, thermoforming materials such as space suit helmets and visors, instrument meter faces and light panels, to thermosetting molded components and reinforced structural laminates. The plastics available at the beginning of the Apollo Program included polyamides, polyesters, polycarbonates, olefins, styrenes, vinyls, acrylics, epoxies, melamines, phenolics, ureas, and many others. As with most of the nonmetallics available for use in the Apollo Program, commercial needs resulted in materials that had almost all of the desired properties except that of flame-resistance in an oxygen atmosphere. Figure 9 shows the properties of plastics materials.

Efforts to improve the flame-resistance of the plastics by the industry are encouraging. For example, an improved polycarbonate which exhibits excellent flame-resistance in air without sacrificing the outstanding transparency and impact resistance for which polycarbonates are known. Several high-temperature flame-resistant plastics have been recently developed, or modified and available on the market which show excellent potential for future space program applications.

1. Typical Plastics for Aerospace Applications

Polyimides. High-strength resin systems that can be used to produce flame-resistant foamed and laminated structures are polyimides (PI), polyquinoxalines (PQ), and polybenzimidazoles (PBI). Polyimide/fiberglass composites for Apollo applications were very successful and were flame-resistant and low-smoke producers even in pure oxygen environments. More than 2000 parts representing more than 50 different design configurations were manufactured from this polyimide system for use in the Apollo Program. A flight tape recorder case is made of polyimide/fiberglas composite and is shown in figure 10. Although PQ and PBI plastics are performing well, the high cost of these materials has limited their applications in the space program.

The polyimides, in film form (Kapton) and the halogenated polyethelenes (Teflon) are outstanding electrical wire insulations. Both have been used in the Apollo and Skylab programs. The Kapton insulation is somewhat stiffer than the Teflon and has a higher service temperature, a fact that though desirable makes conventional thermal stripping difficult.

Rigid and flexible polyimide foams are also available. A series of lightweight resilient moldable polyimide foams having nominal densities of 1, 2, 4, and 6 pounds per ft^3 have been developed under NASA-JSC contract, which would not burn when used as a packaging material in the Skylab environment. This foam represents a class of nonburning, low-smoke producing foams which can operate at temperatures from -320^oF to over 500^oF and which, in static applications, offer excellent thermal acoustic and electrical protection.

Figure 8

Typical Applications of Plastics

Description	Applications
Polyimide	Adhesives, Laminates for Panel Covers, Food Boxes, Film for Thermal Blanket, Wire Insulation, Mechanical Shaver Cases, Flight Tape Recorder Cases
Tetrafluoroethylene (Teflon)	Wire Insulation, Wire Bundle Wrap, Wire Clamps, Liner for Wire Tray
Epoxy	Adhesives, Sealants, Potting Compounds, Conformal Coatings, Fiberglass Laminate
Methyl Methacrylate (Plexiglass)	Dial Faces, Electroluminescent Panels
Polycarbonate	Space Suit Helmet, Dial Faces, Reaction Chamber for Crystal Growth Experiment, Mousehouse for Biostock Experiment
Polypropylene	Plunger Detents, Pins, Lamp Sockets, Tape Over Glass Dial Faces
Acetal (Delrin)	Screws and Washers in SIM* Experiments, Rods in SIM Experiments and Portable Life Support System
Phenol Formaldehyde	Circuit Breakers, Connectors, Connector Inserts
Polyvinylchloride	Wiring Insulation on Bio-Instrumentation
Polyamide	Washer on Electroluminescent
Melamine Formaldehyde	Circuit Breaker, Electronic Packaging Housing, Switch Housing
Chlorotrifluoroethylene	Connector Pin Inserts, Urine Bag

* Scientific Instrument Module

Figure 8 continued

Description	Applications
Polyethylene	Bellows, Gears, Wire Wrap, Identification Sleeves
Diallyl Phthalate	Electrical Connectors, Terminal Boards, Potting Compounds, Terminal Blocks
Polysulfone	Visor for Extravehicular Activity

Figure 9. Properties of Plastics

Description	Specific Gravity gms/cc	Tensile Strength psi	Elongation %	Service Temperature °F	Flammability LOI	Flammability Smoke Density
Polyquinoxalene	1.3	15000-22000	3-7	900	90	20
Polyphenylene Sulfide	1.5	11000-21000	3	600	51	73
Polyimide	1.4	17000-20000	6-18	600	60	0
Aromatic Polyimide	1.4	17000	10	600	44	4
Tetrafluoroethylene-Perfluoro-Alkoxy Copolymer	2.1	4300	300	550	90	3
Polyparabanic Acid Polymer	1.3	15000	15-60	500	43	13
Polyaryl Sulfone	1.36	13000	13	500	35	31
Tetrafluoroethylene	2.1	2000-5000	200-400	500	95	3
Polyarylene	1.3	13200	140	500	57	2
Aromatic Copolyester	1.35	10000	7-9	500	42	109
Tetrafluoroethylene-Ethylene	1.7	12000	200	450	39	2
Chlorinated Aromatic Polyether	1.42	10000	20	400	70	4
Polyimide-Amide	1.38	17000	10	400	43	84
Chlorotrifluoroethylene Copolymer	2.1	8000	200	400	90	53
Polyamide 66	1.45	15000	3	350	28	3
FR Polyester	1.37	5400	10	350	40	35
Polysulfone	1.24	10200	50-100	350	30	10
Polyethersulfone	1.37	12200	20-50	350	37	13
FR Polypropylene	1.25	3600	15	300	25	25
FR Polycarbonate	1.2	9500	100-130	250	32	16

Figure 10. Flight Tape Recorder

Tetrafluoroethylene (TFE). TFE polymer has a combination of mechanical, electrical, chemical, thermal, flame and frictional resistant properties unmatched by other plastic materials. Commercial exploitation of these and other unique properties combined in one material has established TFE polymer as one of the outstanding engineering materials for use in many industrial, military applications. Useful mechanical properties are maintained from -450^o to 500^{o}F. The surface of fabricated parts have an extremely low coefficient of friction. Almost no materials can be bonded; however, special treated surfaces will accept conventional industrial adhesives. TFE resin is almost completely inert to chemical attack but under special conditions, are affected by such substances as alkali metals and halogens. When load is applied over a period of time, creep and cold flow must be considered. Low-loss electrical characteristics remain essentially constant, regardless of frequency, over a wide temperature range. Applications include electrical insulation, packings, valves, gaskets thread sealant, equipment liners, braided hoses, pumps, coatings and many others.

Chlorotrifluoroethylene (CTFE). CTFE is a thermoplastic resin produced in varying formulations from combinations of fluorine-containing monomers, and differs from other fluoropolymers in that its molecular structure contains chlorine. CTFE resins have inherent flexibility, radiation resistance and clarity. They are chemically resistant to all inorganic corrosive liquids including oxidizing acids. CTFE remains functional over a -400^o to 400^{o}F temperature range. Its low vapor transmission makes it an outstanding gas and liquid barrier. In electrical properties, it shows high volume and surface resistivity at both high and low temperatures. CTFE have been fabricated as urine bags, connector pin insert and components for use in the spacecraft. Because of its unique properties CTFE is ideal for flexible cable jacketing, cable assemblies, valves, fittings, pipe seals, gaskets, O-rings, packaging of pharmaceutical and medical supplies applications. It can also be used in surgery and for electrolytic diaphragms.

Polysulfone. Polysulfone is a transparent (light amber), rigid high strength thermoforming plastics which maintain their properties over a temperature range from -150^{o}F to above 300^{o}F. Long term thermal aging at 300 - 400^{o}F has little effect on the physical or electrical properties. Additionally, polysulfone has very low creep and cold flow properties. Depending on the formulation, polysulfone can be molded or extruded for a variety of applications in the areas of electronics, automotive, aircraft and household appliances. Because of its good balance of mechanical, electrical, optical properties and ability to withstand temperature extremes and ease of fabrication, polysulfone was the choice for the gold plated outer protective visor for astronauts and other applications in the spacecraft.

Polycarbonate. One of the most outstanding and versatile groups of thermoplastics, polycarbonate has gained wide acceptance in manned spacecraft as well as unmanned satellites. Unnotched bars show impact resistance greater than 60 ft pounds. The strength compares very favorably with those of some metals. Light transmission is greater than 90 percent. The optical properties compare favorably with acrylics and glass. Their unmatched combination of high impact strength, optical clarity, dimensional and thermal stability, points toward an ever increasing number of applications in the broad areas of appliance,electronics, lighting, automotive and communications. Polycarbonate can be thermoformed into a number of diverse applications where it is superior to other materials such as aircraft ducting, helicopter canopies, bullet proof windshields and safety glass for areas subject to vandal attack or frequent abuse.

2. New Plastics with Potential Aerospace Applications

Polyimides. A linear amorphous aromatic polyimide has recently been marketed which, because it is not cross-linked, has a degree of thermoplasticity. This resin can be procured to a very high molecular weight, with the elimination of all volatiles and subsequently press cured to remove all voids. Composites exhibit levels of toughness, resilience and fatigue resistance not previously obtained in polyimide system. The resin is compatible with a variety of reinforcing fibers ranging from fiberglas to quartz, graphite and boron, and can be produced either by vacuum bag, autoclave molding or compression molding. They exhibit excellent mechanical and electrical properties at ambient temperatures as well as temperatures in the 500°F to 700°F range. As an adhesive, this material provides tough and resilient bonds between metals and/or composites even at high temperatures.

A high-strength polyimide syntactic foam is also available for structural and insulation applications. It is a rigid, high-temperature, nonburning, smokeless material which looks and may be worked like wood. It may be nailed and will retain ordinary wood screws. It is available in densities from 15 to 32 pounds per cubic foot, and is being evaluated for Space Shuttle interior panel applications.

Polyphenylene Sulfide. This polymer has a high thermal stability and can be used at temperatures as high as 600°F for prolonged periods of time. It has outstanding chemical resistance and is nonburning. In air, degradation is essentially complete at 1324°F, but in an inert atmosphere approximately 40 percent of the polymer weight remains at 1864°F.

The polymer is characterized by high stiffness and good retention of mechanical properties at elevated temperatures. These properties and its strong affinity for a variety of fillers provide excellent utility in the molding and coating industries.

Polyparabanic Acid Polymer (PPA). A new thermoforming polymer based on polyparabanic polymer has recently been developed. This material has a linear amorphous aromatic structure and has a high heat distortion temperature as well as outstanding dimensional stability. Films of PPA remain flexible in liquid nitrogen and are reputed to have strengths at 500°F which are comparable to that of tetrafluoroethylene at room temperature. It can be melt processed from powders by conventional compression molring. The material should find application as a film, moldings, coatings, composites, wire insulation and adhesives.

Tetrafluoroethylene-Perfluoro-Alkoxy Copolymer. This polymer is designed for extended service in environments which demand high levels of chemical, thermal, and mechanical performance. It has superior thermal stability which showed no loss in tensile strength, yield or elongation after 5000 hours at 545°F. The combination of toughness, exceptional dielectric properties, non-aging characteristics, weather resistance, excellent flex life, low coefficient of friction, nonburning, and chemical inertness make it useful as a liner for chemical process equipment, in specialty tubing and in molded articles for a variety of end use applications. This material is now finding applications in such electrical areas as high-performance signal, control, communication and power wiring in mass transportation; in oil well logging cables; in critical wiring for utilities; molded coil forms; sockets; connectors; switch components; and insulators. It is also being widely evaluated in applications requiring excellent chemical compatibility together with resistance to damage caused by thermal cycling, vacuum exposure, or mechanical flexing.

Polyarylsulfone. To meet the need for plastic materials with high thermal capabilities, the polyarylsulfones appear to be potential candidates for this type of application. The polyarylsulfones are linear polymers and offer the unique combination of thermoplasticity and retention of structurally used properties at 500°F. They have many outstanding features among which are high tensile strength, high modulus, and excellent thermal oxidative stability. No significant degradation was observed after several thousand hours at 500°F in air. The polyarylsulfones are resistant to hydrolysis even in contact with strong acids and bases. They resist chemical attack and stress cracking by a wide variety of chemicals. The first compound is now being manufactured as a resin for molding compounds, film forming, and coatings. The advantages offered by this polymer in high-temperature performance, solvent resistance, strength, electrical insulating properties, weight savings, and ease of fabrication make the material well suited for previously restricted to metals and ceramics and in areas where conventional thermoplastics or thermosets have proved inadequate.

Aromatic Copolyester. This is a new high-performance aromatic copolyester polymer. The advantages cited for this polymer are flame-resistant, long-term thermal stability, and strength retention at temperatures in excess of 550°F; low-moisture absorption, good friction and wear properties, and superior dielectric performance. It can be injection molded at rapid cycles (15 seconds or less) on conventional unmodified equipment. It is being field tested for a variety of small parts requiring high strength at elevated use temperatures such as electrical/electronic components, bearings for fractional horsepower motors, and radiation resistant valve parts.

Chlorinated Aromatic Polyether. This experimental polymer exhibits high-temperature engineering properties beyond the capabilities of conventional existing thermoplastics. This polymer which is amorphous and transparent with a light tan color. It has unusual resistance to hot water and low pressure steam. It is an excellent electrical insulator and has a low dielectric constant and loss factor which remains at low levels to high temperatures and high frequencies. Because it contains chlorine, the polymer is self-extinguishing in environments containing up to 70 percent oxygen. Moreover, the polymer gives off very little smoke, having one of the lowest smoke generation levels of any of the thermoplastics. Its potential applications include industrial process hot water piping and fittings, insulation for large hot appliances, panels for aircraft interiors, windshields for high-performance aircraft, electrical conduits, equipment for low-pressure steam, and cooling systems for internal combustion engines.

Polyimide-Amide. Polyimide-amide polymer is a new extra high-performance molding resin This polymer provides improved performance in valves, bearings, gears and other functional parts which have primarily been the province of metallic materials. It has outstanding thermal stability (94 percent of original tensile properties are retained after aging at 500°F for 2000 hours), and compatibility with many filler and reinforcing systems. Because of their excellent physical and electrical properties this polymer has earned wide acceptance in magnet wire enamel, decorative finishes for cookware, and laminating varnishes.

Polyethersulphone. Polyethersulphone was developed primarily for use in injection molding but it may also be extruded. It is low-smoke producing, nonburning, and capable of operating at temperatures above 400°F. The polymer shows a good resistance to chemical attack in particular from acids, alkalis, oils, and greases. The effect on the mechanical properties of polyethersulphone when aged in air at 300°F for one year, the yield stress remains unchanged. Accelerated heat aging tests show that the polymer has a predicted useful life of 20 years at 360°F. Other tests show that the material still retains 80 percent of its initial strength after 4 weeks in air at 480°F. These results suggest that polyethersulphone could be suitable for some electrical insulation applications. Other principal application areas forseen are: specialized adhesives, lacquers, components for domestic appliances, printed circuit boards, T.V. components, fuel cells, instrumentation housings, connectors, automotive and aircraft interior decor, bulb housing, etc.

ELASTOMERS

The development of elastomers suitable for the Apollo Program was one of the most challenging materials development problems. The solutions are at dissonance with the requirements even more so than for the other nonmetallics. The solutions to the problem appeared to be to develop heavily fluorinated elastomers that were stable at temperatures beyong those normally encountered in the Apollo Program and to assure, by critical selection of the nonmetallic materials to be used in Apollo spacecraft, that thermal decomposition by fire is highly unlikely. Typical applications and properties of elastomeric materials are shown in figures 11 and 12 respectively.

1. Typical Elastomers for Aerospace Applications

Silicones. Of the elastomers available at the beginning of the Apollo Program, the silicones exhibited the widest range of favorable attributes. Silicones can be cured at low temperatures, they have a good service temperature, good elongation, low compression set and reasonable tensile strength, and, most important for deep space applications, they remain flexible at temperatures lower than any other acceptable elastomer. The silicones, unfortunately make an excellent fuel in pure oxygen and attempts to render them flame-resistant failed until late in the Apollo Program.

Carboxy Nitrosos. Initial efforts to obtain a substitute for silicones were made under NASA-JSC contract using carbosy nitroso rubber (CNR). CNR is a completely fluorinated terpolymer, exhibits excellent elastomeric properties, and is extremely flame-resistant even in pure oxygen environments. Unfortunately, the demand for this elastomer was not sufficient to permit reducing the cost of CNR by production scale-up. Experiments comparing CNR and Teflon (by Thiokol) indicated that at pressures up to 600 psia in pure oxygen, teflon sheet samples could be ignited while CNR sheet samples would not ignite or char. CNR is a versatile rubber compound; products include foams, impregnated fabrics, potting, conformal coatings, adhesives, and films.

Fluorocarbons. Because of the problems encountered with CNR, programs were initiated to continue to develop flame-resistant fluoropolymers, namely viton and fluorel. These materials are available in a variety of compounds, including fabric coatings, spray coatings, foams, adhesives, and moldable gum stock. The compounds have respectable mechanical, chemical and high-temperature (750°F resistant properties). The useful flexibility at very low

Figure 11

Typical Applications of Elastomers

Description	Applications
Silicone	Adhesives (RTV), Potting Compounds, Conformal Coating, Wire Clamps, O-Ring Gaskets, Hoses, Pads, Cushions
Fluorocarbon	Hose, Headrests, Cable Coating Shock Absorbers, Spacer Eyepiece, Adhesives, Flame Protective Surface Coating, Space Suit Boot Soles, Seals on Window Covers, Wire Clamp Fillers, Wire Insulation, Insulation Blanket
Chloroprene	Space Suit Bladder, O-Ring Grommets, Washers, Clamp Pad Adhesives
Butyl	Hatch Seal, O-Ring, Gaskets, Shock Attenuation, Packings
Nitrile	O-Ring, Valve Seats, Valve Packing. Gaskets
Urethane	Potting Compound, Conformal Coating, Sealants, Adhesives, Insulation
Polyacrylic Rubber	Liner in Fuel System
Polyisoprene	Bladder for Water Tank
Fluorosilicone	Heat Shrinkable Tubing

Figure 12. Properties of Elastomers

Description	Specific Gravity of Base Polymer GMS/cc	Tensile Strength, psi	Elongation %	Durometer Hardness Range	Service Temp °F	Flammability LOI*	Flammability Smoke** Density
Natural Rubber	0.9	1500-4000	675-850	40-90	-65-225	20	660
Nitrile	1.00	600-4200	600-700	50-85	-40-250	20	660
Butyl	0.92	2300-3000	680-840	40-90	-65-225	20	660
Styrene Butadiene	0.94	1500-4000	400-800	45-70	-65-225	20	660
Ethylene Propylene	0.86	2400-4000	400-500	60-65	-65-300	20	660
Polysulfide	1.34	600-1300	300-500	40-80	-65-225	22	400
Chloroprene	1.23	1500-4000	60-700	40-90	-65-300	23	660
Chlorosulfonated Polyethylene	1.1	500-2800	200-560	60-95	-65-250	31	230
Butadiene	0.9	3000	500	40-90	-65-225	20	660
Polyurethane	1 05	4500-7500	400-750	55-85	-65-225	25	530
Fluorocarbon	1.4-1.95	1800-2400	150-350	60-90	-40-450	>90	130
Silicone	0.98	300-1500	90-500	40-80	-150-600	22	385
Flurosilicone	1.4	700-1000	140-250	35-80	-75-450	30	150
Polyacrylic	1.10	500-2200	100-400	40-100	0-350	21	400
Carboxy Nitroso	1.93	1000-2000	150-800	35-80	40-375	>95	5
Polytriazines	1.8	1500-2500	300-630	70	0-500	90	15
TFE/PMVE/PPVE	1.9	3000	210	80	0-400	90	5

*Limiting Oxygen Index

**Flaming

temperatures is inferior to that of the silicones, limiting their use for deep space applications. Coatings can be used to protect flexible flammable substrates; however, they were not suitable for applications that required dynamic flexing. A fluorocarbon oxygen hose is shown in figure 13.

Flame-Resistant Silicones. Because of the low-temperature limitations of the fluorocarbon compounds a program was initiated to develop flame-resistant silicone compounds. This program had limited success. All compounds developed were flammable in pure oxygen environment unless extremely heavily loaded with flame retardant. Some compounds, however, self-extinguished in 70 percent oxygen-enriched environments at 6.2 psia. Typically, in addition to halogens for increased flame-resistance results in a corresponding degradation of desirable mechanical properties. The addition of halogens did adversely affect elastomeric resilience.

Fluorosilicones. Fluorosilicones are new engineering materials combining the best properties of fluorocarbons and silicones. A sizeable gap, in useful properties, has long existed between these two thermally-stabled polymers. Fluorocarbons are highly resistant to fuels and solvents while many silicones are not. Silicones are serviceable at very low temperatures while fluorocarbons are not. Cross-breeding has resulted in fluorosilicones with most of the strengths of both parent materials and other unique advantages.

Fluorosilicone rubber provides exceptional resistance to prolonged immersion in fuels, oils and solvents coupled with unexcelled silicone stability. It resists compression set and maintains good tear and tensile strength over wide temperature extremes up to 450°F in air, or 350°F when immersed in solvent-like fluids. Unlike fluorocarbon elastomers, fluorosilicone has outstanding resistance to low temperature and remains stable in prolonged exposure to -75°F and below. It can be easily fabricated into virtually any size or shape by molding, extrusion, calendering, dispersion coating or foaming. It is also available in a wider range of hardness than fluorocarbons. Fluorosilicone inherits the resistance of silicones to radiation, ozone, moisture, weathering, aging and electrical stress.

Fluorosilicone is ideal for fuel and solvent resistant O-rings, seals, gaskets, diaphragms, connector inserts, valves, wire and cable insulation, and other products.

Fluorosilicones are also available as adhesives, sealants, lubricants and fluids.

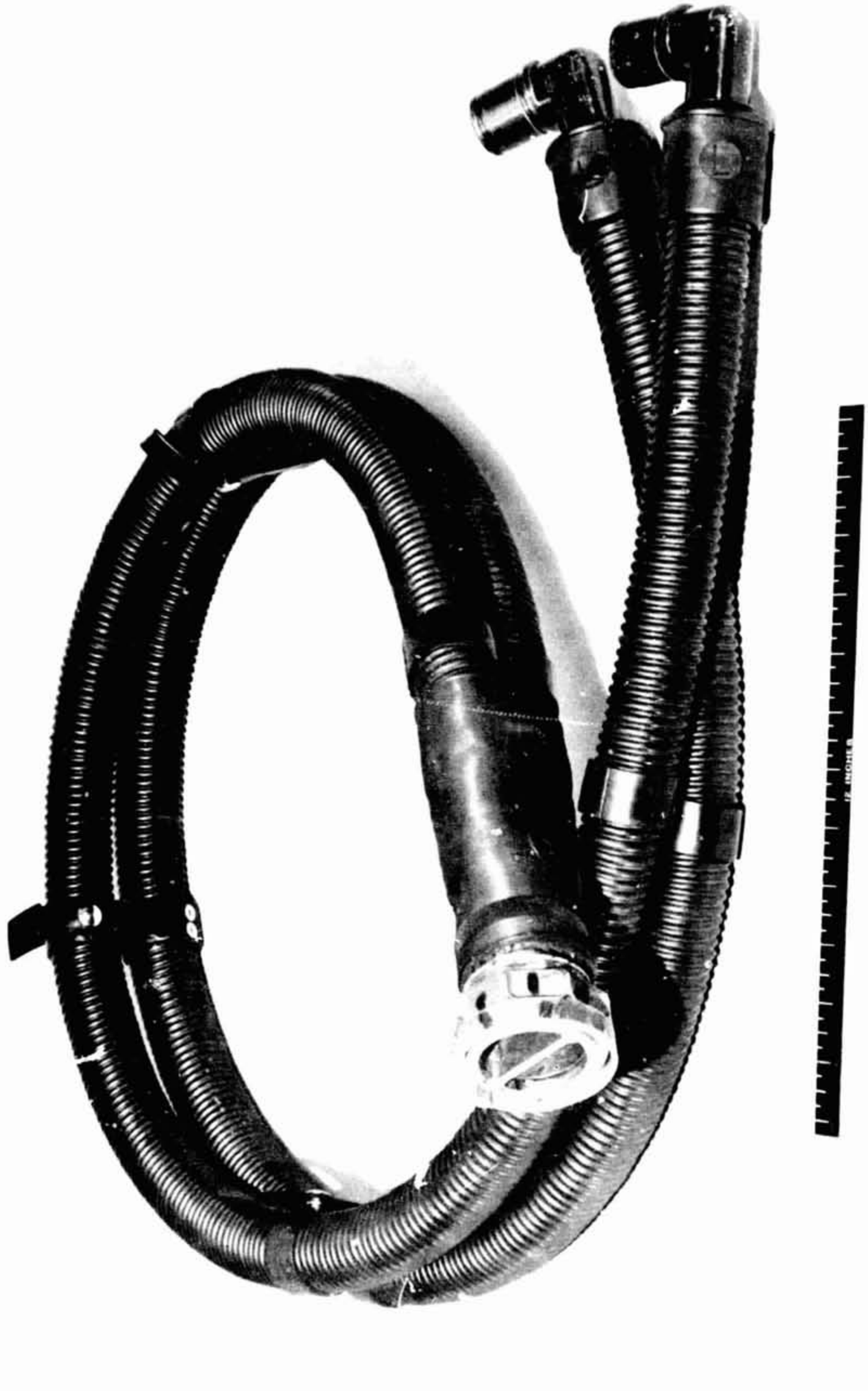

Figure 13. Oxygen Hose

2. New Elastomers with Potential Aerospace Applications

Few new elastomeric materials have been developed under Air Force contract, notably, the polytriazines, and a terpolymer of Tetrafluoroethylene, prefluoromethyl vinyl ether, and perfluorophenyl vinyl ether.

Polytriazines. The polytriazines have been found to be extraordinary in their ability to retain their elastomeric characteristics and strength at and after aging at extremely high temperature. It appears to be superior in this respect to other known elastomers. Properties of the elastomers are not degraded by exposure to temperatures of 500°F. The polymer is highly resistant to most fuels and solvents. Tests at 212°F in fuel and water (31 days) show only traces swelling suggesting its for fluid seals and sealants. The Hydrolytic stability of the vulcanized polymer appears good. It has survived 72 hours exposure in boiling water without changes.

TFE/PMVE/PPVE Terpolymer. The terpolymer of tetrafluoroethylene (TFE), perfluoro methyl vinyl ether (PMVE) and perfluorophenyl vinyl ether (PPVE) is not degraded after 400°F exposure. Immersion in 50/50 N_2H_4 - unsymmetrical dimethylhydrazine (UDMH) for three months at room temperature also had no effect upon mechanical properties. This seems to be a most promising elastomer for O-ring, seals, gaskets in N_2O_4 application

TECHNOLOGY UTILIZATION

A major objective of NASA is to encourage maximum commercialization of aerospace materials for the benefit of general public. It appears certain that, just as NASA has been able to render the spacecraft safe from fire, a commercial and military usage of these nonmetallic materials can and will result in safer homes, clothing, aircraft, hospital, marine craft, and automobiles, etc. Towards this end, the NASA Technology Utilization Office has funded several programs to test the feasibility of utilizing flame-resistant aerospace materials in nonaerospace applications. Typical examples of these programs are presented as follows:

Fire Suit

NASA has engaged in a cooperative effort with Houston City Fire Department to design, fabricate, and evaluate fire suits utilizing flame-resistant materials. This effort culminated in a NASA prepared specification for fire protection for the fireman, while providing comparable or increased functional properties. The garments which have been developed and fabricated under this program are identified as proximity and structural fire fighters suits and ancillary clothing items. As shown in figures 14, 15 and 16, each clothing item is required to accomplish a different function as regards protection of personnel involved in fire fighting or rescue operations.

Structural and proximity fire fighters clothing are designe' o fulfill the following functions:

Figure 14. Structural Fire Fighter's Suit

Figure 15. Proximity Fire Fighter Suit

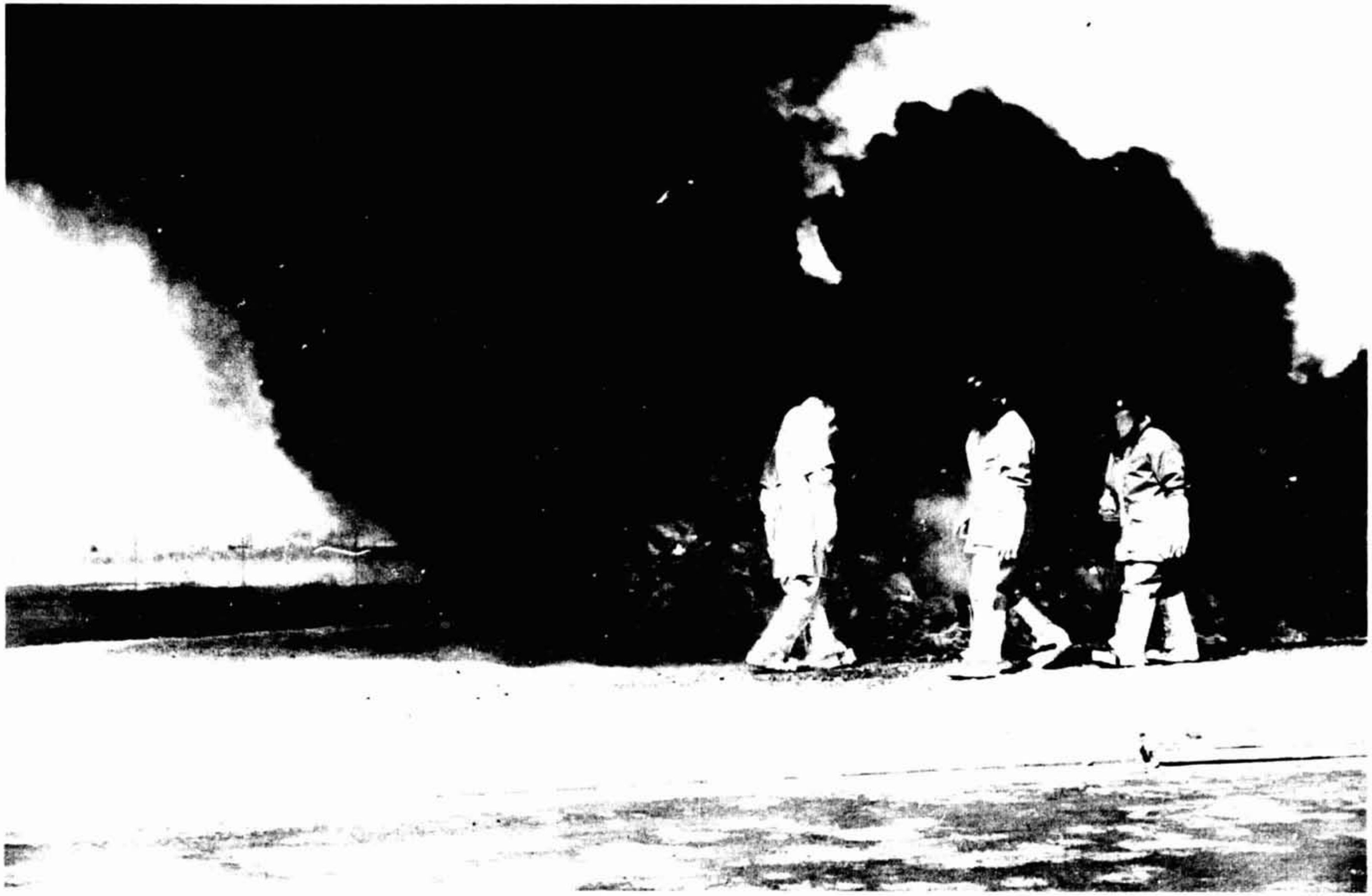

Figure 16. Fire Fighter Suit Demonstration

Structural Fire Fighters Suit. This suit is normally worn by personnel engaged in fire fighting activities. It is designed to be protective in nature, including safeguarding against temperature extremes; possible exposure to flashing, sparks, or embers; steam or hot water; sharp objects; and abrasion and other hazards encountered during fires and emergencies.

Proximity Fire Fighter Suit. This type of clothing is designed to protect fire-fighting personnel from radiant heat as may be encountered in working close to extremely hot fires. Should rescue of personnel be required these suits may be required to withstand intermittent exposure to direct flame.

The garments have been provided to fire departments across the nation for field evaluation under all possible climatological conditions.

Aircraft Cabin Interior Refurbishment

Many of the flame-resistant materials developed for spacecraft applications, when properly adapted for use in aircraft interiors can make a significant contribution toward a fire-safe aircraft cabin interior. Therefore, NASA has refurbished its executive aircraft with aerospace materials to obtain baseline data on durability, cleanability, and the other factors which are important if materials are to be accepted by commercial airlines. A photograph of a refurbished Gulfstream aircraft is shown in figure 17.

A Boeing 737 Air Frame has been transferred to NASA-JSC for confirmatory flammability testing to verify the superiority of the new materials in resisting fire propagation. The flammability tests were conducted utilizing the current and aerospace materials to obtain flammability smoke and toxicity data. Latest tests indicated that the materials have greatly reduced fire spread, smoke and toxic gas evolution. Details on these flammability tests are covered in the paper entitled "Fire-Resistant Aircraft Materials Development and Evaluation Program," by Richard Bricker and Robert Stuckey.

Household Interior Furnishings

To demonstrate the many possibilities for use of aerospace materials as interior furnishings in apartment buildings, nursing homes, hospitals, etc. NASA has furnished four typical rooms in a controlled flammability test program. Each room was furnished so that instrumented comparisons of fire safety could be made between the variety of current commercial available and flame-resistant aerospace materials.

The following are the descriptions of each room:

1. The "typical room" furnished with items made of conventional materials ignited easily and burned rapidly; after 8 minutes, the contents of the room were nearly destroyed.

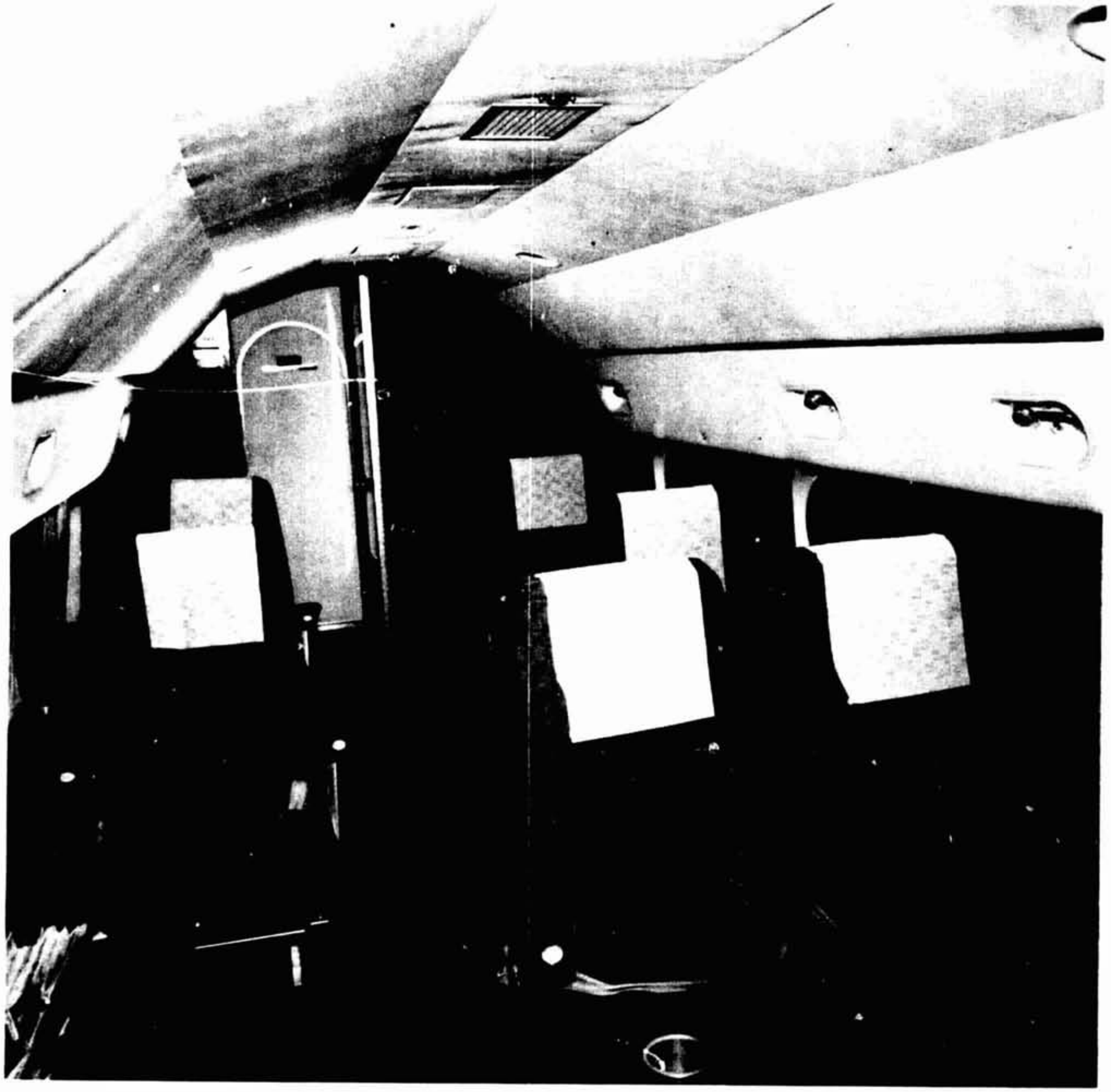

Figure 17. Aircraft Cabin Interior Refurbishment

2. The "improved room," furnished with materials selected as being among the best commercially available, showed substantial improvement over the "typical room." There was slower fire spread. However, the relatively complete destruction of the room contents resulted large amounts of smoke, made it clear that further improvements were needed. This fire was stopped after 29 minutes.

3. The "space-age room" was furnished completely with new materials that were not yet commercially available. It did not ignite under the normal ignition conditions and demonstrated the substantial improvement in fire resistance for those materials close to the ignition source. A second and larger ignition arrangement showed that this room can burn, but the difficulty in achieving this confirmed the improved fire resistance with use of "space age" materials.

4. The "mixed room ensemble" was furnished with materials identical to the "typical room." The only exception was substitution of the bed from the "space-age room." Control of fire spread illustrated that careful placement of flame-resistant materials in the fire paths would reduce the fire hazard of an otherwise ordinary room.

Figures 18, 19 and 20 show the "space-age room" interior furnishings before and after the fire as compared with the "improved room" after the fire.

In the related but separate field that was funded by Life Science Directorate, the following program was accomplished.

Biological Isolation Garment

Prior to lunar explorations many unknowns existed regarding the lunar surface, and in particular, there was a remote possibility that there could exist microbial life forms which could be highly infectious either human or earth life. Thus, a garment was developed to prevent possible contamination of the earth atmosphere with extraterrestrial life forms. The garment was designed to contain all particles of 0.45 micron size and to prevent particles from penetrating into the wearer and thus afford protection in contagious areas. It maintains a habitable environment without the use of any ground support ventilation or cooling system, and provide the crewman with unrestricted mobility while wearing the garment.

This garment becomes great interest to medical researchers in the area of immuno-deficiency and aplastic-anemia. NASA was contacted by the National Cancer Institute associated with patients receiving chemotherapy for lukemia. Requests for isolation garment information were received from the Boston Children's Hospital Medical Center, University of Minnesota Health Service Center, and other medical institutions. Recently, a request was received from the Baylor College of Medicine, Texas Medical Center, outlining a need for germ-free suit for use by a 2-1/2 year old child who is affected with severe immuno-

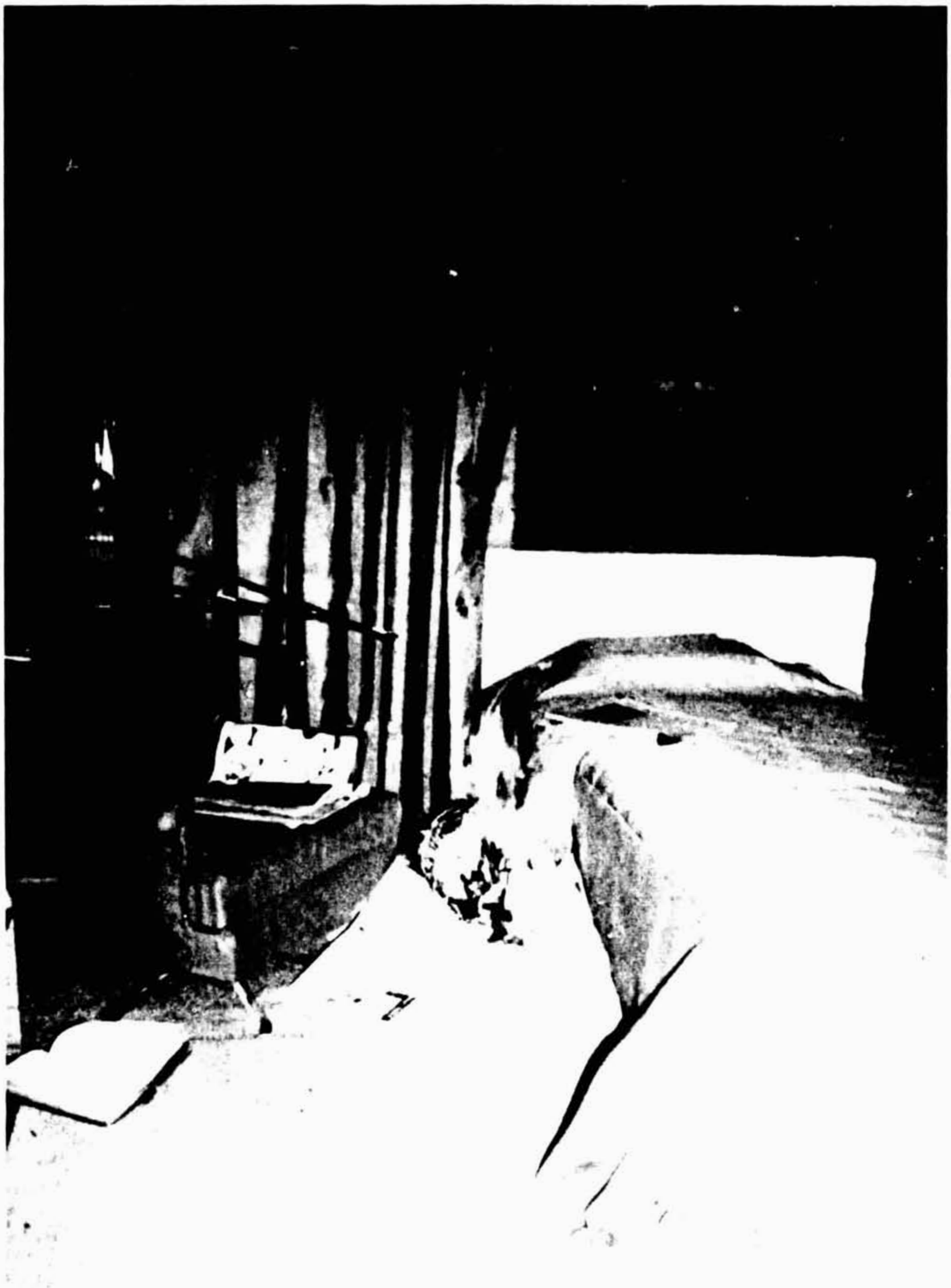

Figure 18. "Space-Age" Room Interior Furnishing Before Fire

Figure 19. "Space-Age" Room After Fire

Figure 20. "Improved Room" Interior Furnishing After Fire

deficiency, and has lived in a germ-free bubble since birth. Another cancer patient's gown was designed and developed and successfully used for oxygen-enriched hyperbaric chamber application at M. D. Anderson Hospital. A bio-isolation garment is shown in figure 21.

Additionally, and possibly on a much larger scale, such a suit would be very useful in isolating other patients with a variety of diseases that require limited exposure to other people and the environment such as heart, kidney, or other transplant patients.

CONCLUDING REMARKS

Many of the flame-resistant nonmetallic materials that were developed for the Apollo and Skylab programs are finding commercial and military applications. Interchanges of information are taking place with the government agencies, industries, educational institutions, which are interested in applications of fire-safe nonmetallic materials. They are particularly applicable to the design of aircraft, mass transit interiors, to residential and public building constructions, to nursing homes, and hospitals, and to other fields of fire safety applications. Figures 22, 23 and 24 show the potential non-aerospace applications of flame-resistant aerospace materials.

Figure 21. Bioisolation Garment

Figure 22

Potential Nonaerospace Application of Flame Resistant Aerospace Textiles

Household	Commercial or Industrial
Decorative furnishings such as drapes and upholstery; carpets and rugs, bed spreads, table cloth, clothings, blankets, mattresses, sofa tickings, sleep wear, sewing threads, sweaters	Thermal insulations, fire barriers or protective covers, fire protective clothing, rescue services, furnishings for nursing homes, hotels, hospitals and public buildings, aircraft and mass transit furnishings, uniforms, restraint harnesses, hospital gowns, racing car driver garment, packaging, tents, tarpaulins, cargo compartment liners, cargo covers, mooring lines, tether and towlines, industrial filters, hot gas filtration, filtration of corrosive chemicals, filtration felt, electrical insulations.

Figure 23

Potential Nonaerospace Applications of Flame Resistant Aerospace Plastics

Household	Commercial and Industrial
Furnitures and fixtures, wall covering, decorative panels, interior furnishings, mattresses and covers, pillows, shower curtains, baby pants, window shades, toys, boots, air mattresses, gloves, protective coatings, window frames, door moldings, weather stripping, floor coverings, seat covers, lamp bases	Sporting goods, office equipment, small appliances, automotive components such as crash pad, arm rest, molding, etc., machinery parts, instrument cases, housings, bottles, building panels, tiles, luggage, paints, adhesives, vehicle windows, street light lamps, cookware coating, radomes, motor insulation, mechanical fasteners, biomedical components, visors, business machines, computer parts, gears, nonlubricated bearings, molded and extruded articles, laminates.

Figure 24

Potential Nonaerospace Application of Flame Resistant Aerospace Elastomers

<u>Household</u>

Decorative or texturized coated fabrics for upholstery, draperies, seat covers and clothing; foams for mattresses, sofas, and pillows; decorative paints for walls and panels. toys, air mattresses, sleeping bags.

<u>Commercial or Industrial</u>

Fire protective paints or coatings for warehouses, hotels, schools, nursing homes, hospitals, and public buildings; ceiling tiles, floor coverings, wall panels, wire and cable insulation, packaging, seat foams for automobiles, aircraft and mass transits; automotive parts and accessories, fuel pipeline insulations, furniture and fixture covers, hospital equipment, mine safety equipment, appliance parts, fire protective coating for mail bags, aircraft interior coatings, gas masks, survival equipment, coating for cargo covers, and tents, shields for hazardous operations, oxygen hoses, adhesives, sealants, O-rings, gaskets, diaphragms.

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FIRE-RESISTANT AIRCRAFT MATERIALS DEVELOPMENT AND EVALUATION PROGRAM

Richard W. Bricker and Robert N. Stuckey

INTRODUCTION

Although commercial aircraft provide a remarkably safe means of transportation, when accidents do occur they sometimes involve fires that result in loss of human life, destruction of the aircraft, or both. A 1967 review of commercial jet incidents and accidents (ref. 1) revealed that fires caused or contributed to passenger deaths in 12 of 16 impact-survivable aircraft accidents occurring from 1958 to 1966. All 12 accidents involved external fuel fires that resulted in interior cabin fires in 11 cases. Several additional accidents resulting in loss of life because of fire or toxic products have occurred since 1967 (ref. 1). Fires in unattended aircraft have also resulted in gutted aircraft interiors. These accidents illustrated the need for improved fire-resistant materials for aircraft interiors.

Since the early 1960's, the manufacturers of commercial aircraft and the airlines, aided by the Federal Aviation Administration (FAA), the Aerospace Industries Association of America, Inc. (AIA), the Air Line Pilots Association, and the National Fire Protection Association have sought fire safety improvements by screening, testing, and using improved nonflammable and fire-resistant materials. The test programs included full-scale mockup flammability tests of aircraft interior configurations (refs. 1 to 5). Experience has shown that full-scale mockup tests are necessary. Individual materials that self-extinguish in laboratory tests may, when used in a final configuration with other materials, develop synergistic reactions to the ignition source, the configuration geometry, and the environmental conditions, resulting in a large fire.

As a result of the Apollo spacecraft command module fire in 1967 and of the ensuing investigations related to the Apollo Program, the Skylab Program, and so on, new materials having excellent fire-resistant qualities in an oxygen-enriched environment have been developed. The oxygen enrichment creates more stringent conditions than those encountered on present commercial aircraft. Some of these new promising materials were selected as candidates for this program.

PROGRAM OBJECTIVES

The overall objectives of this program are to provide a more fire-resistant commercial aircraft interior and to improve the fuselage insulation barrier between the cabin interior and an exterior fuel fire. Significant secondary objectives are to reduce the smoke and toxic gas production of the materials and to meet the end item use requirements pertaining to wearability, color fastness, and aesthetic appeal. The fuselage insulation materials must meet stringent requirements pertaining to acoustic attenuation, low density, and water repellency.

Although some work has been completed on improving insulation materials, this paper will present only the results of the NASA Lyndon B. Johnson Space Center (JSC) interior cabin materials development and evaluation.

MATERIALS APPLICATIONS AND REQUIREMENTS

The JSC program has been directed towards meeting the aircraft manufacturing requirements pertaining to physical properties of the material and towards improving the fire resistance by applying more stringent requirements concerning flammability and smoke production along with seeking materials that have a relaively high degradation temperature.

PHYSICAL PROPERTIES

The physical properties of candidate materials were given special attention and evaluation with a goal of providing newly developed and modified spinoff materials which meet or exceed the present standards.

Some of the spinoff materials from the Apollo and Skylab programs could not meet the serviceability and maintainability requirements of the aircraft cabin materials. Actually, spacecraft materials were not required to last longer than the mission, the longest of which was approximately 81 days (Skylab 3). Aircraft cabin materials must last several years to be economically useful.

Weight, which is important in aircraft fabrication, was controlled by the choice of lightweight high strength substrates used for the coated fabrics and by optimizing the coating thickness. The substrate also contributes to good tensile and tear strengths.

Aesthetic appearances of decorative skins were maintained by the conventional silk screening processes.

Cleanability is one of the most critical properties, since frequent cleaning is required without the use of harsh or flammable solvents, which should not be used or allowed on aircraft.

Cost continues to be a major hurdle in adapting space materials and in fabricating new materials for aircraft interiors. A small increase in unit price to the airline industry can result in a significant amount due to the large number of aircraft acquired by the airlines. Cost of the candidate materials was reduced by the use of lower priced substrates and optimizing the quantity of materials used.

In addition to optimum chemical and physical properties, a new material must be readily fabricated on conventional equipment with no major retooling (which would increase the cost). Also, the material must be capable of being installed in the aircraft with relative ease.

FIRE RESISTANCE AND RELATED REQUIREMENTS OF DEVELOPED MATERIALS

In order to make a significant contribution, chemical properties of materials more stringent than those currently in force had to be established for the newly developed and modified spinoff materials.

In the JSC program, the LOI (Limiting Oxygen Index) test was adopted for determining the flammability properties of materials rather than the FAA bunsen burner type test. The LOI test yields a number which is indicative of the flammability or, conversely, the fire resistance of the material. This number is the percent of oxygen in a mixture of oxygen and nitrogen below which a material will not sustain combustion. An LOI of 22-24 has been determined to be equivalent to the acceptable criteria of the FAA and other similar flame propagation tests. Based on JSC experience, a minimum LOI of 30 was established as the requirement for all newly acquired and developed aircraft cabin materials. It was felt that this value would screen out the most hazardous materials and provide candidates for specific cabin applications.

Many of the aircraft interior materials when pyrolyzed or burned produce copious quantities of smoke. The quantity of smoke is measured by determining, by optical methods, the reduction of visibility caused by the smoke from a burning test sample. The measurement is given numerically in terms of DSM (Maximum Specific Optical Density). In order to further upgrade the materials selections for aircraft cabin interiors, the SMD requirement was made more stringent by setting an average value of 50 rather than the previously proposed value of 200.

When a material is pyrolyzed or burned, certain gases, potentially toxic, are given off in addition to the smoke. Evaluation of toxicity is a complicated phenomenon requiring constant testing of materials under various conditions and environments by experienced biochemical and medically trained personnel. The materials selected for application in aircraft cabins (Table I) are currently undergoing toxicity tests in the JSC environmental health branch.

Concurrent with full-scale toxicity testing, a thermal stability requirement of 390°F determined by TGA (Thermogravimetric analysis) in air was established as an offgassing screening test. Materials that do not offgas toxic products at temperatures up to 390°F would provide additional evacuation time shoud a fire occur. However, it has been determined that a person's lungs fail if air or gas at a temperature of approximately 390°F or greater is inhaled. Some gases are evolved below 390°F; however, these are mainly water vapor and very small quantities of innocuous residual solvents and reactants. The ideal cabin materials are those which do not outgas below 390°F.

There are five areas where uncoated textile materials (Table

II) not derived from the space program are used in the JSC program. These materials shown in Table II are readily available from commercial sources in quantities sufficient to satisfy the needs of the airline industry. They do not represent any sponsored or in-house research and development effort on the part of NASA, although considerable R and D effort on the part of industry was necessary to bring them to their current state of acceptability. They also do not represent the best possible materials available from the viewpoint of maximum flame resistance and minimum smoke generation. Materials such as Durette, PBI, Teflon, and fiberglass, which have played such an important part in the Apollo and Skylab programs, do not have the required aesthetic properties to satisfy the needs of the airlines. The very properties which provide their superior flame resistance work against their ability to be dyed by conventional dyes and processes.

Since those materials listed in Table II are commercial materials, it was thought expedient to use the FAA 12 second vertical flammability test in lieu of the more stringent criteria established for the newly developed materials. Actually, only the upholstery and floor covering materials are required to be tested by this procedure, and the established requirement is a maximum after-flame of 15 seconds and a maximum char length of 8 inches. There are no FAA flammability requirements for the headrest covers or the ticking but seat belts are required to pass a rather mild horizontal flammability test while not exceeding a maximum burn rate of 2.5 inches per minute.

Materials and Applications

Table I shows the materials selected for consideration of interior cabin application, with the exception of the textiles which were generally off-the-shelf items. The first column shows the application and the second column shows the first generation development materials which in most cases have been used in NASA Grumman Gulfstream aircraft. Although the first generation materials met the physical and fire resistance requirements, the materials in column 3 were a second generation development to reduce costs and provide more practical materials while retaining good physical and fire-resistant qualities.

LABORATORY TESTING

Physical Properties

The JSC and industry developed materials are exposed to laboratory tests defined in airframe manufacturers specifications. Since these tests provide go/no-go results, materials selected for further evaluation are limited to those that meet the necessary physical requirements. Additional evaluation of end-item usage of materials has been conducted by installing the materials in four Gulfstream aircraft used by NASA Headquarters and other centers as executive aircraft. Only those materials that have met the laboratory test requirements and proven themselves in service on the NASA Gulfstreams are covered in this report.

Fire Resistance and Related Results

The application and laboratory test results for the more economical second generation materials are shown in Table III. All of the materials exceed the minimum LOI goal of 30. The seat cushion foam exceeds the maximum smoke DSM requirement of 50 since the material is basically a modified polyurethane foam which is inherently smoky. The weight loss for several of the materials ranges from 4 to 10% at 390°F. These losses consist primarily of water vapor and probably could be eliminated by a post cure at some elevated temperature.

Table II shows the laboratory test results for the off-the-shelf textile materials. Some of these materials did not meet the JSC desired goals concerning LOI or smoke density; however, when exposed to the FAA flammability tests, each material exceeded the FAA requirements. The smoke density for each material is well below the proposed FAA standard of 200.

FULL-SCALE TESTING OF CABIN MATERIALS

Tests

Three full-scale tests were performed in a Boeing 737 fuselage to evaluate the selected materials. Materials for test 1 were supplied by United Airlines and included pre-1968 Boeing 737, 727, and 707 material configurations. Materials used in tests 2 and 3 were firest generation fire-resistant materials, also representative of interior materials installed in two NASA Gulfstream aircraft for in-use evaluation. Details of the test interiors are given in Tables IV and V. The interior configurations before testing are shown in figures 1 to 4. A smokeless fuel was used in test 3; otherwise, the setup was the same as that of test 2. Results of full-scale tests conducted on second generation fire-resistant materials have not yet been fully analyzed and therefore will not be covered in this paper.

Test Setup

A 15-foot-long section of a Boeing 737 fuselage (fig. 5) was furnished to simulate the passenger cabin of a commercial jet transport. Sidewalls, windows, ceiling panels, hatracks, passenger service units, and three rows of triple seats were installed along one side of this fuselage section. In addition, to protect the outer aluminum skin of the fuselage, the entire section was lined with a high-temperature ceramic insulation of an alumina-silica composition. A typically furnished interior is shown in figure 6 and a schematic of the test setup in figure 7.

The ignition source for tests 1 and 2 consisted of 1 quart of of JP-4 aircraft fuel contained in a 1 by 1 foot pan and having a burning time of approximately five minutes. The pan was placed under the outboard seat of the middle row of seats (fig. 7) and ignited electrically. For test 3, the JP-4 fuel was replaced by 1.25 quarts of a smokeless fuel (50% acetone and 50% methanol) to avoid masking the smoke produced by the burning materials. The additional fuel was used to compensate for the lower energy per unit mass content of the smokeless fuel. For all three tests, an airflow rate of 200 ft^3/min was provided through the 15-foot test section as shown in figure 7. Two carbon dioxide fire extinguisher systems were installed in the fuselage for terminating the tests. One system was located in the 15-foot test section for local extinguishment, and a larger capacity system was installed throughout the fuselage to provide protection if the fire spread beyond the test section. This test setup basically duplicated the 15-foot mockup test conducted by the AIA in 1967 and 1968 (ref. 1).

Instrumentation

Instrumentation was provided to measure temperatures, cabin pressure, smoke density, and heat flux. In addition, two separate systems were used to take gas samples every 30 seconds during the tests. Toxic product percentages were determined by subsequent analyses of these samples. Color and infrared movies were taken during the tests and still photographs before and after each test. Black and white and infrared television (TV) cameras were also used to monitor the tests. (In addition, six persons observed the tests through windows on the side of the fuselage opposite the test region.) Besides duplicating the AIA instrumentation, additional instrumentation was provided to allow a more detailed measurement and evaluation of test results. Instrumentation locations are shown in figure 7.

RESULTS AND DISCUSSION

Because the test methods used in this program were selected to allow correlation and comparison with the AIA test results (ref. 1), the results of the JSC tests are compared to the AIA results, as well as to each other. In addition, results of fire tests conducted by the FAA on aircraft passenger seats (ref. 2) are discussed and compared to the JSC test results. Flammability testing cannot be considered an exact science; hence, results of separate test programs can be compared in general terms only. Any numerical values hould be interpreted as approximations, not as exact numbers. Gas analysis results, in particular, are acutely affected by variations in test parameters and sampling techniques.

Pre-1968 Materials Test (Test 1)

Test Results. Smoke was observed immediately after ignition of the JP-4 fuel source in test 1. This initial smoke appeared to come mainly from the JP-4 ignition source; however, some smoke was observed coming from the outboard seat cushion as it was ignited by the JP-4 fire. The fire increased in size as the outboard seat and the adjacent sidewall began to burn. Visibility of the fire was lost to observers, TV monitors, and motion picture cameras at approximately 60 seconds elapsed time as black smoke filled the cabin. Temperatures in the test section increased slowly until 60 seconds; then, the temperatures increased more rapidly as the fire spread and more materials were ignited. Apparently, a flash fire, which is a rapid burning of accumulated hot combustible gases, began at approximately 95 seconds because of an accumulation of such gases along the ceiling of the cabin interior. Indicative of the flash fire phenomenon was a rapid increase of cabin temperatures (fig. 8) followed by oxygen depletion to a concentration of less than 5% (fig. 9). In addition, the concentration of nonhydrolyzable products of combustion (carbon dioxide, carbon monoxide, methane, and ethylene) increased rapidly as the oxygen was depleted (figs 10 to 13). Data for hydrolyzable products of combustion (chlorides, fluorides, and cyanides) are not available for test 1 because of an error in analyzing the gas samples.

Thermocouple (TC) data indicate that the flash fire originated beneath the hatrack, spread to the ceiling and to the seats, and propagated beneath the hatrack for the full length of the test section. The propagation path along the forward end of the test section cabin walls was downward from the hatrack, as illustrated by a post-test photograph (fig.14). The damage to the seats other than the one directly above the ignition source was more severe at the top of the seats. This damage indicated heating and burning from above and is further evidence of a flash fire. The damage is shown in figures 15 and 16.

At 140 seconds, as the flash fire progressed, the maximum radiant heat flux measured at standing head level in the center aisle (fig. 17) was between 5 and 6 BTU/ft^2-sec. Reduction of visibility, as illustrated in figure 18, occurred rapidly with loss of visibility of the fire at 60 seconds and 83% smoke density measured at the ceiling smoke detector. Because of the high temperatures generated by the flash fire, the test was terminated after 240 seconds and the fire was extinguished with carbon dioxide.

Comparison With Other Tests. In general, the JSC test 1 and the AIA Present In-service Materials Test were similar in configuration and materials, and they produced similar results in temperatures and smoke densities. During the AIA Present In-service Materials Test of pre-1968 materials, a similar flash fire occurred; however, it occurred much later than that in JSC test 1 and produced slightly lower temperatures. Oxygen depletion and toxic gas production for the two tests had the same trend but were different in concentration. This difference possibly was due to variations in cabin volume and in sampling technique. The FAA seat tests on similar materials also resulted in a flash fire with comparable temperatures and products of combustion (ref. 2). The smoke density levels measured during JSC test 1 followed the same pattern as the levels recorded for the FAA seat tests of similar materials (ref. 2). The levels were characterized by a rapid reduction of visibility. Smoke production was not continuously measured during the AIA tests; therefore, no smoke density comparisons for JSC test 1 and the AIA test can be made. Because of the similarity of the results of these tests, the improved-materials test results also can be compared generally with the results of the earlier AIA and FAA tests.

New Materials Test (Test 2)

Test Results. Test 2 also began with an immediate indication of smoke coming mainly from the JP-4 ignition fuel and the outboard seat cushion above the fuel fire. The fire slowly increased in size until, at approximately 45 seconds elapsed time, it intensified as the fire-resistant material decomposed and released flammable gases. Unlike the materials used for test 1, however, the fire-resistant materials burned or decomposed only where exposed to the JP-4 fuel fire and did not allow the fire to propagate; therefore, the amount of combustible gases liberated during test 2 was apparently insufficient to produce a flash fire.

After ignition, the smoke density increased, and visibility of the fire was lost at approximately 150 seconds as smoke filled the cabin. In addition, cabin temperatures slowly increased, peaked at approximately 150 seconds, and then began to decrease (fig. 19). Temperatures measured at the sidewall and seat armrest above the fuel pan reached 1250°F; however, motion pictures revealed that the TC's at these locations were partly subjected to direct flame impingement from the ignition source, both during this test and during tests 1 and 3. The gradual decrease in oxygen (fig. 9) and the gradual increase in carbon monoxide and hydrocarbons (figs 11 to 13) indicate a typical open fire and absence of a rapid-burning flash fire. A typical open fire would gradually cease as the oxygen content of the air reached approximately 15% (ref. 2). Examination of figures 9 and 19 shows that the temperatures began decreasing as the oxygen content approached the 15% level. Maximum heat flux measured during test 2 (fig. 17) was less than 0.5 BTU/ft^2-sec at 140 seconds after fuel ignition.

Figures 20 to 24 show clearly that flames did not propagate, and damage was confined to the seat above the fire and the adjacent sidewall. The ceiling was severely damaged (fig. 21), but, because of inadequate insulation behind panels adjacent to the ignition source, flames melted through the sidewall and spread between the sidewall and insulation to the unprotected back side of the ceiling panels, which had a flammable paper honeycomb core. The flames then melted through the aluminum skin above the ceiling panels, and the test was terminated after 280 seconds to prevent destruction of the fuselage. The paper honeycomb ceiling panels were not intended for involvement in the fire since they were known to be flammable and fire-resistant ceiling materials are to be evaluated in subsequent tests.

Comparison With Other Tests. Far less material damage occurred in test 2 than in test 1, and propagation of the fire was limited (figs 15 and 20). A comparison of ceiling temperatures (fig. 25) indicated a maximum temperature of 450°F for test 2, whereas, during test 1 the temperature at the same location was more than 1400°F. Temperatures at other locations were also significantly lower in test 2 than those measured in test 1. Maximum heat flux levels in test 2 were only one-fifteenth as high as those in test 1 (fig. 17). The levels of carbon monoxide and carbon dioxide were significantly lower in test 2 than in test 1 (figs 10 and 11). Also, the loss of visibility because of smoke density occurred significantly later in test 2 than in test 1, as shown in figure 18.

The concentrations of nonhydrolyzable products of combustion produced during JSC test 2 were much lower than the concentrations found in JSC test 1 and those reported for the AIA test. The results of the AIA Present In-service Materials Test were used to provide baseline data on the hydrolyzable products of combustion. As shown in Table VI, the maximum chloride value in JSC test 2 was higher than the AIA-measured concentration, and the fluoride and cyanide values were considerably lower. Because of slight differences in the test configuration and in the gas sampling and analyzing techniques, no direct comparison of the JSC and AIA hydrolyzable products of combustion has been attempted.

However two important factors indicated by these data should be pointed out. First, although much greater amounts of fluorine-base polymers were present in JSC test 2 than in the AIA test, the measured fluoride concentration was relatively low, as expected. A fluoride absorber (or scavenger) had been compounded into the Fluorel formulation to capture and convert the reactive fluorine species to a solid ash; this formulation resulted in reduction of the amount of toxic gases released; such as carbonyl fluoride and hydrogen fluoride. Second, the cyanide concentration reduction was also expected because of the replacement of the urethane-base seat cushion material used in JSC test 1 and in the AIA test with a fire-resistant urethane foam. This new urethane material will not sustain combustion and, therefore, will not release toxic cyanide products of combustion, such as hydrogen cyanide, unless exposed to an external heat source.

Analysis of the comparative results of tests 1 and 2 also indicates that more time would be available to combat and extinguish an in-flight cabin fire or an unattended ground fire in an aircraft refurbished with the improved materials. Although comparative results show that a significant improvement was attained in test 2, the unexpected burning of the paper honeycomb ceiling panels (with their additional contribution to thermal and combustion products) resulted in some masking of the real improvement provided by the new materials. As previously stated, there was evidence that a flash fire did occur in test 1; however, for test 2, all evidence points to the conclusion that no flash fire occurred. (See the preceding discussion and figs 17 and 25.)

New Materials Test with Smokeless Fuel (Test 3)

Test Results. During test 3, it was visually observed and later verified by motion pictures that the smokeless fuel (acetone and methanol) did not produce a fire as dynamic as the JP-4 aircraft fuel fire. More time was required to ignite the smokeless fuel and for the fuel to reach maximum burning temperature. In addition, the flames of the burning smokeless fuel were not as large and did not extend outward from beneath the seat to impinge on the adjacent sidewall as much as did the flames of the burning JP-4 aircraft fuel. Consequently, cabin temperatures increased slowly to a maximum value of 500°F (at the sidewall adjacent to the fuel pan, at window level) at 200 seconds elapsed time, and then decreased slowly (fig. 26). Smoke production was slight (fig. 18) until 80 seconds, when the smoke began to increase slowly. A level of 55% was measured at the ceiling smoke detector 240 seconds after ignition. The test 2 level was 94%.

The data indicate that a typical open fire occurred, similar to the fire that occurred in test 2, rather than a rapid-burning flash fire such as that observed during test 1. Damage to the seat above the fuel fire was almost identical to that in test 2, but sidewall damage was less severe. Ceiling damage was also less severe because additional firebreak insulation, which had been added to fill the gap between existing insulation and the sidewalls, prevented propagation of flames to the back side of the ceiling panels. Consequently, major damage was sustained only by the seat directly above the fuel fire; thus, lower cabin temperatures, less radiant heat, and smaller concentrations of combustible products resulted. Because the fire was small, the test was continued for 840 seconds before termination; however, test values beyond 300 seconds are not reported.

Comparison With Other Tests. A comparison of the data from figures 17, 19, 25, and 26 shows that the radiant heat flux and the cabin temperatures measured at the center of the test section for test 3 were approximately half the values for test 2. Examination of the gas analysis results (figs 10 to 13 and 27 to 29) shows the same general trend of a 50% reduction for many of the products of combustion.

Because identical materials were used in tests 2 and 3, the differences in visibility (94 and 55%, respectively, at 240 seconds elapsed time (fig. 18)) resulted partly from the additional smoke produced by the JP-4 fuel. Some of these differences also undoubtedly were due to the smaller fire and less burning of materials that occurred in test 3. This information also indicates that a significant portion of the reduction in visibility within the cabin for tests 1 and 2 was due to the smoke produced by the JP-4 ignition source. However, even after considering the smoke contribution of the JP-4 fuel, the smoke density of test 1 would still be considerably greater than that of test 2.

Results of tests 2 and 3 also showed that the type of ignition fuel used influenced the results of the tests because of differences in amounts of thermal input and smoke production. The additional burning that occurred in test 2 was possibly a more significant contribution to the reduction in the parameters used for comparing the results of tests 3 and 2. As previously mentioned, this burning occurred because of inadequate insulation behind wall and ceiling panels in test 2. The ceiling burned and contributed to the fire, resulting in higher temperatures and larger quantities of combustion products in test 2 than in test 3.

CONCLUDING REMARKS

Three full-scale aircraft flammability tests were performed to evaluate the effectiveness of improved fire-resistant materials by comparing their burning characteristics with those of older aircraft materials.

In test 1, pre-1968 materials were tested to correlate with previous tests of similar materials by the Aerospace Industries Association of America, Inc., and to provide a baseline for subsequent tests. The test resulted in significant fire propagation, rapid loss of visibility, evidence of flash fire (characterized by rapid oxygen depletion and rapid temperature increase), significant quantities of toxic gases, and high temperatures. Major fire damage was sustained throughout the test section.

Test 2, in which newer improved fire-resistant materials were tested, resulted in less fire propagation, lower temperatures, a longer time lapse before loss of visibility, and a significant reduction of toxic gas concentrations because of the much smaller fire. No flash fire occurred (therefore, minimum oxygen depletion) and the fire damage was very limited. Unlike the materials used for test 1, the fire-resistant materials burned or decomposed only while exposed to the fuel ignition source and did not propagate the fire significant distances from the ignition source. Unfortunately, some increase in temperature and combustion products occurred during test 2 because of the burning from the back side of the flammable paper honeycomb ceiling panels. This unexpected burning probably detracted to some extent from the degree of improvement that could be expected of the new materials.

In test 3, the JP-4 aircraft fuel ignition source was replaced with a smokeless fuel (acetone/methanol). The result was an even greater reduction in temperatures, smoke, toxic gas production, and fire damage than observed in the previous test of the newer materials. Part of the reduction during test 3 can be attributed to the provision of more insulation to prevent burning of flammable ceiling materials, such as burned in test 2. The results of test 3 documented the significance of the smoke produced by the JP-4 aircraft fuel in reducing cabin visibility and also permitted an evaluation of the smoke produced only by the fire-resistant materials. As in test 2, no flash fire was observed during the 5 to 6 minute visible portion of test 3. Furthermore, analysis of all other evidence indicates that no flash fire occurred at any time during the test.

Results from tests 2 and 3 demonstrated that use of the improved materials would provide some degree of additional safety during aircraft cabin fires. Substantial ignition sources would be required to ignite the improved materials. When ignition from such sources occurs, the fire would remain somewhat subdued for a significant time, thus permitting adequate time for implementation of extinguishment procedures.

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TABLE I. - FIRE RESISTANT AIRCRAFT CABIN MATERIALS

APPLICATION	FIRST GENERATION DEVELOPMENT	SECOND GENERATION DEVELOPMENT
WALL SKINS	FLUOREL ON FIBERGLASS OVER-COATED WITH KEL-F 800	KYNAR DECORATIVE LAMINATE
WINDOW SHADES	FLUOREL ON FIBERGLASS OVER-COATED WITH KEL-F 800	KEL-F 2401D ON FIBERGLASS
HATRACK AND CEILING COVERINGS	FLUOREL ON FIBERGLASS OVER-COATED WITH KEL-F 800	KEL-F 2401D ON FIBERGLASS
MOLDED PARTS (PSU, SEAT TRAY)	KEVLAR IMPREGNATED WITH 6113 RESIN	POLYARYLENE (STILAN)
CEILING PANELS	KRAFT PAPER HONEYCOMB WITH PHENOLIC COATING & SKINS	FX RESIN ON NOMEX PAPER HONEYCOMB FX RESIN ON FIBERGLASS HONEYCOMB FX RESIN ON FIBERGLASS SKIN-FRONT FX RESIN ON FIBERGLASS SKIN-BACK
SEAT CUSHIONS AND CARPET PAD	SCOTT HIGH RESILIENT FOAM TREATED WITH ADP & COATED WITH FLUOREL	MOBAY RESILIENT FOAM 115014-6 TREATED WITH ADP AND COATED WITH FLUOREL L-3203-6
ARM REST AND DADO PANEL	BLUE FLUOREL ON DURETTE OVER-COATED WITH KEL-F 800	BLUE KEL-F 2401B ON NYLON

TABLE II. - TEXTILE MATERIALS LABORATORY TEST RESULTS

MATERIAL	USE	FAA FLAMMABILITY VERTICAL - 12 SEC			LOI	SMOKE DENSITY DSM
		AFTER FLAME (SEC)	AFTER GLOW (SEC)	CHAR LENGTH (IN)		
100% NOMEX, ANCHORAGE II BLUE 69/1211	UPHOLSTERY	0	3	2.3	28	34
100% NOMEX PILE CARPET	FLOOR COVERING	0	0	0.5	30	132
MODACRYLIC/POLYESTER WEFTAMATIC FABRIC, STYLE 6186	TICKING	0	0	4.5	25	92
FIRE RETARDANT NONWOVEN CELLULOSIC S/AMK 770	HEADREST COVER	0	0	5.8	32	15
NOMEX SEAT BELTS, S/WMX 1856	SEAT BELT	0	0	0.3	34	122

TABLE III. - LABORATORY TEST RESULTS

APPLICATION	SECOND GENERATION DEVELOPMENT			
	MATERIAL	LOI FLAM.	DSM SMOKE	THERMAL STAB. AMBIENT WT LOSS % AT 390°F
WALL SKINS	KYNAR DECORATIVE LAMINATE	54	4	0 (617°F)
WINDOW SHADES	KEL-F 2401D ON FIBERGLASS	>99	7	0 (518°F)
HATRACK AND CEILING COVERINGS	KEL-F 2401D ON FIBERGLASS	>99	7	0 (518°F)
MOLDED PARTS (PSU, SEAT TRAY)	POLYARYLENE (STILAN)	41	4	0 (>887°F)
CEILING PANELS	FX RESIN ON NOMEX PAPER HONEYCOMB	32	26	10
	FX RESIN ON FIBERGLASS HONEYCOMB	41	4	5
	FX RESIN ON FIBERGLASS SKIN-FRONT	64	4	7
	FX RESIN ON FIBERGLASS SKIN-BACK	51	3	4
SEAT CUSHIONS AND CARPET PAD	MOBAY RESILIENT FOAM 115014-6 TREATED WITH ADP & COATED WITH FLUORED L-3203-6	58	105	6
ARM REST AND DADO PANEL	BLUE KEL-F 2401B ON NYLON	40	53	0 (473°F)

TABLE IV. - PRE-1968 MATERIALS USED IN TEST 1

Part description	Materials used	Comments
Ceiling panel	Vinyl-covered paper-core/wood-edged fiberglass sandwich	Original Boeing 727 part (Current Boeing 727 part is Nomex-core/foam-edged fiberglass sandwich.)
Sidewall panels	Tedlar vinyl/aluminum laminate	Standard Boeing 737 part
Floor covering	None used	--
Hatrack bullnose	Vinyl-covered urethane foam	Standard Boeing 727 part
Hatrack	Paper-core/aluminum-edged fiberglass sandwich; underside of AMS-3570 foam covered with supported vinyl	Original Boeing 727 part (Current Boeing 727 part is Nomex-core sandwich.)
Passenger service unit	Polysulfone	Original Boeing 737 part (Current Boeing 737 part is polycarbonate.)
Seats	Cushions: AMS-3570; cushion fabric: nylon-wool-rayon combination; armrests: foam rubber covered with natural leather; seat back and literature pocket: supported vinyl; seatbelt: nylon	Standard Boeing 707 part

TABLE V. - NEW FIRE-RESISTANT MATERIALS USED IN TESTS 2 AND 3

Part description	Materials used	Comments
Ceiling panel	Fiberglass coated with white Fluorel L-3203-6, overcoated with Kel-F FX703, applied to identical ceiling panels of pre-1968 materials test (test 1)	--
Sidewall panels	Durette 400-5 coated with Fluorel L-3203-6, overcoated with Kel-F FX703, applied to aluminum sheet	--
Floor covering	Wool carpet treated with ammonium dihydrogen phosphate and high-resilience foam padding treated with Fluorel L-3203-6	--
Hatrack bullnose	Fiberglass coated with white Fluorel L-3203-6, overcoated with Kel-F FX703, placed over high-resilience foam treated with Fluorel L-3203-6	--
Hatrack	Paper-core/aluminum-edged fiberglass sandwich, underside of treated high-resilience foam, covered by fiberglass coated with white Fluorel L-3203-6, overcoated with Kel-F FX703	Paper-core/aluminum-edged fiberglass sandwich was original Boeing 727 part
Passenger service unit	PRD-49 felt impregnated with 6113 resin and painted with white Fluorel L-3203-6	--
Seats	Cushions: treated high-resilience foam; cushion fabric: Proban wool; armrests: Durette 400-5 coated with blue Fluorel L-3203-6, overcoated with Kel-F FX703; seat back: Proban wool; seatbelt: Nomex	--

TABLE VI. - CONCENTRATIONS OF OXYGEN AND OF GASEOUS COMBUSTION PRODUCTS

Oxygen and products of combustion	Pre-1968 materials test (test 1)	New materials test (test 2)	New materials test with smokeless fuel (test 3)
Minimum concentration			
Oxygen, percent	4.1	15.5	17.8
Maximum concentration			
Carbon dioxide, percent	9.2	2.4	1.5
Carbon monoxide, p/m	3360	623	407
Methane, p/m	15 480	395	147
Ethylene, p/m	3260	232	54
Chloride (as hydrogen chloride), p/m . . .	[1]275	540	281
Fluoride (as carbonyl fluoride), p/m . . .	[1,2]188	65	58
Cyanide (as hydrogen cyanide), p/m	[1]1000	46	23

[1]Data from similar AIA test of pre-1968 materials (ref. 1).
[2]Converted from hydrogen fluoride.

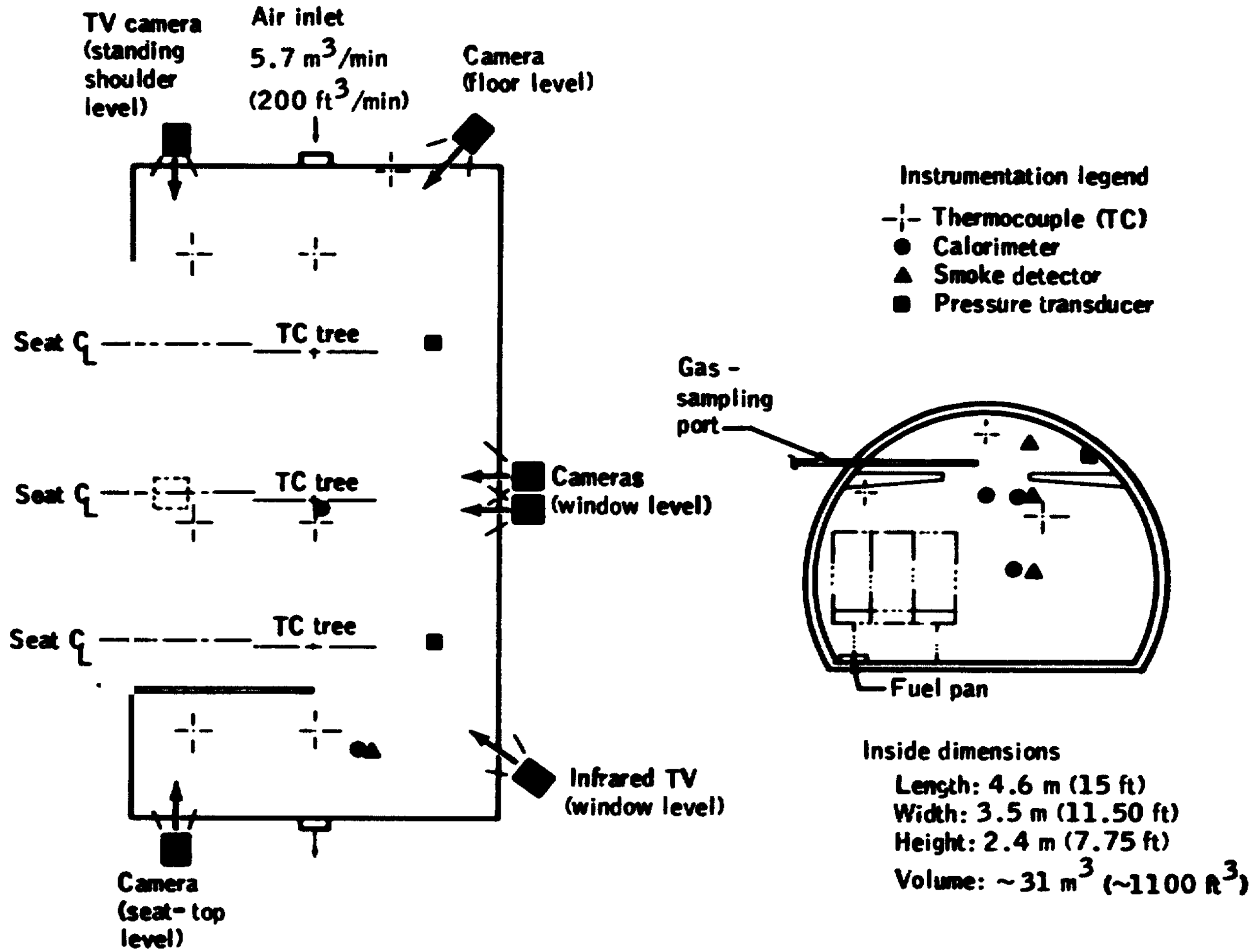


Figure 7. - Test setup and instrumentation locations.

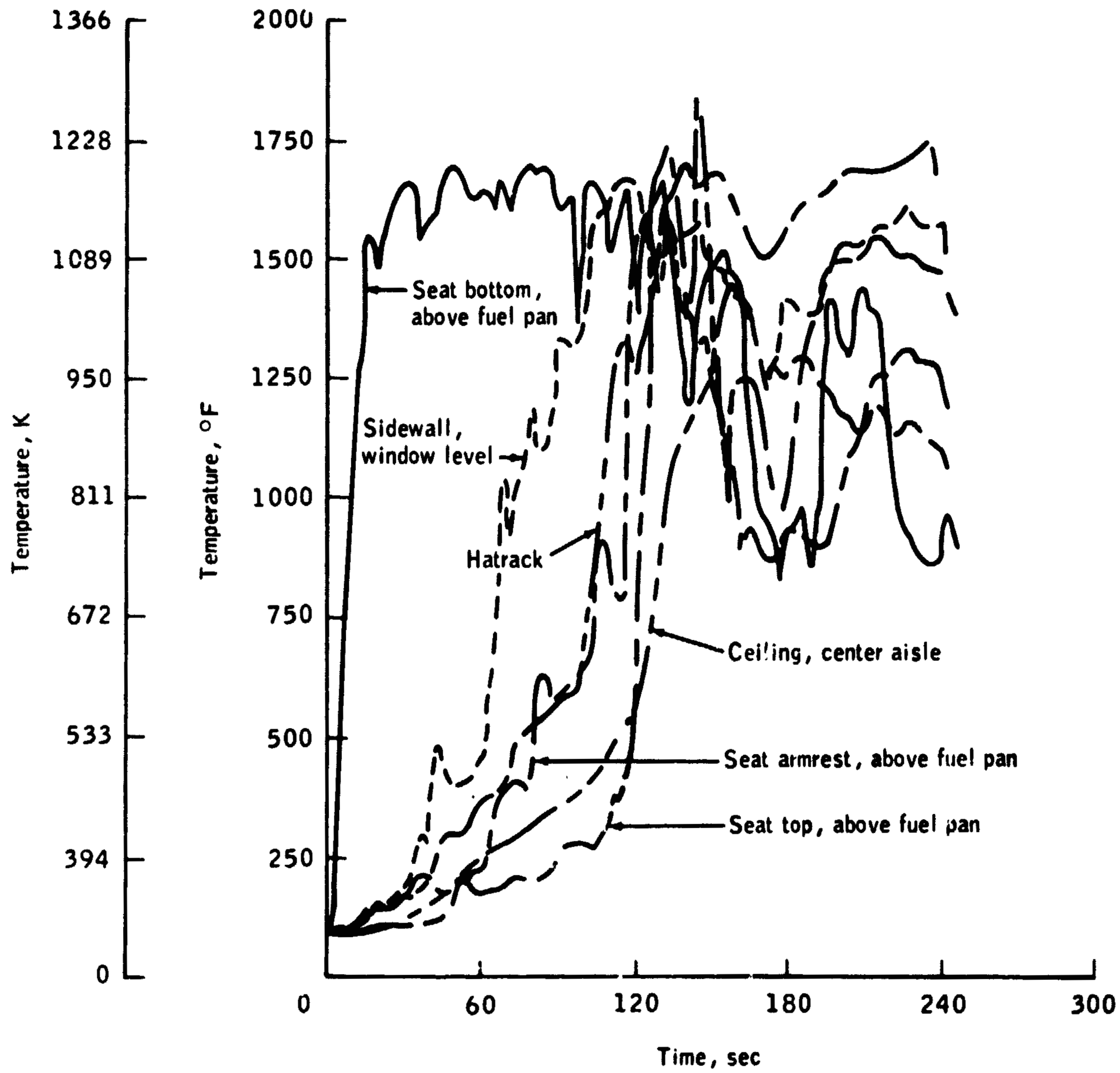


Figure 8.- Temperatures at center of test section, pre-1968 materials.

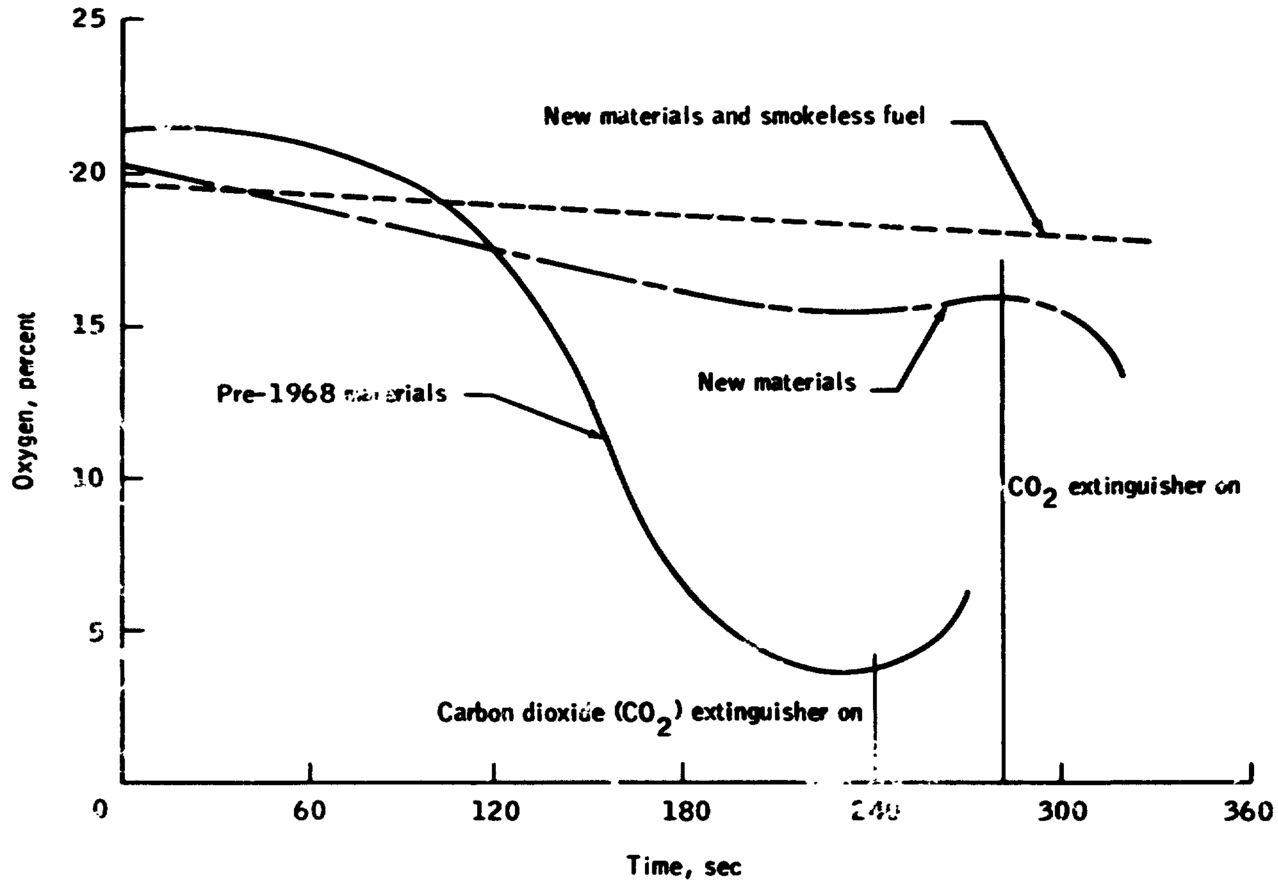


Figure 9.- Oxygen concentration.

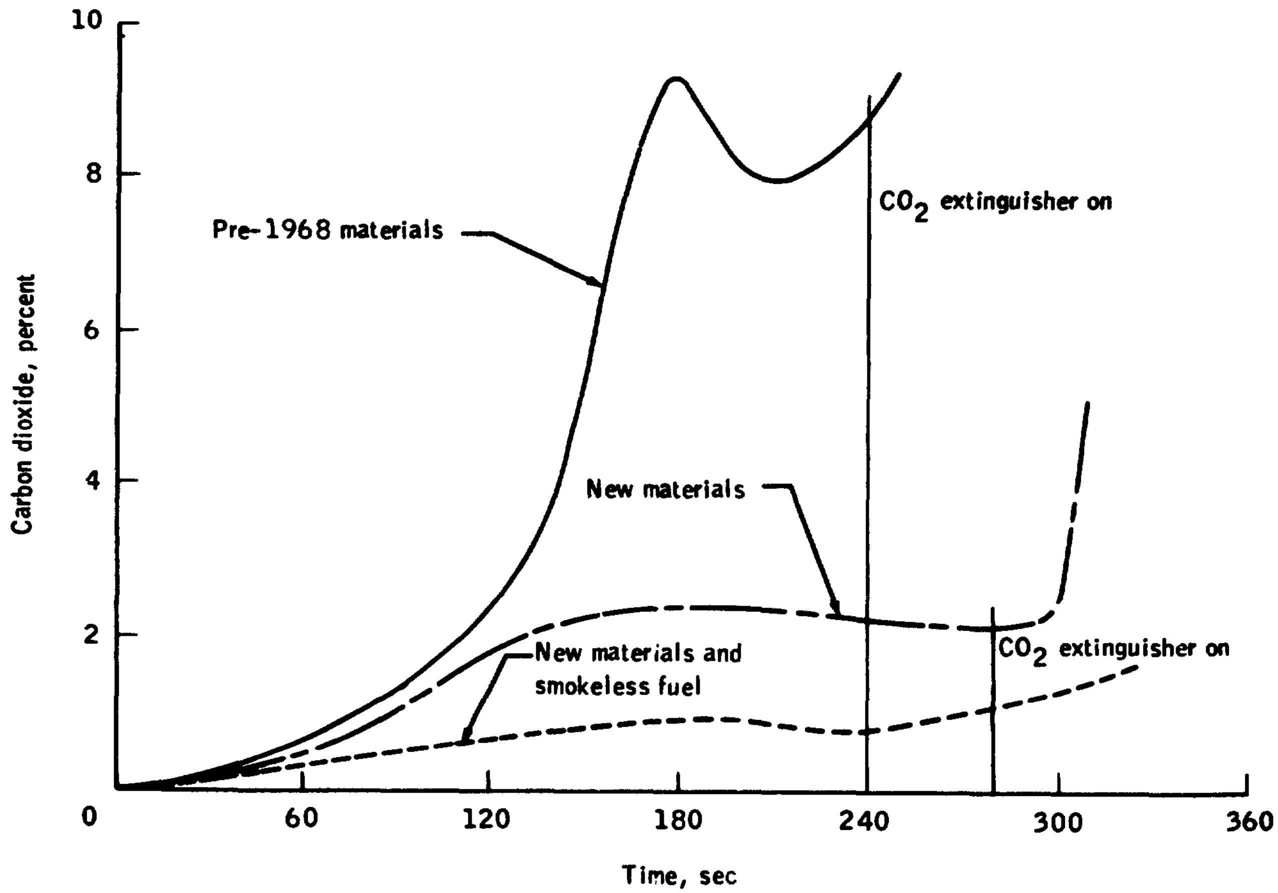


Figure 10.- Carbon dioxide concentration.

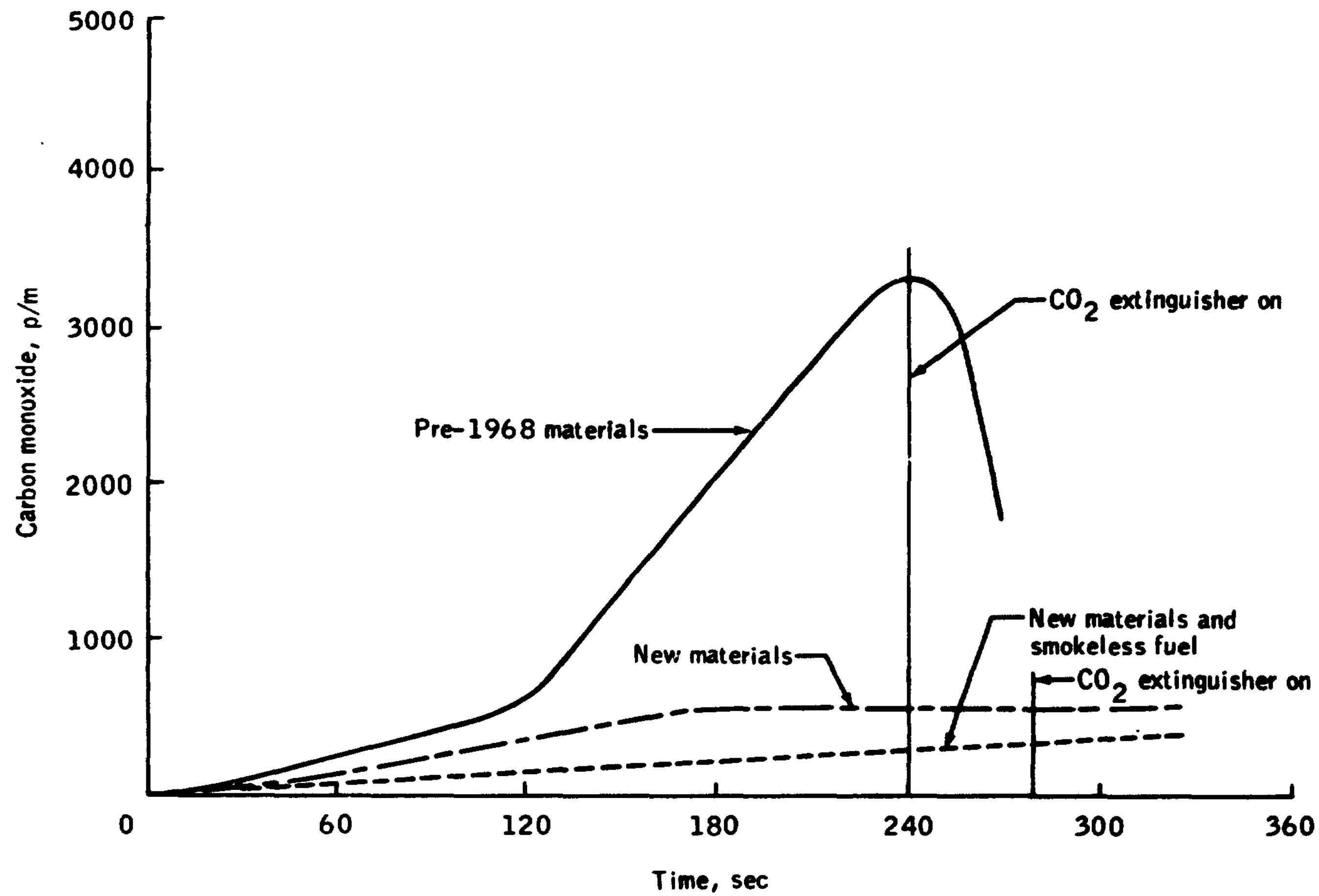


Figure 11.- Carbon monoxide concentration.

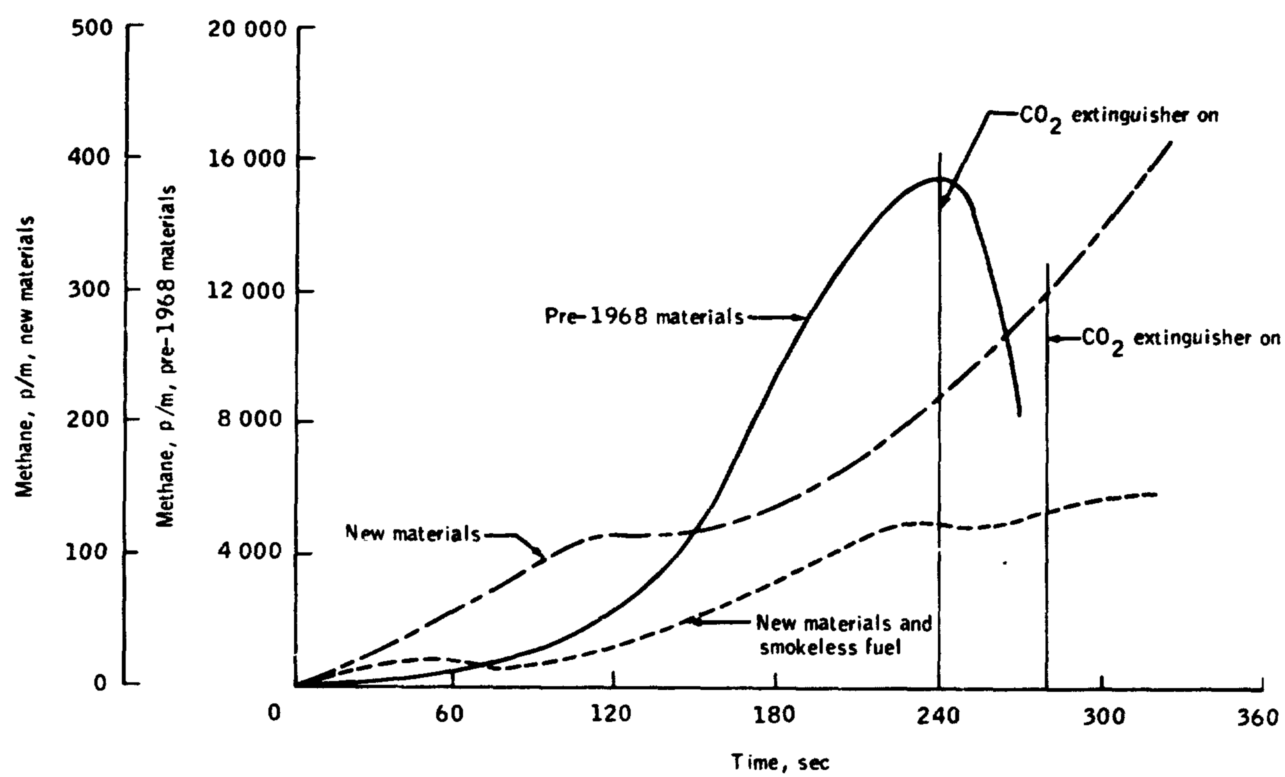


Figure 12.- Methane concentration.

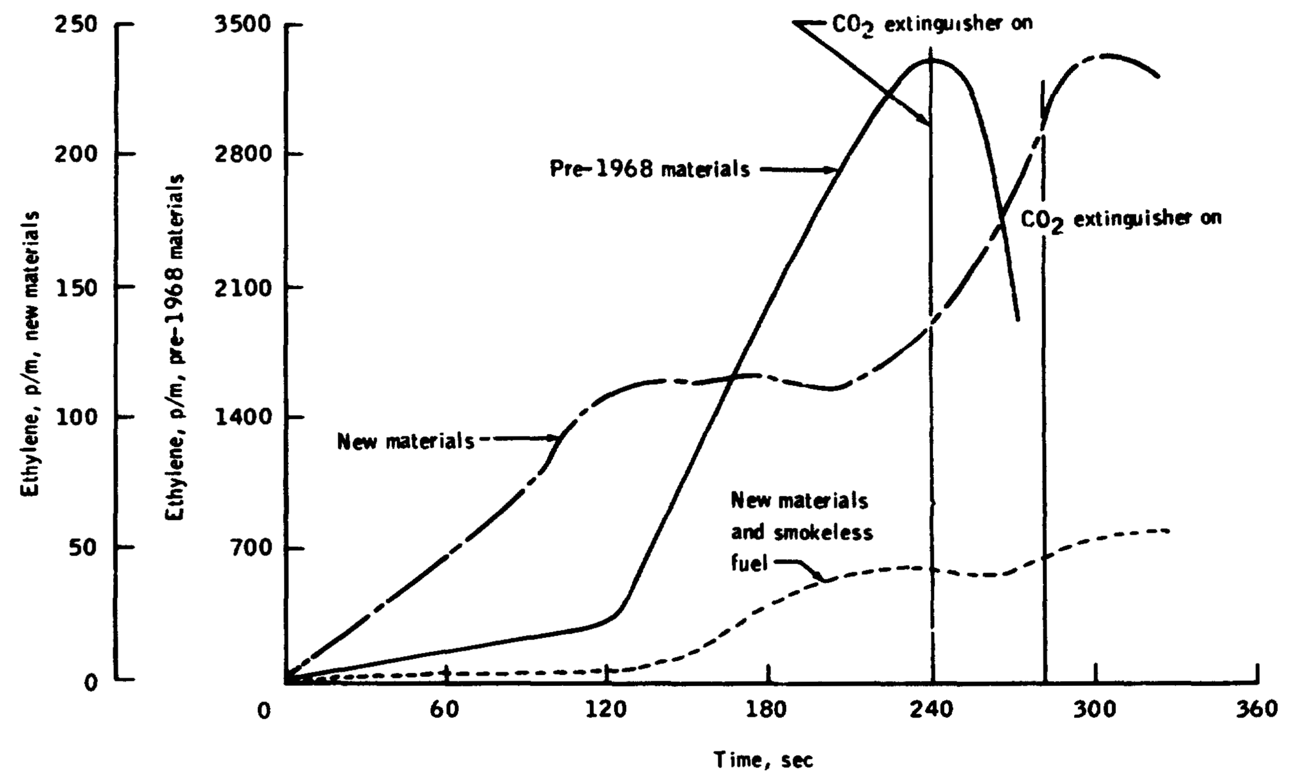


Figure 13.- Ethylene concentration.

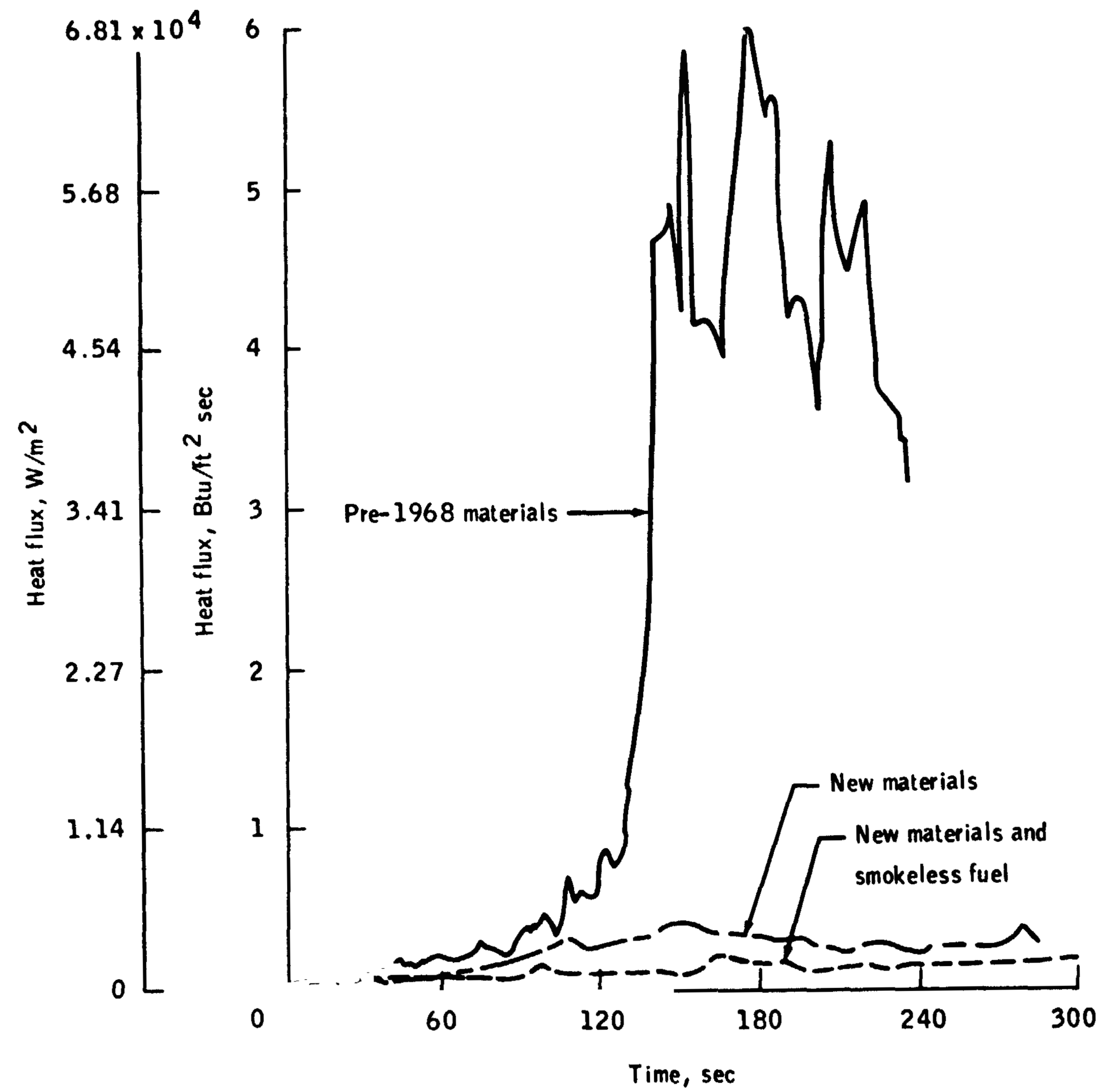


Figure 17.- Heat flux at center of test section, center aisle.

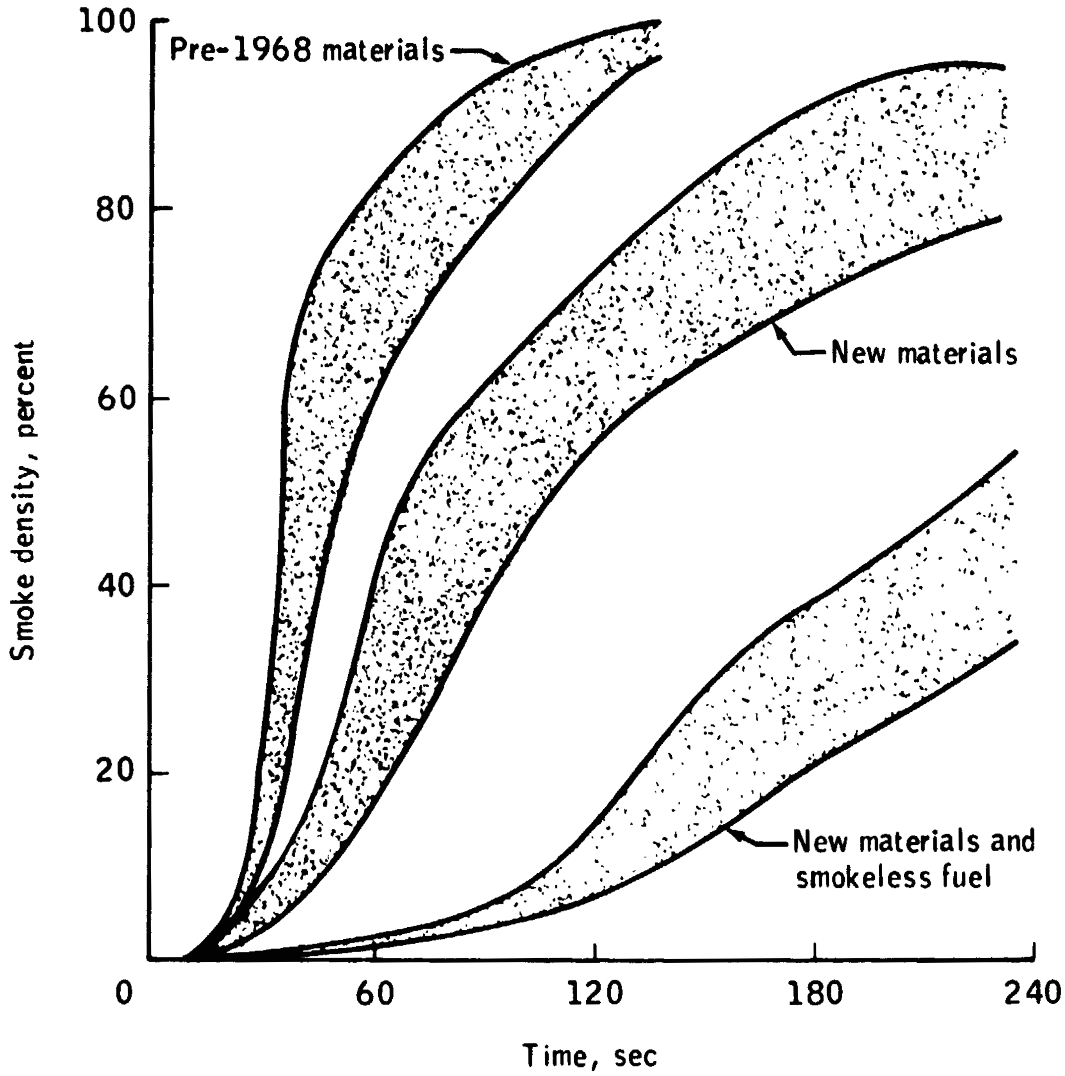


Figure 18.- Minimum and maximum smoke density levels.

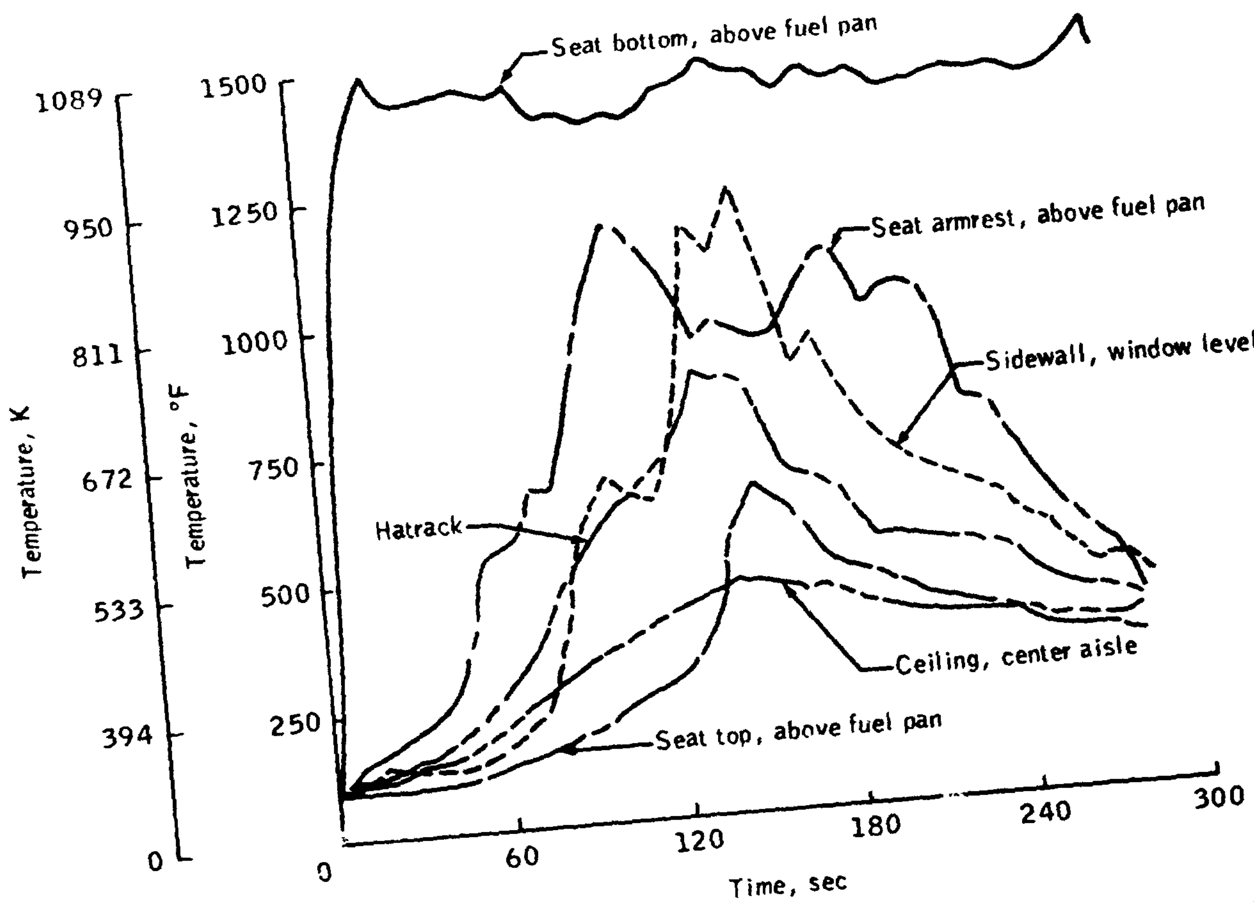


Figure 19.- Temperatures at center of test section, new materials.

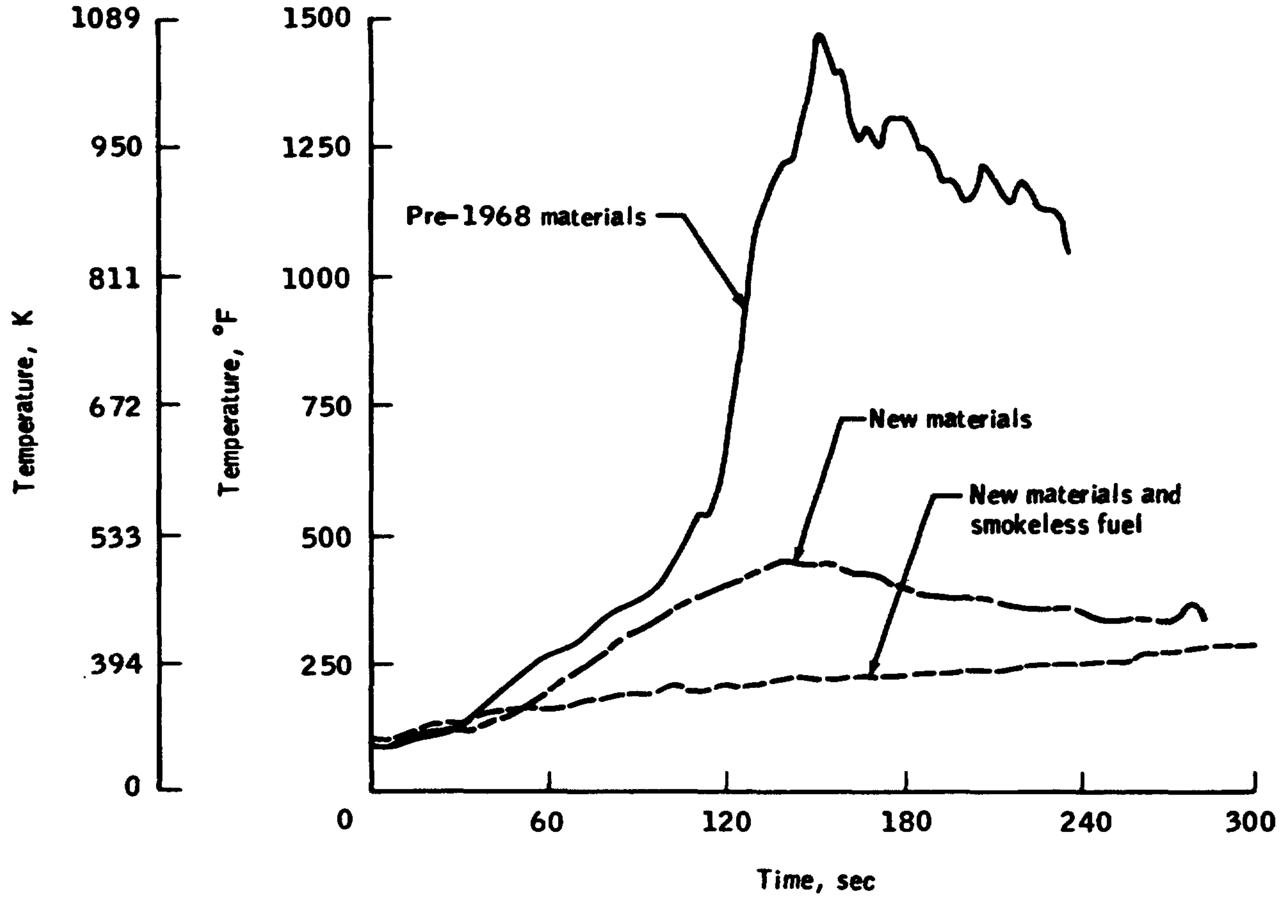


Figure 25.- Ceiling temperatures at center of test section, center aisle.

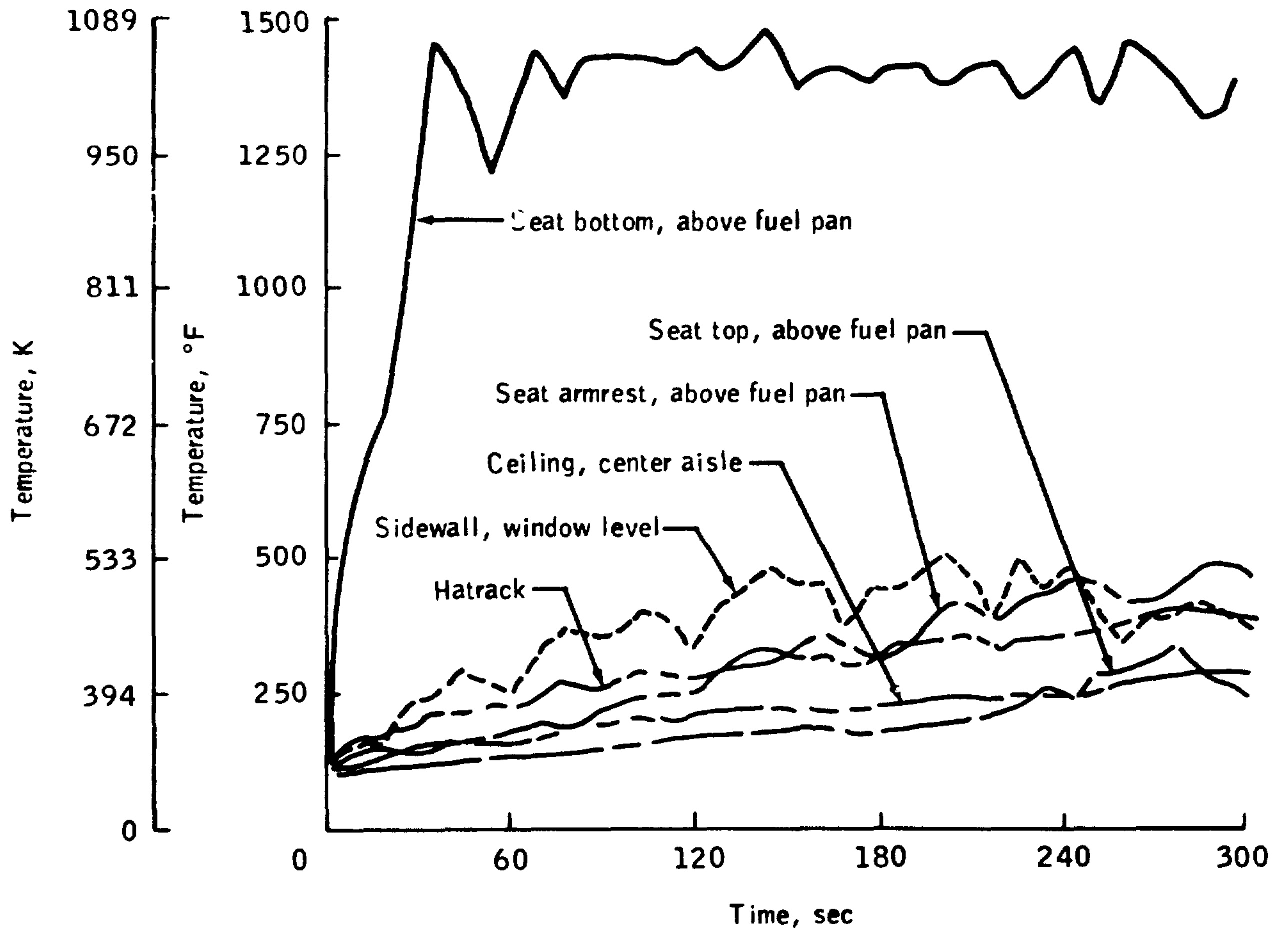


Figure 26.- Temperatures at center of test section, new materials ·d smokeless fuel.

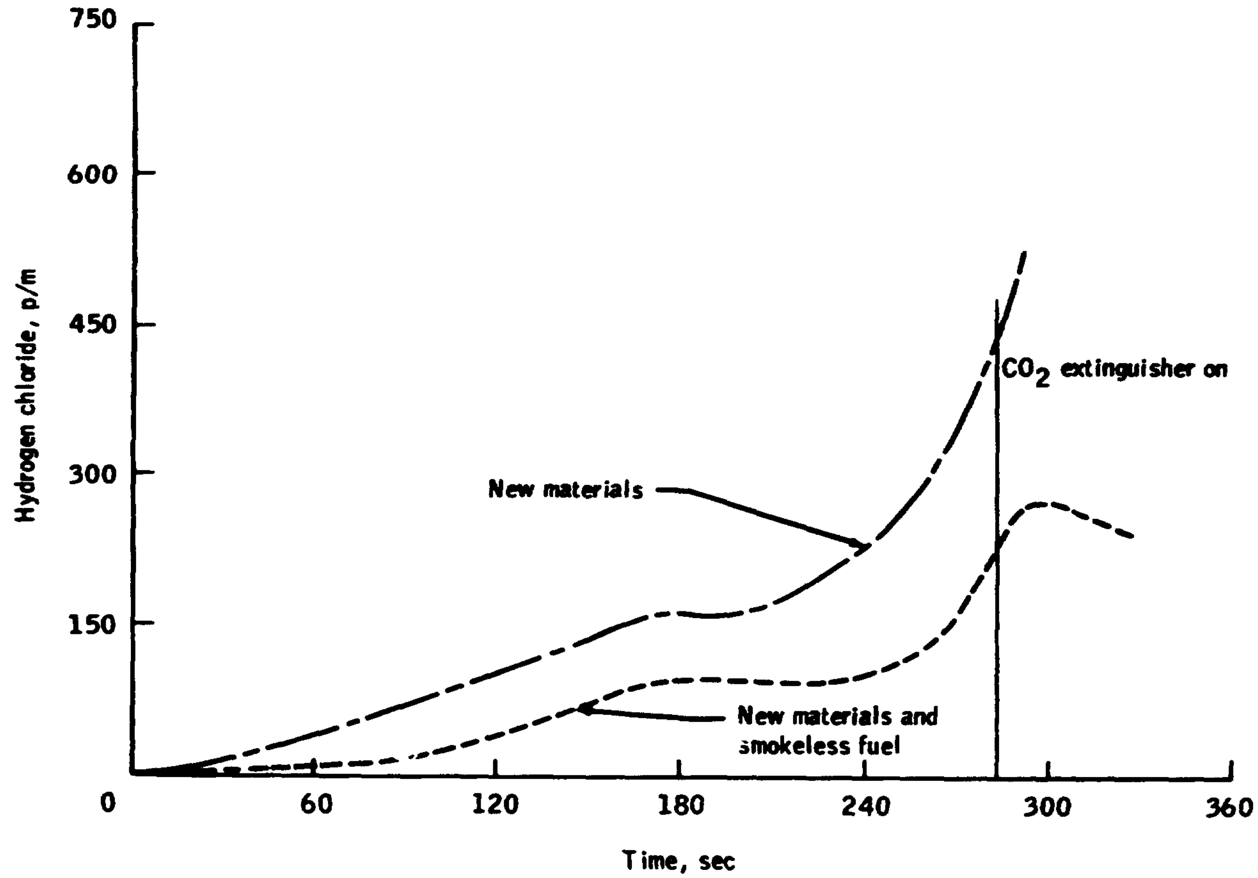
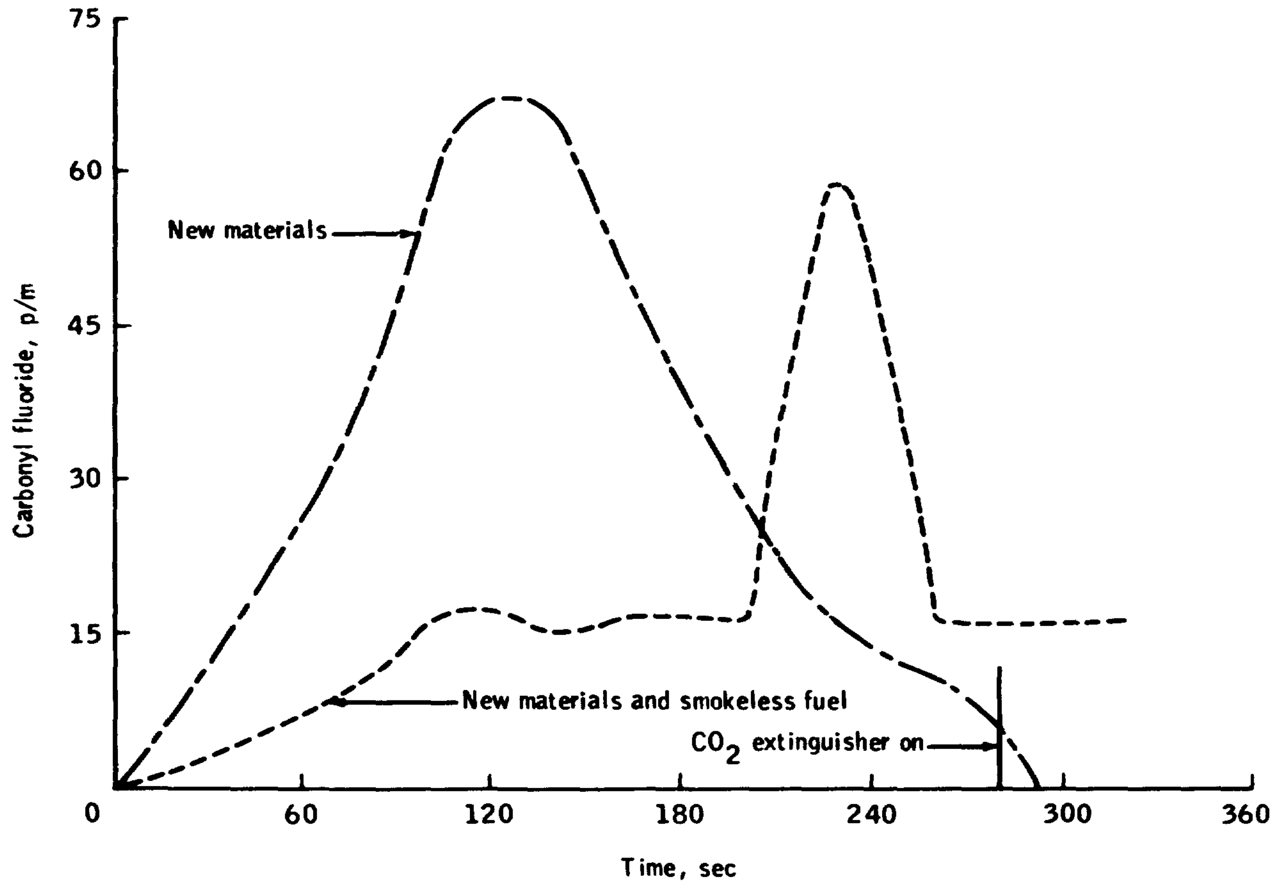


Figure 27.- Chloride (as hydrogen chloride) concentration.



Figur : 28.- Fluoride (as carbonyl fluoride) concentration.

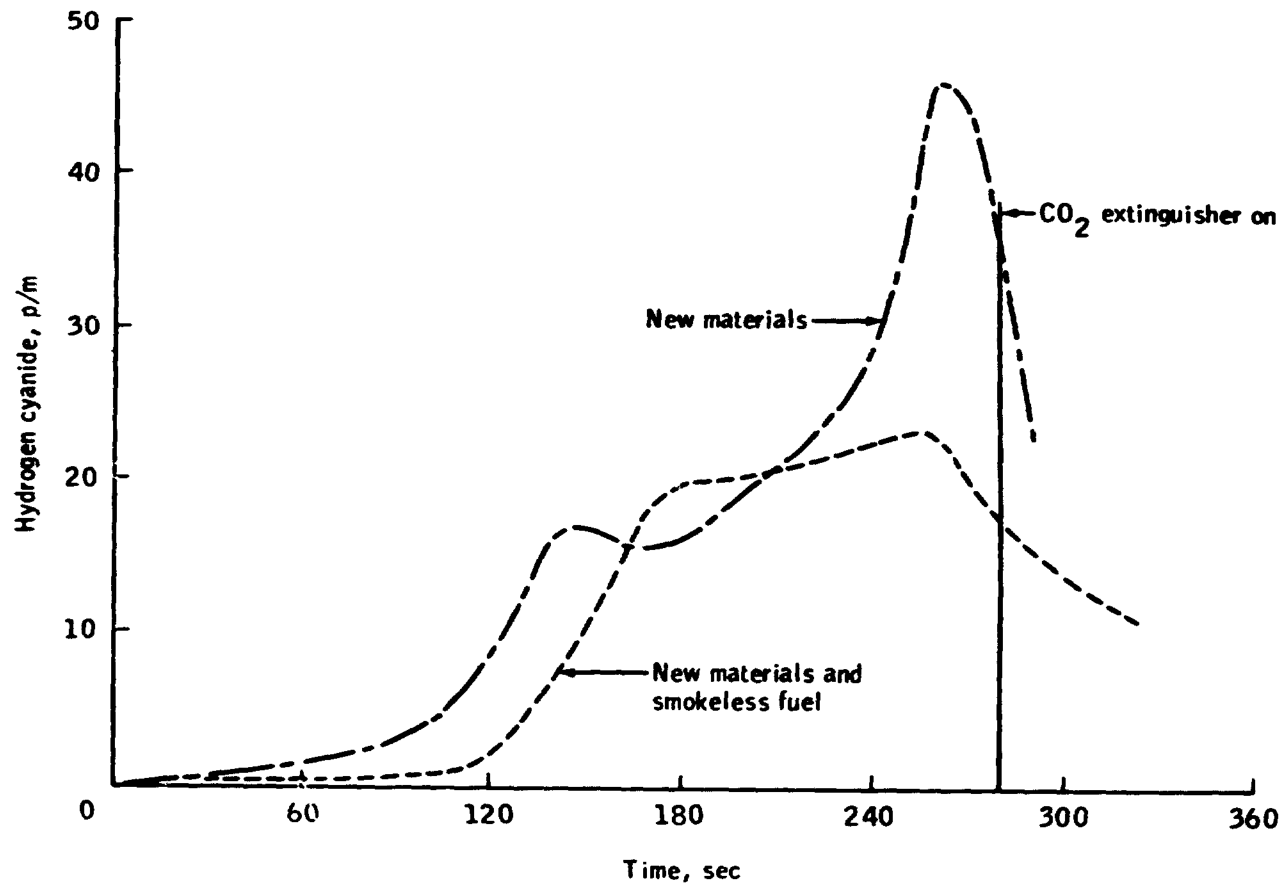


Figure 29.- Cyanide (as hydrogen cyanide) concentration.

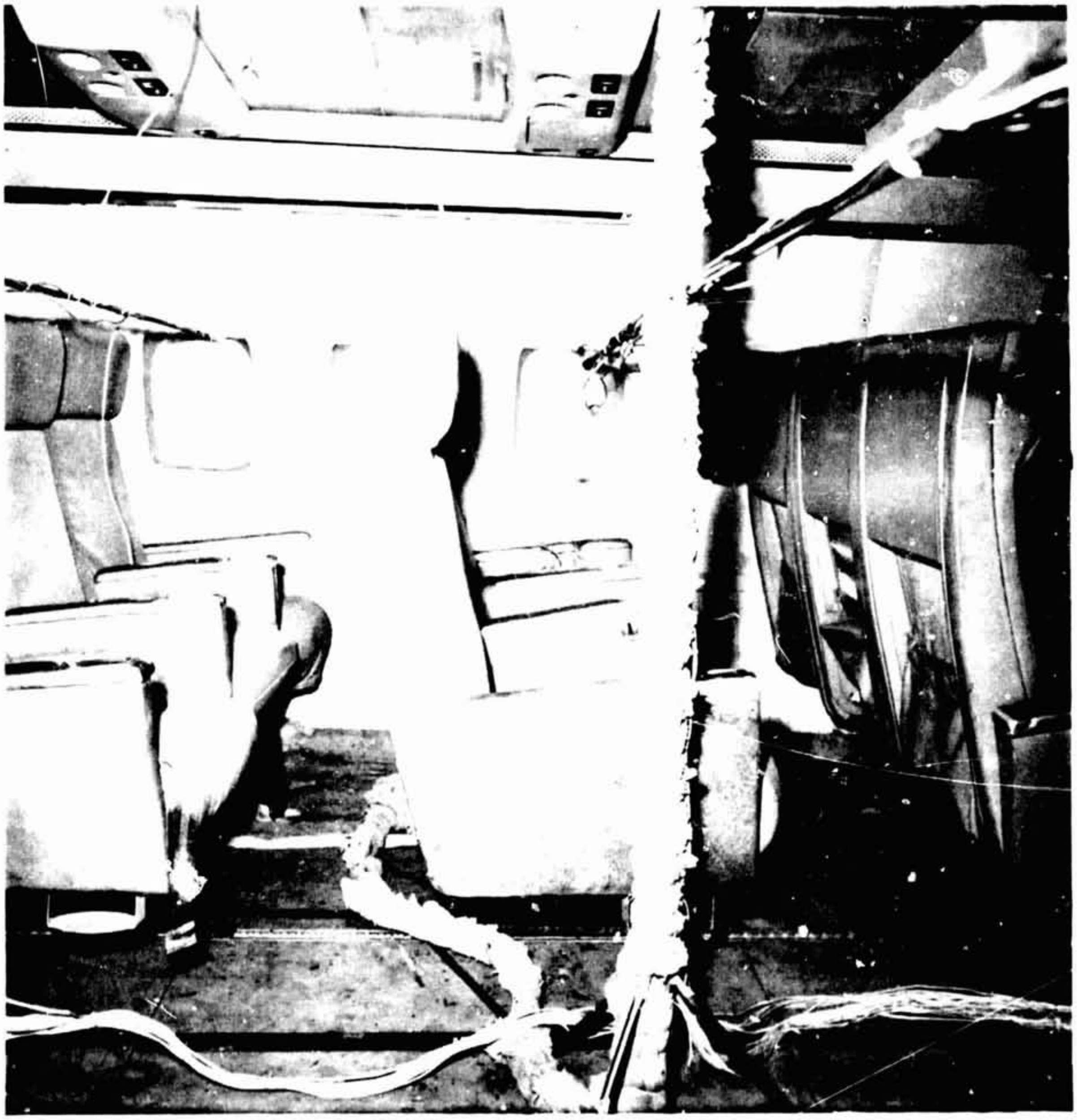


Figure 1. - Test configuration for test 1 using pre-1968 materials, side view.

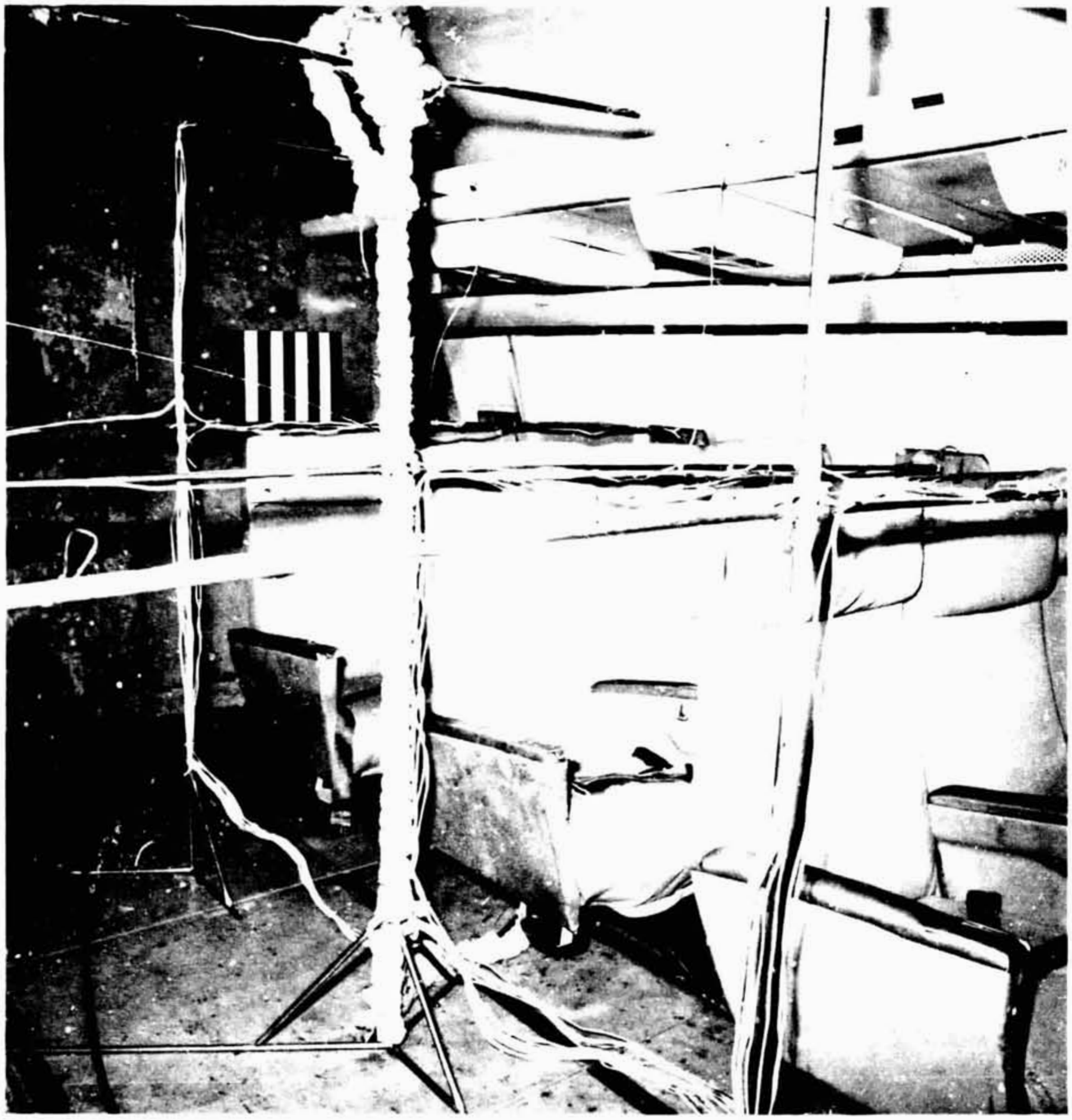


Figure 2. - Test configuration for test 1 using pre-1968 materials, front view.

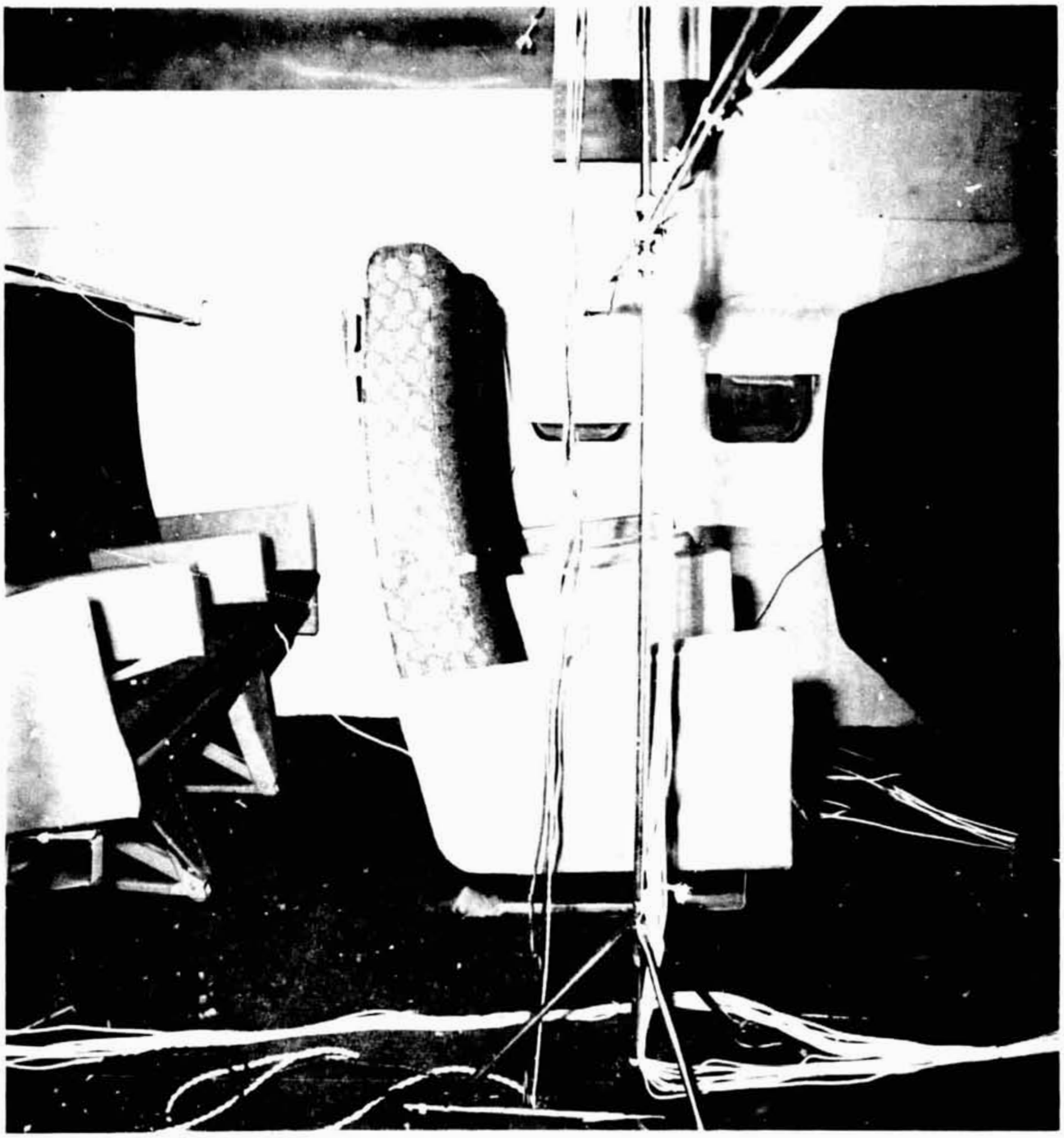


Figure 3. - Test configuration for tests 2 and 3 using new materials, side view.

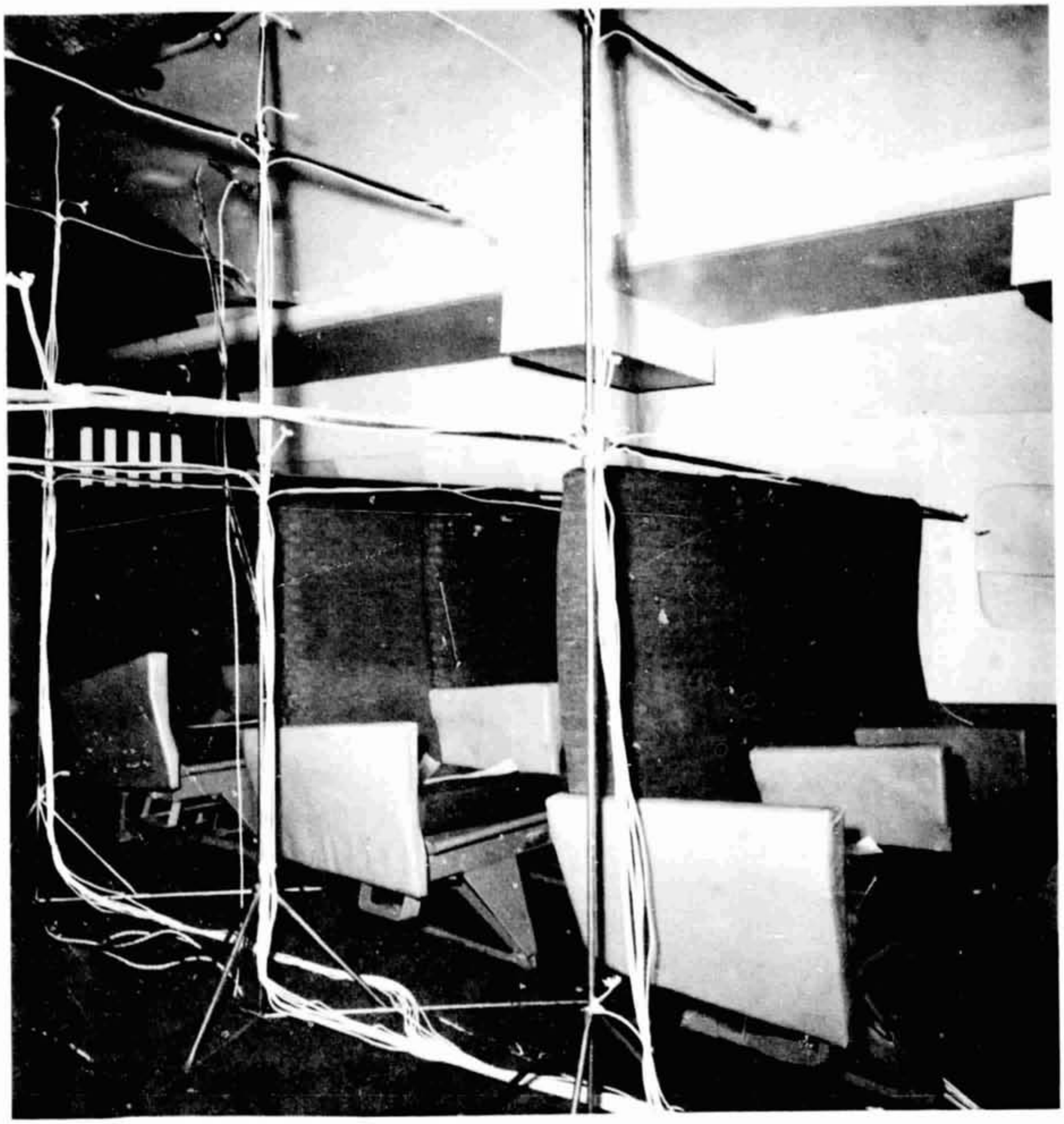


Figure 4. - Test configuration for tests 2 and 3 using new materials, front view.

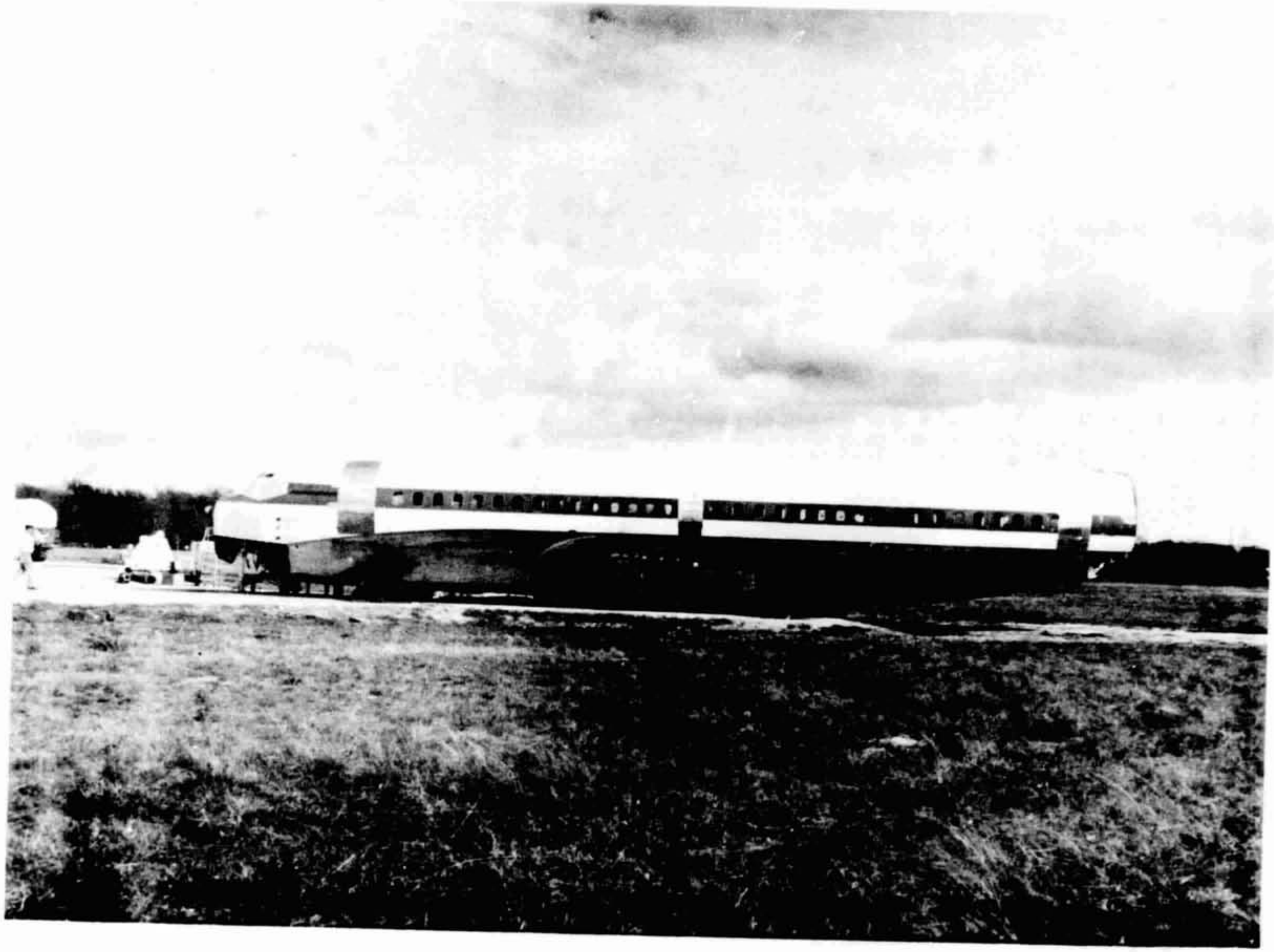


Figure 5. - Boeing 737 test fuselage.

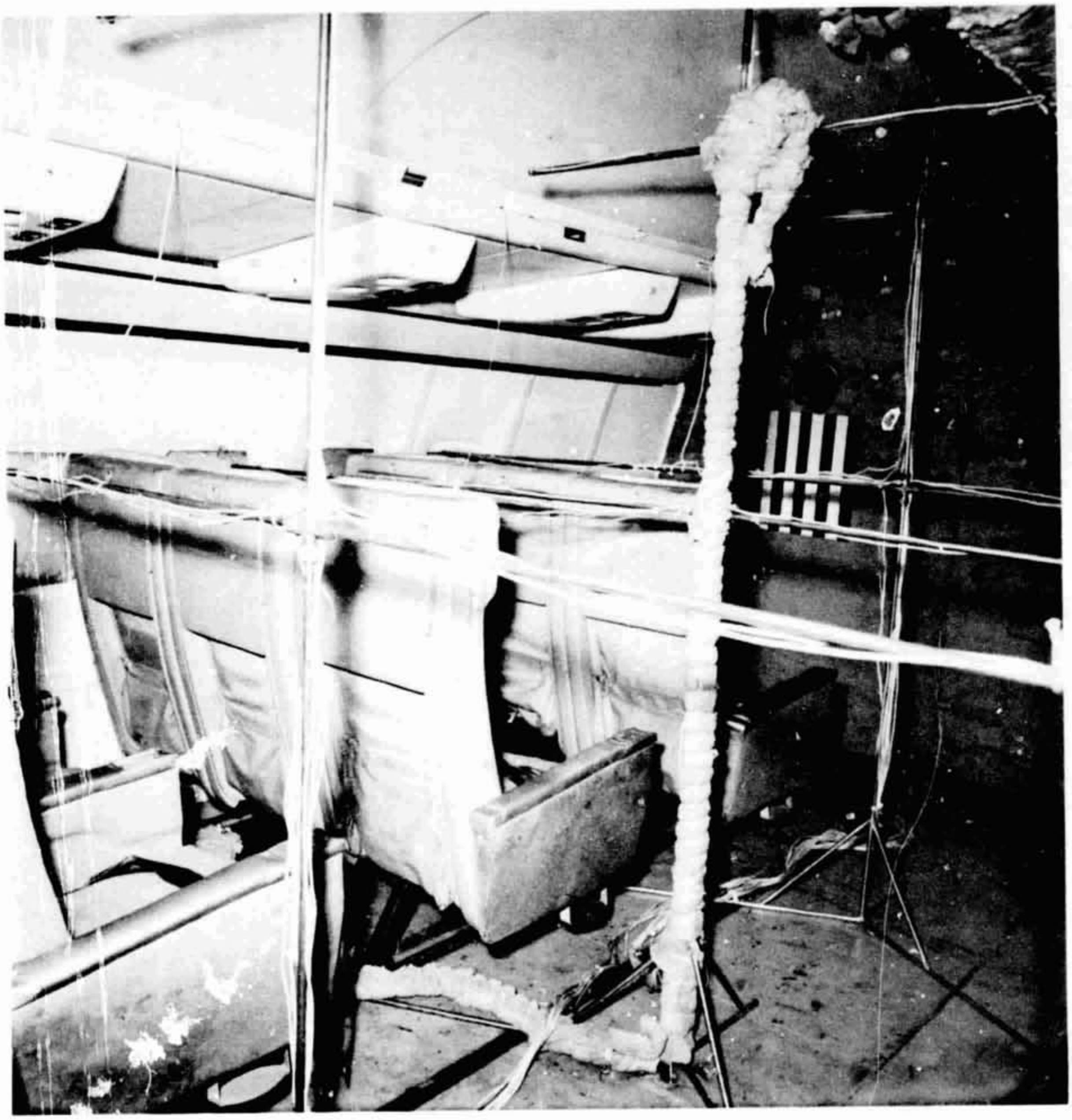


Figure 6. - Typically furnished 4.6-meter (15 foot) test section.

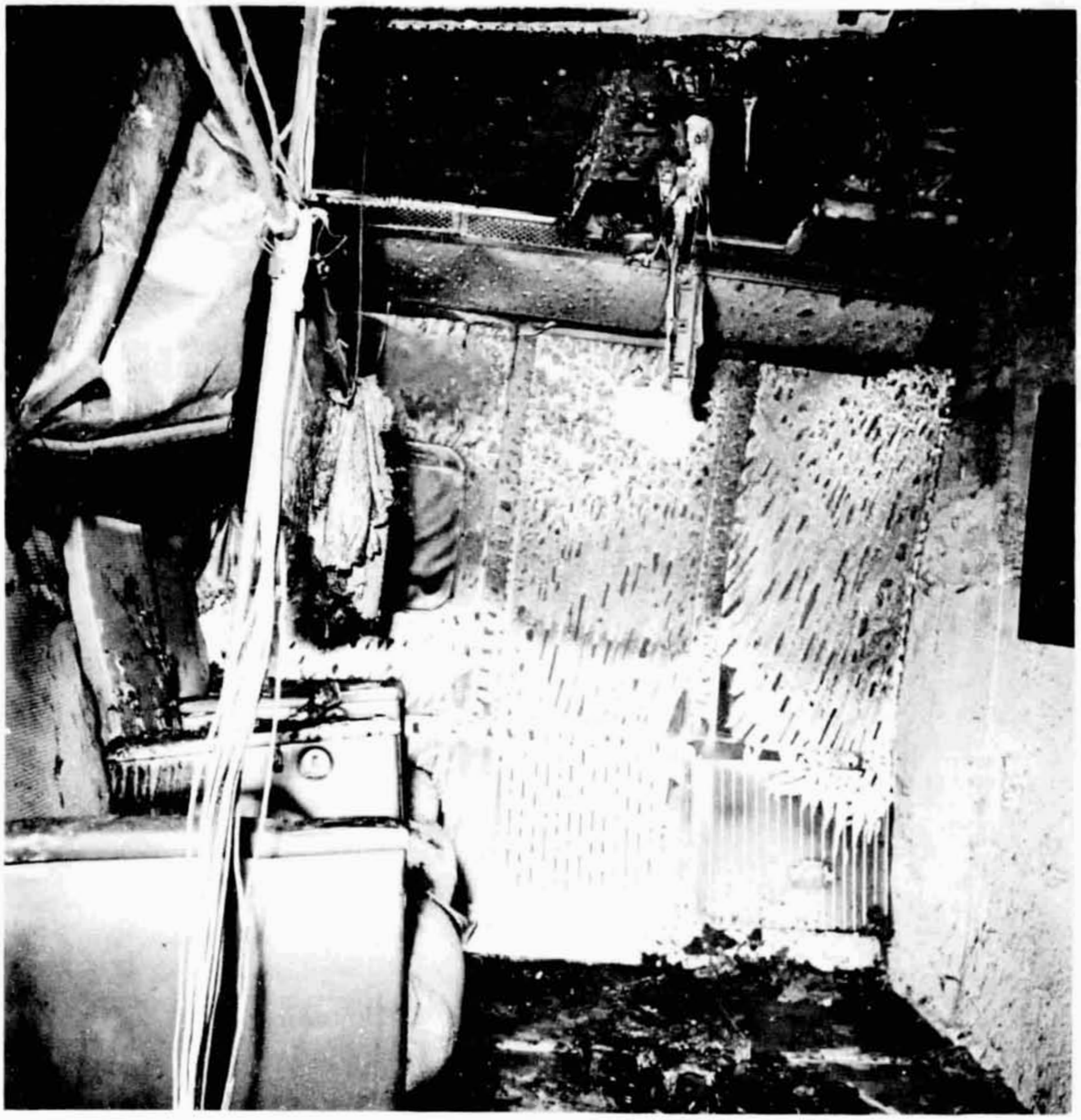


Figure 14.- Sidewall fire damage for test 1 using pre-1968 materials.

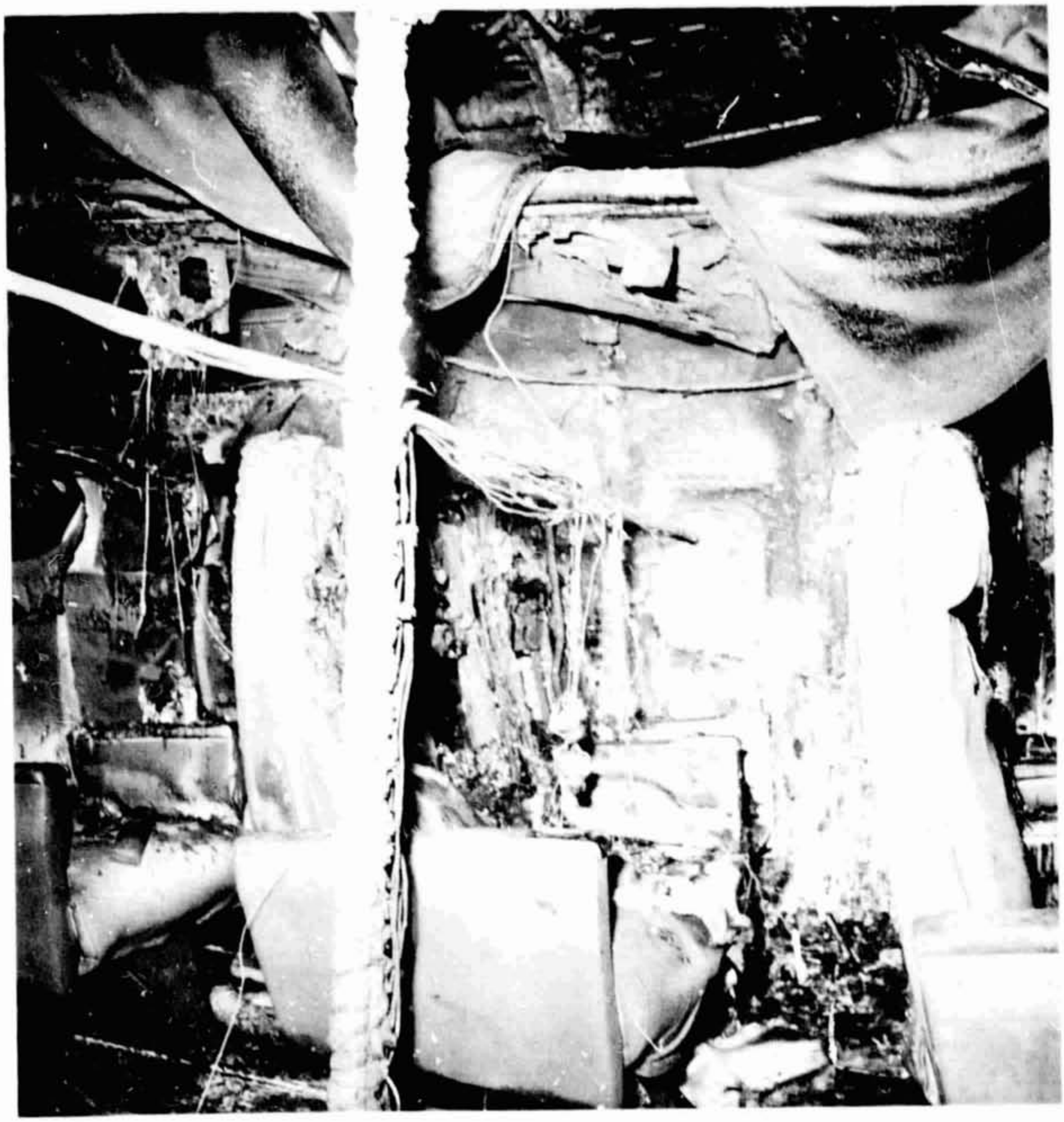


Figure 15.- Fire damage for test 1 using pre-1968 materials, side view.

Figure 16.- Fire damage for test 1 using pre-1968 materials, front view.

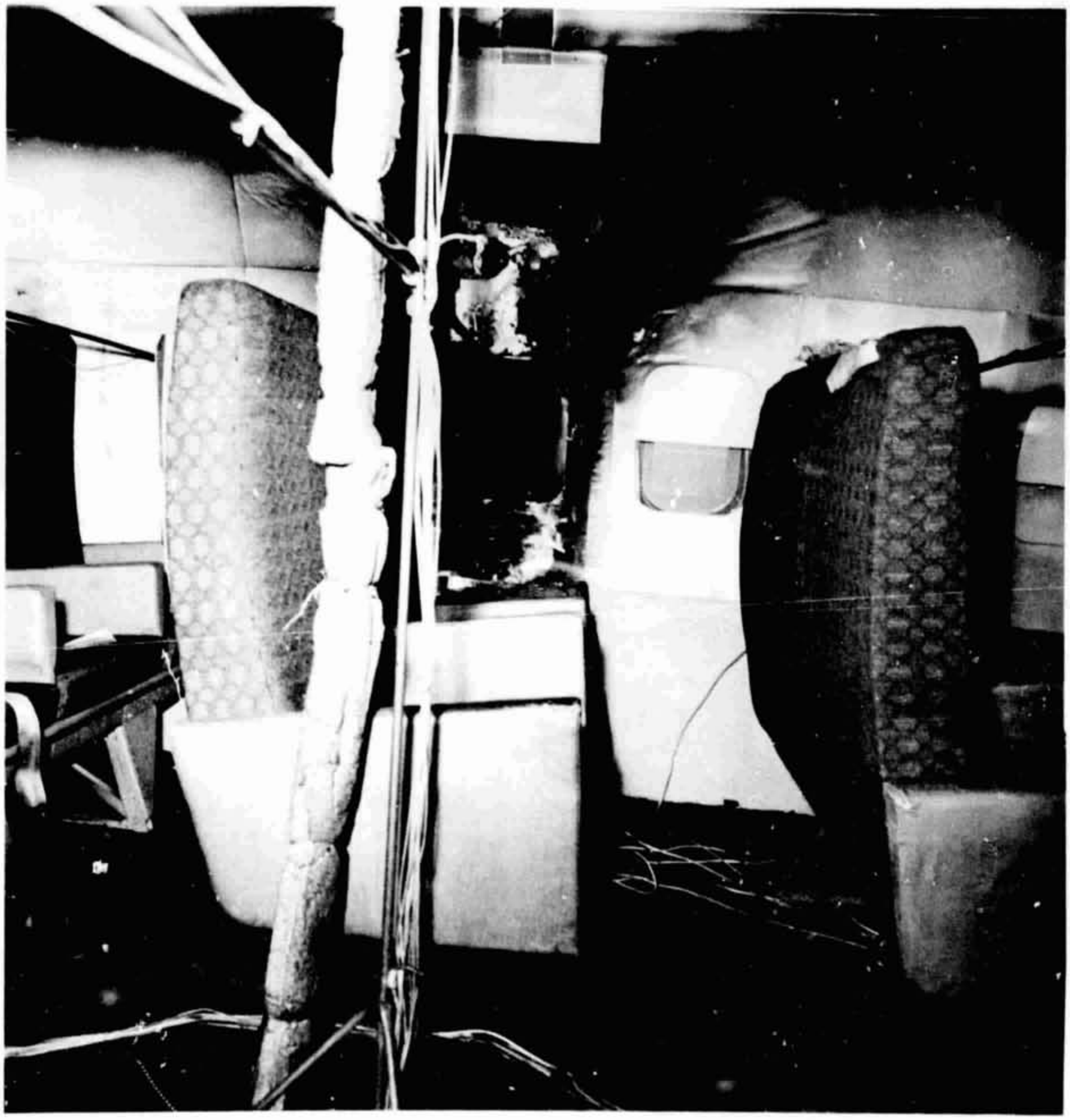


Figure 20.- Fire damage for test 2 using new materials, side view.

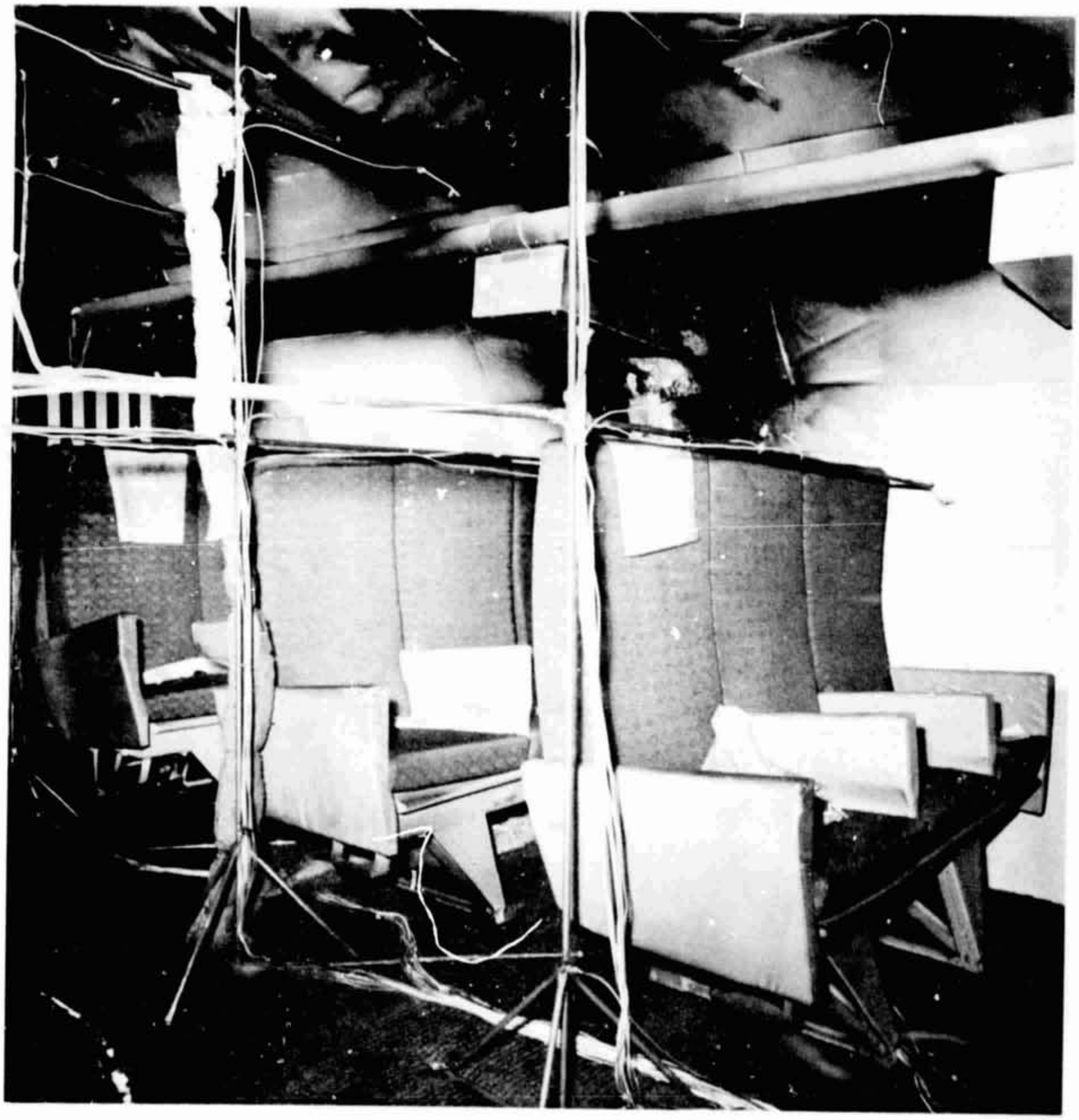


Figure 21.- Fire damage for test 2 using new materials, front view.

Figure 22.- Seat bottom fire damage for test 2 using new materials.

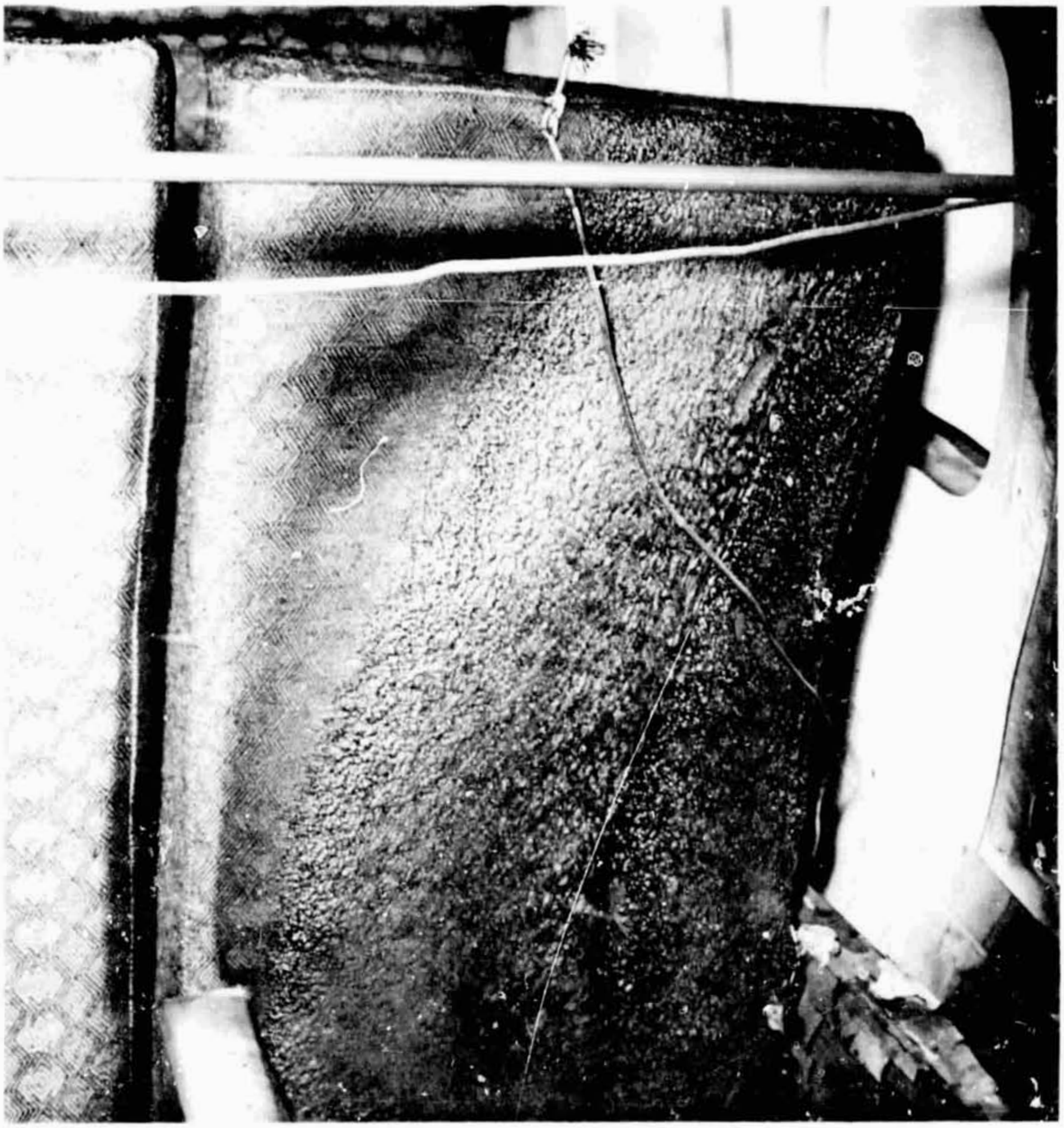


Figure 23.- Seat top fire damage for test 2 using new materials.

Figure 24.- Seat back fire damage for test 2 using new materials.

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